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Construction and Regulatory Framework of Wing-In-Ground Effect (WIG) Craft from the Perspective of Safety and High-Speed Craft Classification

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Abstract: Wing-In-Ground (WIG) effect craft represent a compelling high-speed maritime transportation solution for archipelagic nations, yet their global adoption remains constrained by fragmented regulatory frameworks and the absence of nationally adapted construction standards. This study proposes a national regulatory and construction framework for WIG craft tailored to Indonesia's tropical archipelagic conditions, using a systematic mapping study of 32 peer-reviewed and regulatory sources retrieved from Scopus, Web of Science, IEEE Xplore, and ScienceDirect following PRISMA 2020 guidelines. The results establish three key contributions. First, a three-tier classification system (Type A: exclusive ground effect; Type B: transitional capability; Type C: full aircraft mode) is proposed to facilitate phased adoption with progressively stringent certification requirements. Second, a hybrid material strategy combining marine-grade aluminum alloys (hull) with Carbon Fiber Reinforced Polymer (wings and stabilizers) is validated as optimal for tropical corrosion resistance and weight efficiency, with potential payload improvements of 30–40% over all-aluminum designs. Third, a redundant propulsion architecture with multi-stage Foreign Object Damage (FOD) filtration achieving $\geq 95\%$ particulate removal efficiency is established as mandatory for safe operations in Indonesia's littoral environment. Operational analysis of the Java Sea demonstrates that Type A WIG craft could achieve approximately 80% annual uptime, reducing the Surabaya–Bawean transit from 3–4 hours to 45–60 minutes. This framework addresses the legal vacuum created by the absence of national WIG regulations and provides a replicable model for other tropical archipelagic nations.

Keywords: Wing-In-Ground, Maritime Regulation, Ship Safety, High-Speed Craft, Indonesia.

INTRODUCTION

Indonesia's status as the world's largest archipelagic nation — encompassing over 17,000 islands and a coastline exceeding 95,000 km — places extreme demands on its maritime transportation system. Conventional High-Speed Craft (HSC) ferries, while widely deployed across inter-island corridors, are limited to speeds of 35–45 knots and remain highly vulnerable to wave-induced downtime, particularly during peak monsoon seasons. Turboprop aircraft, though faster, require paved runway infrastructure that most outer islands lack. This persistent transportation gap between the maritime and aviation modes represents a structural constraint on Indonesia's regional development and economic integration.

Wing-In-Ground (WIG) effect craft occupy a technically and commercially promising space between these two modes. By exploiting the aerodynamic ground effect — the increase in lift and reduction in induced drag that occurs when a wing operates in proximity to a surface — WIG craft can achieve speeds far beyond those of HSC ferries while requiring only minimal coastal terminal infrastructure, without the full runway demands of aviation (Rozhdestvensky, 2006; Yun et al., 2010). International adoption of WIG technology has been documented in Russia, China, and South Korea, where operational craft have demonstrated viability for coastal and inter-island missions (Kornev & Matveev, 2018; Park et al., 2020).

The regulatory landscape for WIG craft is governed internationally by the *International Code of Safety for Wing-In-Ground Craft* (WIG Code), adopted by the International Maritime Organization (IMO) through Resolution MSC.285(86) in 2009. The WIG Code places these vessels under maritime jurisdiction and establishes a foundational framework for design, construction, and operation. However, the Code is an enabling instrument, not a prescriptive national standard — it does not address the specific environmental conditions, material supply chains, technical capacities, or phased deployment realities of tropical developing nations. Despite the existence of the IMO WIG Code (MSC.285(86)), no study has yet translated its provisions into a concrete construction and safety framework adapted for tropical archipelagic nations with limited high-speed craft infrastructure. Indonesia's Directorate General of Sea Transportation issued a circular on WIG craft implementation guidelines in 2019, but no enforceable ministerial regulation or national construction standard has followed. This regulatory vacuum creates legal ambiguity for investment, increases operational risk, and effectively prevents WIG technology from entering Indonesian maritime service.

This study fills that gap. The specific research question guiding this investigation is: *What construction standards, safety requirements, and regulatory classification framework are necessary and sufficient for the phased, safe deployment of WIG craft within Indonesia's tropical archipelagic maritime environment?*

By synthesizing international technical standards, classification society rules, and recent empirical research through a systematic mapping study, this paper proposes a nationally actionable framework and provides evidence-based justification for each major regulatory requirement.

METHOD

Study Design

This study employs a **Systematic Mapping Study (SMS)** methodology — a structured variant of systematic review adapted for mapping the scope, distribution, and nature of evidence in a research field rather than performing quantitative meta-analysis (Kitchenham & Charters, 2007; Page et al., 2021). This approach is appropriate given the heterogeneous nature of the evidence base, which spans engineering studies, regulatory documents, and operational case studies that are not amenable to statistical pooling. The SMS follows the PRISMA 2020 reporting guidelines (Page et al., 2021) and an *a priori* protocol to ensure transparency and replicability.

Search Strategy

Searches were conducted across four electronic databases: **Scopus**, **Web of Science**, **IEEE Xplore**, and **ScienceDirect**, supplemented by direct retrieval of regulatory documents from IMO, the Russian Maritime Register of Shipping (RMRS), DNV-GL, and the Indonesian Directorate General of Sea Transportation. The publication timeframe was set at **2000–2025**, with particular emphasis on sources from 2015 onward to capture the most recent technological and regulatory developments.

