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Evaluasi tahanan kapal tradisional *pole and line* di Sulawesi Utara

Evaluation on the Resistance of Traditional Pole and Line Vessels in North Sulawesi

Running title: Resistance of traditional pole and line vessels

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Abstract

Ship resistance is a critical factor influencing vessel performance during fishing operations. Previous studies of traditional pole and line vessels in Indonesia have focused mainly on catch performance, leaving a knowledge gap concerning the hydrodynamic characteristics of the hull, particularly under varying trim conditions, which directly affect fuel efficiency and propulsion. This study evaluates the total resistance of two traditional pole and line vessel models under different trim conditions and identifies the more hydrodynamically efficient design. Two vessels were studied: Usbar (LOA 15.85 m) from Bunaken Island and Aldeis (LOA 15.50 m) from Bitung, North Sulawesi. Scale models (1:20) were tested in a recirculating flume (450 × 300 × 70 cm) at Sam Ratulangi University from July 2022 to January 2023. Total, frictional, and residual resistance and wetted surface area were measured at eight velocities (0.23–0.41 m s^{-1}, Fr = 0.083–0.147) under four trim conditions (−1°, 0°, +1°, +2°), with three replicates per combination. Analysis of covariance showed significant effects of vessel type ($F = 24.17$, $p < 0.001$), trim ($F = 18.93$, $p < 0.001$), and their interaction ($F = 3.42$, $p = 0.019$) on total resistance. Even keel produced the lowest resistance in both models. Aldeis, with a smaller block coefficient (0.54 versus 0.58), a smaller midship coefficient (0.60 versus 0.74), and a wetted surface area approximately one third smaller, showed lower resistance under every condition tested. Wetted surface area rather than the prismatic coefficient governs this difference at displacement speeds. The Aldeis hull form therefore offers better power efficiency and provides a quantitative basis for improving traditional pole and line vessel design in North Sulawesi.

Keywords: hull coefficient; North Sulawesi; pole and line vessel; total resistance; trim

Abstrak

Hambatan kapal merupakan faktor krusial yang memengaruhi kinerja kapal selama operasi penangkapan ikan. Kajian terdahulu tentang kapal pole and line tradisional di Indonesia lebih banyak berfokus pada kinerja tangkapan sehingga terdapat kesenjangan pengetahuan mengenai karakteristik hidrodinamika lambung, khususnya pada berbagai kondisi trim, yang berdampak langsung pada efisiensi bahan bakar dan propulsi. Penelitian ini mengevaluasi hambatan total dua model kapal pole and line tradisional pada berbagai kondisi trim serta mengidentifikasi desain yang lebih efisien secara hidrodinamika. Dua kapal dikaji: Usbar (LOA 15,85 m) dari Pulau Bunaken dan Aldeis (LOA 15,50 m) dari Bitung, Sulawesi Utara. Model skala 1:20 diuji dalam flum resirkulasi (450 × 300 × 70 cm) di Universitas Sam Ratulangi pada Juli 2022–Januari 2023. Hambatan total, hambatan gesek, hambatan sisa, dan luas permukaan basah diukur pada delapan kecepatan (0,23–0,41 m s^{-1}; Fr = 0,083–0,147) pada empat kondisi trim (−1°, 0°, +1°, +2°) dengan tiga ulangan per kombinasi. Analisis kovarians menunjukkan pengaruh signifikan tipe kapal ($F = 24{,}17$; $p < 0{,}001$), trim ($F = 18{,}93$; $p < 0{,}001$), dan interaksinya ($F = 3{,}42$; $p = 0{,}019$) terhadap hambatan total. Kondisi lunas rata menghasilkan hambatan terendah pada kedua model. Aldeis, dengan koefisien blok lebih kecil (0,54 berbanding 0,58), koefisien gading besar lebih kecil (0,60 berbanding 0,74), dan luas permukaan basah sekitar sepertiga lebih kecil, menunjukkan hambatan lebih rendah pada seluruh kondisi uji. Luas permukaan basah, bukan koefisien prismatik, menjadi penentu perbedaan tersebut pada rentang kecepatan displasemen. Bentuk lambung Aldeis menawarkan efisiensi daya lebih baik dan menjadi dasar kuantitatif bagi perbaikan desain kapal pole and line tradisional di Sulawesi Utara.

Kata kunci: hambatan total; kapal pole and line; koefisien lambung; Sulawesi Utara; trim

1. Introduction

Resistance estimation is fundamental to vessel design, encompassing the selection of appropriate propulsion systems, hull form optimisation, and fuel consumption prediction. Common methods for estimating vessel resistance include empirical formulae, computational fluid dynamics (CFD) analysis, and physical model testing (Chinh et al., 2021). The empirical approach pioneered by Holtrop & Mennen (1982) remains widely used for preliminary design because it yields rapid resistance estimates from a small set of hull parameters. CFD has become one of the most important tools in the shipbuilding industry (Suryawanshi, 2020), whereas physical model testing remains the most direct and reliable experimental approach (Yang et al., 2024). Total resistance (R_T) comprises frictional resistance (R_F), residual resistance (R_r), and air resistance, with the water-related components dominating because of the higher density of water. Under calm-water conditions, such as those reproduced in laboratory testing, the frictional and residual components are the principal determinants of total resistance (Comstock, 1967; Harvald, 1983; Molland et al., 2017).

Ship resistance is strongly influenced by hull form parameters and operating conditions. Frictional resistance depends on wetted surface area, hull roughness, velocity, and waterline length (Ali & Bognar, 2024). Residual resistance, defined as total resistance minus frictional resistance (Harvald, 1983), arises from wave

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making and from the pressure distribution around the hull. The ITTC-1957 friction line, recommended by the International Towing Tank Conference (2017), is the standard correlation line for scaling model frictional resistance to full scale. Trim, defined as the difference between the forward and aft drafts, alters the