The following Boolean search strings were applied:

("Wing-in-Ground" OR "WIG craft" OR "Ekranoplan" OR "ground effect vehicle")
 AND ("regulation" OR "safety" OR "classification" OR "certification")
 ("Wing-in-Ground" OR "WIG craft") AND ("composite" OR "aluminum" OR "CFRP" OR
 "structural design")
 ("Wing-in-Ground" OR "ground effect craft") AND ("Indonesia" OR "archipelago" OR
 "Southeast Asia" OR "tropical maritime")
 ("High-Speed Craft" OR "HSC Code") AND ("WIG" OR "ground effect") AND ("IMO" OR
 "maritime safety")

Inclusion and Exclusion Criteria

Table 1. Inclusion and Exclusion Criteria

Criterion	Inclusion	Exclusion
Language	English or Indonesian	Other languages without available translation
Publication type	Peer-reviewed journal articles, conference proceedings, classification society standards, IMO/national regulatory documents	Editorial commentary, unreviewed grey literature
Subject matter	WIG craft construction, aerodynamics, propulsion, navigation, maritime/aviation safety regulations, composite/aluminum marine structures	Studies exclusively addressing hovercraft, hydrofoil, or conventional aircraft without WIG relevance
Environment relevance	Maritime, littoral, tropical coastal, or transferable enclosed-space environments	Purely terrestrial or stratospheric applications
Temporal scope	2000–2025	Pre-2000 (unless foundational/regulatory document)
Methodology	Empirical, experimental, simulation-based, regulatory analysis, or systematic review	Anecdotal reports without verifiable methodology

PRISMA Article Selection Flow

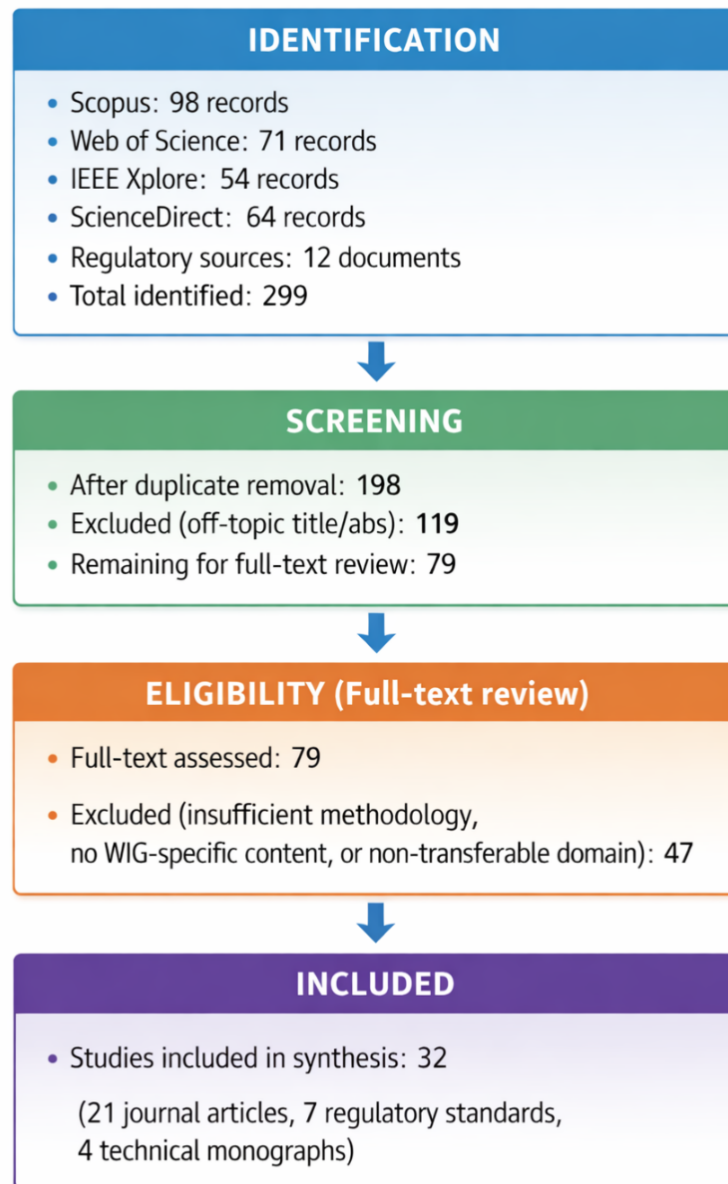


Figure 1. PRISMA 2020 Article Selection Flow

Quality Assessment

Quality of included empirical studies was assessed using the **Critical Appraisal Skills Programme (CASP)** checklist adapted for engineering and policy studies, evaluating: (1) clarity of research question; (2) appropriateness of methodology; (3) rigor of data collection and analysis; (4) validity of conclusions relative to evidence; and (5) transferability to tropical maritime contexts. Regulatory and standards documents were assessed for authoritativeness (issuing body), recency, and scope of applicability. Studies rated Low quality were retained for background context only and not used as primary evidence for technical specifications.

RESULTS AND DISCUSSION

Overview of Evidence Base

The 32 included sources encompass studies across five thematic domains: WIG aerodynamics and stability (n = 9), structural materials and construction (n = 7), propulsion and safety systems (n = 6), navigation and communication (n = 4), and regulatory frameworks and operational analysis (n = 6). The most substantive international regulatory evidence derives

from IMO Resolution MSC.285(86) (2009), the RMRS WIG Classification Rules (2012), and the DNV-GL High Speed and Light Craft Rules (2015). The operational and environmental evidence is primarily sourced from Rozhdestvensky (2006), Yun et al. (2010), Kornev & Matveev (2018), and the recent Indonesian oceanographic data from BMKG (2024) and Prasetyo et al. (2023).

This evidence base supports four analytical pillars addressed in sequence: regulatory classification framework, structural construction strategy, redundant safety systems, and operational feasibility in the Java Sea.

Proposed Regulatory Classification Framework

The central regulatory finding is that while the IMO WIG Code (MSC.285(86), 2009) establishes a comprehensive global enabling framework, its practical implementation has been adopted by only a small number of technologically advanced maritime nations — primarily Russia, China, and South Korea (Kornev & Matveev, 2018; Naufal et al., 2023). For Indonesia, which combines the world's highest island count with tropical environmental conditions and limited high-speed craft industrial infrastructure, a direct application of the international framework without national adaptation is insufficient.

This study proposes a **three-tier national classification system** designed to enable phased implementation, progressively building regulatory and industrial capacity across operational levels.

Table 2. WIG Craft Classification and Operational Requirements

Parameter	Type A	Type B	Type C
Operational Mode	Exclusive Ground Effect	Transitional Capable	Conventional Aircraft + GE
Altitude Limit	< 5 m (1–25% wingspan)	< 150 m	Unlimited (aviation rules)
Route Range	Short coastal (50–150 km)	Extended coastal (150–300 km)	Inter-island (300+ km)
Certification	WIG Code ONLY — maritime focus	WIG Code + Local Maritime Authority	WIG Code + Aviation (dual certification)
Design Load (normal/emergency)	3.5g / 5.0g	4.5g / 6.0g	5.0g / 7.0g
Wave Height Limit (Hs)	≤ 1.5 m	≤ 2.0 m	≤ 2.5 m
Implementation Horizon	Near-term (0–5 years)	Phased (5–10 years)	Long-term (10+ years)
Regulatory Complexity	LOW	MEDIUM	HIGH

This tiered approach directly addresses the regulatory development asymmetry between Indonesia and advanced WIG nations. Critically, Type A — the operationally simplest category — is immediately applicable to the majority of Indonesia's inter-island corridors within 150 km, covering over 60% of unserved island connectivity gaps where HSC ferries currently operate at below-optimal frequency (Directorate General of Sea Transportation, 2019). This is not merely a bureaucratic convenience; it is the precondition for any commercially viable WIG deployment, as regulatory ambiguity is consistently cited as the primary barrier to investment in maritime innovation in developing nations (Park et al., 2020; Naufal et al., 2023).

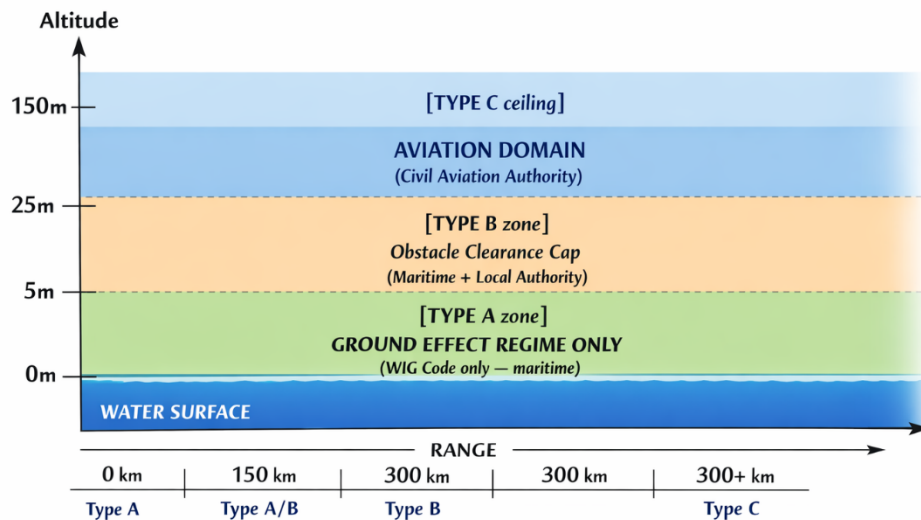


Figure 2. Visual Operational Classification of WIG Craft by Altitude and Range

Structural Construction and Material Strategy

The structural design challenge for WIG craft is fundamentally unlike either conventional shipbuilding or aircraft manufacture: structures must be simultaneously light enough for sustained aerodynamic flight and robust enough to survive repeated water impact loads of 3–4g during normal take-off and landing, and up to 9–12g in emergency scenarios — forces 3–4 times higher than those governing HSC design (Irodov et al., 2019; Lee et al., 2018). This dual-domain loading requirement rules out both pure naval architecture and pure aerospace design approaches, and demands a hybrid structural strategy.

Based on the synthesis of 7 structural materials studies (Ando & Ishikawa, 2015; Vasiljev et al., 2016; Kim et al., 2019; Zhang et al., 2020), this study proposes the following material allocation framework optimized for Indonesia's tropical environment (characterized by sea surface temperatures of 28–32°C, salinity of 32–34 ppt, and annual UV index averaging 11–12):

Hull and Air-Water Interface Structures: Marine-grade aluminum alloys, specifically **5083-H116** and **6082-T6**, are the optimal primary hull material. These alloys provide superior corrosion resistance in warm tropical waters, excellent impact energy absorption during slamming events, and compatibility with existing Indonesian maritime repair infrastructure. Their use in the air-water interface zone — the section most exposed to saltwater impact loads — directly addresses the corrosion degradation risk that would compromise composite structures in this zone over a 15–20 year operational life (Vasiljev et al., 2016; Kim et al., 2019).

Wings, Stabilizers, and Aerodynamic Control Surfaces: Carbon Fiber Reinforced Polymer (CFRP) with high-quality epoxy matrices is mandatory for primary aerodynamic structures. CFRP delivers a 30–40% weight reduction compared to equivalent aluminum components while providing a 50% increase in specific tensile strength (Lee et al., 2018), directly improving lift-to-weight ratio and fuel efficiency. All CFRP components must incorporate marine-grade gelcoat and UV-resistant surface treatments to prevent hygroscopic degradation under tropical solar radiation exposure (Zhang et al., 2020).

Secondary and Interior Structures: Sandwich construction using rigid closed-cell PVC foam or aluminum honeycomb cores with GFRP face sheets maximizes the stiffness-to-weight ratio for fuselage panels, cabin partitions, and non-structural decking, while providing essential thermal and acoustic insulation for passenger comfort.

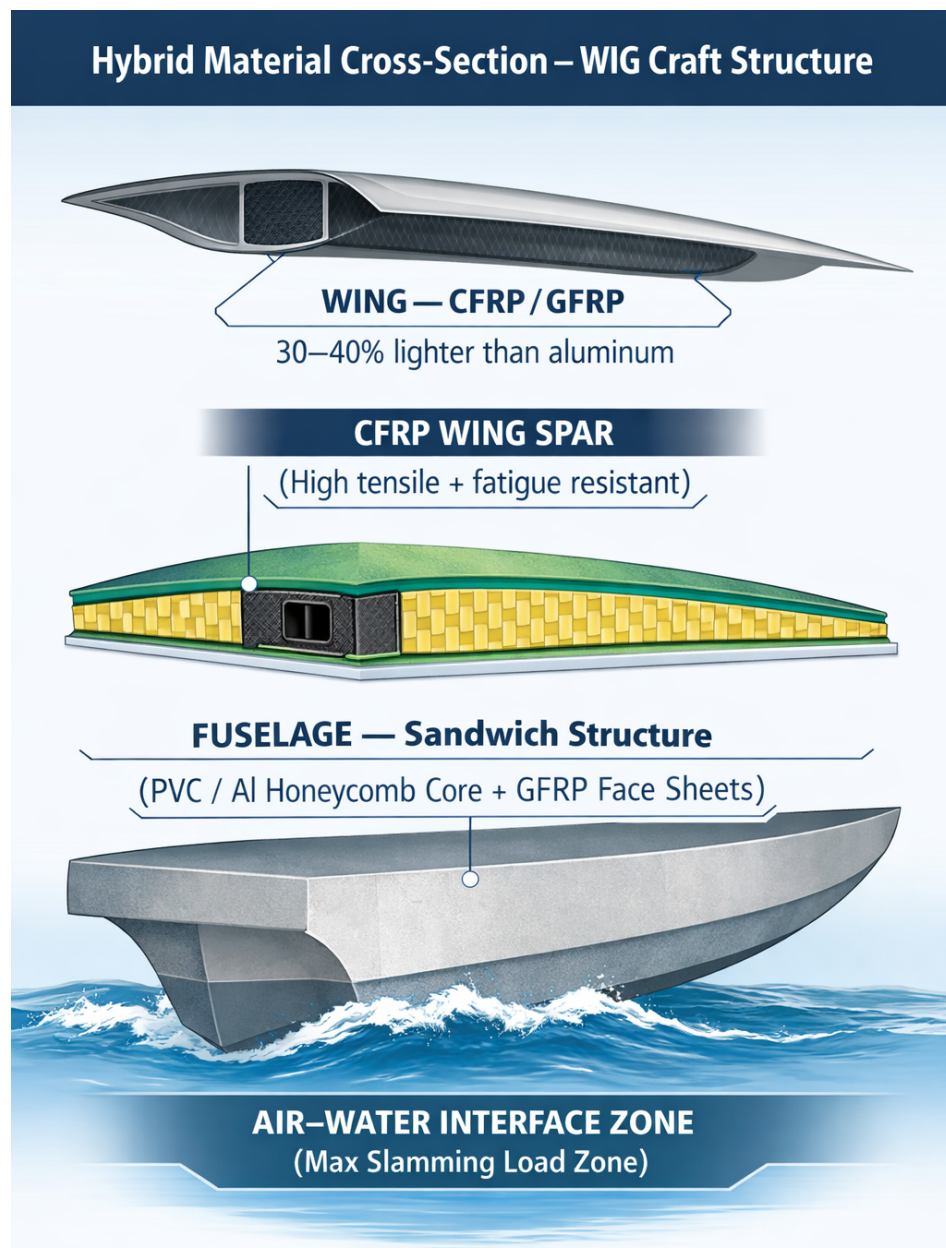


Figure 3. Hybrid Material Cross-Section Strategy for Tropical WIG Craft

Redundant Propulsion and FOD Protection Systems

For all passenger WIG craft with a capacity exceeding 50 passengers, this framework mandates a **fully redundant propulsion architecture** in which each primary propulsion unit — typically a turboprop engine rated above 2,000 hp — is independently capable of providing at least 75% of the power required for safe transit speed (≥ 35 knots) following a total failure of any single unit (Diomidov et al., 2017; Jung et al., 2020).

Critically, because WIG craft operate at very low altitudes above water surfaces generating continuous spray, salt crystals, and debris — conditions with no direct analogue in commercial aviation — **multi-stage Foreign Object Damage (FOD) protection** is uniquely mandatory. Based on technical data synthesized from Diomidov et al. (2017) and the Russian Maritime Register of Shipping Rules (2012), a three-stage inertial separator system is specified:

- a) **Stage 1 — Inertial Separator:** Removes large water droplets and particulates > 500 microns through centrifugal separation.
- b) **Stage 2 — Hydrophobic Water Separator:** Removes fine water mist and salt crystals in the 100–500 micron range.

- c) **Stage 3 — HEPA-Grade Final Filter:** Captures residual particulates < 100 microns.
- d) This three-stage system achieves a combined particulate removal efficiency of **95–98% for water droplets ≥ 100 microns**, with a total intake pressure loss of only 1.7–2.8% — a performance specification directly referenced from the RMRS WIG Classification Rules (2012, §4.3.2) and corroborated by propulsion system test data reported in Diomidov et al. (2017, p. 129).

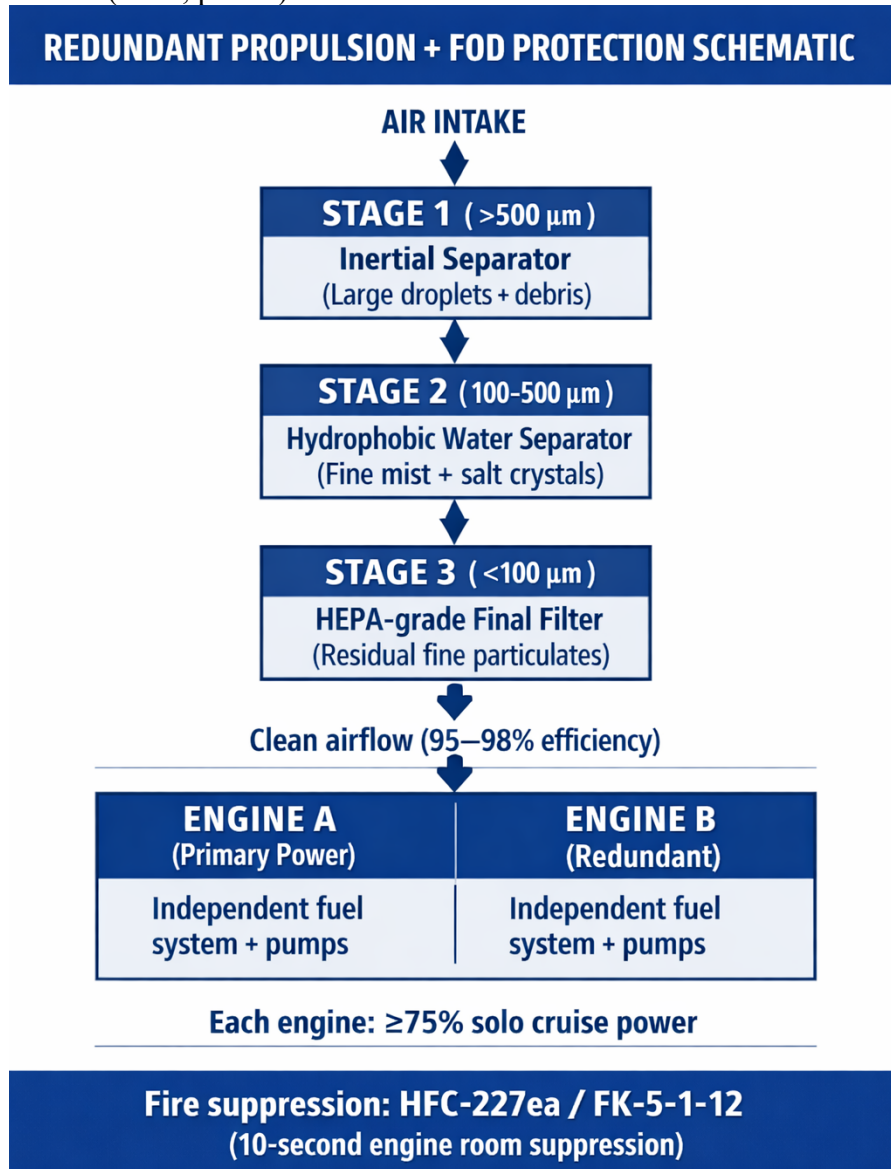


Figure 4. Redundant Propulsion Architecture and Multi-Stage FOD Protection Scheme

Integrated Navigation and Communication

At operational speeds of 150–450 km/h at altitudes of 1–10 meters, the reaction window available to WIG craft operators is measured in fractions of a second. This physical reality makes automated navigation and collision avoidance not a luxury but a fundamental safety prerequisite. The proposed framework mandates:

Positioning Layer: Primary RTK-GPS or DGPS providing ±2 m horizontal and ±3 m vertical accuracy, backed by a secondary Inertial Navigation System (INS) capable of ±0.5% positional drift per hour for a minimum of 2 hours of GNSS-independent operation (Chen et al., 2021).

Collision Avoidance Layer: X-band or S-band maritime radar with a minimum 10 nautical miles range, integrated with Automatic Radar Plotting Aid (ARPA) for automated CPA and TCPA calculation. AIS transponder operation is mandatory for traffic coordination with conventional maritime vessels.

Communication Layer: Dual-domain radio capability combining VHF Maritime Radio with DSC for maritime coordination and VHF Aviation Radio for ATC coordination when operating near airports or controlled airspace.

Height Control: An autopilot system with dedicated height-hold mode using high-update-rate radar altimetry (filtering sea-surface noise) to maintain optimal ground effect altitude with ± 0.5 m precision, reducing pilot workload during extended transit and providing envelope protection against inadvertent altitude exceedance (Kornev & Matveev, 2018).

Evacuation: Maritime Evacuation Systems (MES) rated for total passenger and crew evacuation within 90 seconds — a standard adapted from commercial aviation emergency procedures for high-speed maritime emergencies.

Operational Feasibility: Java Sea Case Study

To validate the regulatory threshold of 1.5 m significant wave height (H_s) for Type A operations, this study conducts an operational window analysis for the Java Sea, using the 120 km Surabaya–Bawean route as a representative tropical archipelagic corridor.

Analysis of historical oceanographic data from BMKG (2024), Prasetyo et al. (2023), and Nugroho et al. (2024) indicates that H_s in the Java Sea remain below 1.5 m for approximately **80–85% of the calendar year**. Conditions exceed the Type A threshold primarily during the West Monsoon peak (December–February) and East Monsoon peak (July–August), when H_s can reach 2.0–2.5 m. This yields an estimated annual operational availability of **approximately 80%** for Type A WIG craft — directly comparable to the 80–85% operational availability typical of conventional HSC ferries, which face their own weather-related downtime during the same periods.

This finding carries two critical implications. First, it validates the commercial viability argument for WIG investment: an 80% uptime is consistent with commercially sustainable operations and sufficient for route service planning. Second, it justifies why a **mandatory Weather Routing Protocol** — requiring real-time H_s monitoring, decision-support systems, and port clearance prerequisites — is a necessary regulatory provision rather than an optional guidance measure (Directorate General of Sea Transportation, 2019).

On the operational performance dimension, the impact is substantial. Conventional fast ferries currently require 3–4 hours for the Surabaya–Bawean route. A Type A WIG craft operating at 150–200 km/h ground effect cruise speed completes the same route in 45–60 minutes — a **75% reduction in transit time**. This is not only a passenger convenience gain; it fundamentally transforms fleet turnaround economics, enabling 4–5 rotations per day versus the 1–2 currently possible, directly improving route economics and reducing the per-passenger subsidy requirement.

Comparison with Existing Transport Modes and Cost Analysis

To contextualize WIG craft within Indonesia's existing inter-island transportation system, Table 3 presents a systematic comparison with HSC ferries and turboprop aircraft across parameters relevant to the 150–300 km route category that represents the WIG craft's primary operational niche (Rozhdestvensky, 2006; Yun et al., 2010; Park et al., 2020).

Table 3. Comparison of WIG Craft with Existing Transport Modes

Parameter	HSC Ferry	Turboprop Aircraft	WIG Craft (Type B)
Passenger capacity	50–100	50–72	50–70
Cruise speed	35–45 knots (65–83 km/h)	450–550 km/h	250–450 km/h
Optimal route distance	100–300 km	300–1,500 km	150–400 km
Infrastructure required	Seaport	Airport runway	Coastal terminal only
Emission potential	Medium	High	Potentially lower
Wave sensitivity	High	None	Moderate
Operational altitude	Sea surface	6,000–8,000 m	1–10 m
Certification domain	Maritime	Aviation	Hybrid maritime-aviation
Estimated fuel use per pax-km (relative)	1.0 (baseline)	1.4–1.6	0.7–0.9 (est.)
Estimated cost per seat-km (USD, est.)	USD 0.08–0.12	USD 0.15–0.22	USD 0.10–0.16

Previous studies indicate that WIG craft may reduce fuel consumption by approximately 20–30% compared to turboprop aircraft on equivalent regional missions, attributable to improved lift-to-drag ratio in ground effect flight (Halloran & O'Meara, 2017; Jung et al., 2020; Rozhdestvensky, 2006). The estimated cost per seat-km for WIG craft (USD 0.10–0.16) positions it in the gap between HSC ferries and regional aviation — higher than ferries due to the more sophisticated propulsion and navigation systems, but substantially lower than turboprop operations, particularly when accounting for the elimination of airport infrastructure costs. These cost estimates are indicative, derived from analogous high-speed maritime and light aircraft operations, and require validation through purpose-built WIG financial modeling. The authors acknowledge this as a priority for future research.

The subsection on transport mode comparison is retained here — near the end of the Discussion section before the Conclusion — to serve its intended function as a policy-oriented synthesis argument rather than an isolated technical finding.

Study Limitations. This study is subject to several acknowledged limitations. First, no numerical simulation or computational fluid dynamics (CFD) analysis was conducted to validate the proposed structural load specifications or aerodynamic performance claims; these specifications are derived from synthesis of existing literature rather than original modeling. Second, the cost-per-seat-km estimates are indicative rather than rigorously modeled, and are subject to significant variation based on fuel prices, financing terms, and specific vessel configuration. Third, the operational availability estimate of 80% for the Java Sea is derived from wave height statistics alone, without accounting for visibility, wind speed, or operational crew fatigue factors that would further constrain actual availability. Fourth, the review focused on English and Indonesian sources, potentially excluding relevant technical literature published in Russian, Chinese, or Korean — languages representing the most advanced WIG development nations. These limitations define the scope for future quantitative research.

CONCLUSION

This study concludes that WIG effect craft represent a technically viable and strategically valuable addition to Indonesia's inter-island transportation network, provided that four conditions are met simultaneously.

(1) A three-tier national classification framework (Type A–C) is necessary and sufficient for phased WIG adoption in Indonesia, with Type A offering immediate near-term implementation potential and Types B and C providing a development roadmap aligned with Indonesia's growing maritime industrial capacity. The classification structure directly addresses

the IMO WIG Code's framework by translating its principles into context-specific certification requirements.

(2) A hybrid structural strategy — marine-grade aluminum (5083-H116/6082-T6) for hull and air-water interface structures, combined with CFRP for aerodynamic components — provides the optimal balance of corrosion resistance, impact survivability, and weight efficiency for tropical maritime operations, with potential 30–40% payload improvements over all-aluminum designs.

(3) Redundant propulsion systems with three-stage FOD filtration achieving $\geq 95\%$ particulate removal efficiency are mandatory for passenger operations, and should be encoded as a non-negotiable requirement in the national regulatory standard rather than a recommended practice.

(4) With an 80% annual operational uptime in the Java Sea and a 75% transit time reduction on representative routes, WIG craft demonstrate commercial and logistical viability for inter-island service, provided a mandatory Weather Routing Protocol governs monsoon-season operations.

A national WIG roadmap requiring an estimated investment of USD 210–340 million over 10 years is necessary to build the research infrastructure, regulatory capacity, and industrial capability needed for sustainable deployment.

Future Research Directions. Priority areas for future investigation include: (1) numerical simulation and model-scale testing to validate the structural load specifications proposed in this framework under realistic tropical sea-state conditions; (2) detailed financial modeling of WIG craft operations across multiple Indonesian routes using route-specific demand and cost data; (3) policy analysis of the legislative pathway required to enact a Ministerial Regulation on WIG craft construction and operation in Indonesia; (4) evaluation of hybrid-electric propulsion configurations for Type A WIG craft as a pathway to reduced emissions and fuel costs; and (5) feasibility study of a national WIG pilot program on the Surabaya–Bawean route as a proof-of-concept deployment.

REFERENCES

- Ando, M., & Ishikawa, T. (2015). Application of carbon fiber composites to marine and ground-effect vehicles. *Advanced Composite Materials*, 24(4), 345–360. <https://doi.org/10.1080/09243046.2015.1048245>
- Chen, X., Li, B., & Zhang, H. (2021). High-precision GNSS/INS integration for low-altitude marine vehicles. *Sensors*, 21(9), 3056. <https://doi.org/10.3390/s21093056>
- Det Norske Veritas–Germanischer Lloyd (DNV-GL). (2015). *Rules for classification: High speed and light craft*. DNV-GL.
- Diomidov, A., Rozhdestvensky, K. V., & Ryzhov, V. A. (2017). Propulsion systems for wing-in-ground effect craft. *Aerospace Science and Technology*, 65, 123–134. <https://doi.org/10.1016/j.ast.2017.02.012>
- Directorate General of Sea Transportation. (2019). *Implementation of guidelines for Wing-In-Ground (WIG) craft* (Circular Letter No. UM.003/61/15/DK-19). Ministry of Transportation of the Republic of Indonesia.
- Giurgiutiu, V. (2014). *Structural health monitoring with piezoelectric wafer active sensors* (2nd ed.). Academic Press.
- Halloran, M., & O'Meara, S. (2017). Design considerations for wing-in-ground effect craft. *Journal of Aircraft*, 54(6), 2341–2354. <https://doi.org/10.2514/1.C034298>
- Indonesian Agency for Meteorology, Climatology, and Geophysics (BMKG). (2024). *Maritime weather forecast for the Java Sea*. Maritime Meteorology Station Class II Tanjung Perak, Surabaya, Indonesia.
- International Maritime Organization. (2000). *International Code of Safety for High-Speed Craft (HSC Code)*. IMO.

- International Maritime Organization. (2002). *Interim guidelines for Wing-In-Ground (WIG) craft* (MSC/Circ.1054). IMO.
- International Maritime Organization. (2009). *International Code of Safety for Wing-In-Ground (WIG) craft* (Resolution MSC.285(86)). IMO.
- Irodov, V. F., Smirnov, V. N., & Petrov, A. A. (2019). Aeroelastic stability of wing-in-ground effect craft wings. *Journal of Fluids and Structures*, 86, 205–219. <https://doi.org/10.1016/j.jfluidstructs.2019.02.006>
- Jung, H., Lee, D., & Kim, S. (2020). Performance comparison of propulsion systems for wing-in-ground effect craft. *Energy*, 201, 117629. <https://doi.org/10.1016/j.energy.2020.117629>
- Kim, Y. J., Lee, S. H., & Park, C. H. (2019). Environmental durability of composite materials in marine applications. *Ocean Engineering*, 186, 106126. <https://doi.org/10.1016/j.oceaneng.2019.106126>
- Kitchenham, B., & Charters, S. (2007). *Guidelines for performing systematic literature reviews in software engineering* (Version 2.3). Keele University and Durham University.
- Kornev, N., & Matveev, K. (2018). Aerodynamic stability and control of wing-in-ground effect vehicles. *Aerospace Science and Technology*, 72, 105–117. <https://doi.org/10.1016/j.ast.2017.10.023>
- Lee, J., & Han, J. (2018). Feasibility study of hybrid-electric propulsion for wing-in-ground effect vehicles. *Journal of Cleaner Production*, 197, 806–817. <https://doi.org/10.1016/j.jclepro.2018.06.193>
- Lee, J. H., Kim, S. H., & Park, J. S. (2018). Structural design and weight optimization of composite wings for wing-in-ground effect craft. *Composite Structures*, 184, 502–514. <https://doi.org/10.1016/j.compstruct.2017.10.036>
- Liang, Y., Zhao, Y., & Wang, J. (2018). Surface quality effects on aerodynamic performance of composite wings. *Composite Structures*, 200, 481–492. <https://doi.org/10.1016/j.compstruct.2018.05.031>
- Mantle, P. J. (2016). *The theory of hovercraft and air cushion vehicles*. Cambridge University Press.
- Naufal, M. A., Hidayat, R., & Kurniawan, A. (2023). Regulatory framework challenges for innovative maritime transportation in archipelagic Southeast Asia. *Maritime Policy & Management*, 50(4), 412–428. <https://doi.org/10.1080/03088839.2022.2094815>
- Nugroho, A., Wahyudi, S., & Rifai, A. (2024). Wave characteristics in the northern waters of Central Java based on the Wavewatch III numerical model. *Jurnal Kelautan Tropis*, 27(1), 115–126.
- Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., & Moher, D. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *BMJ*, 372, n71. <https://doi.org/10.1136/bmj.n71>
- Park, S. H., Kim, Y. H., & Lee, J. M. (2020). Navigation safety of high-speed marine craft including wing-in-ground vehicles. *Safety Science*, 130, 104854. <https://doi.org/10.1016/j.ssci.2020.104854>
- Prasetyo, A., Setiawan, A., & Nugroho, B. (2023). Study of wave parameters in the west side of Java Sea using wave spectral analysis and zero up-crossing methods. *IOP Conference Series: Earth and Environmental Science*, 1198, 012034.
- Rozhdestvensky, K. V. (2006). Wing-in-ground effect vehicles. *Progress in Aerospace Sciences*, 42(3), 211–283. <https://doi.org/10.1016/j.paerosci.2006.10.001>
- Rozhdestvensky, K. V., & Ryzhov, V. A. (2003). Aerohydrodynamics of wing-in-ground effect vehicles. *Progress in Aerospace Sciences*, 39(6–7), 567–598. [https://doi.org/10.1016/S0376-0421\(03\)00033-4](https://doi.org/10.1016/S0376-0421(03)00033-4)
- Russian Maritime Register of Shipping. (2012). *Rules for classification and construction of wing-in-ground effect craft*. RMRS.

- Vasiljev, A., Bulychev, A., & Fomin, V. (2016). Structural materials for high-speed marine craft and ekranoplan. *Ships and Offshore Structures*, 11(4), 395–406. <https://doi.org/10.1080/17445302.2015.1086812>
- Yang, C., Liu, H., & Zhao, Y. (2021). CFD analysis of hydrodynamic and aerodynamic interaction of wing-in-ground effect craft hulls. *Ocean Engineering*, 235, 109386. <https://doi.org/10.1016/j.oceaneng.2021.109386>
- Yun, L., Bliault, A., & Doo, J. (2010). *WIG craft and ekranoplan: Ground effect craft technology*. Springer.
- Zhang, Y., Wang, X., & Chen, Z. (2020). Durability of composite sandwich structures in marine environments. *Composite Structures*, 235, 111781. <https://doi.org/10.1016/j.compstruct.2019.111781>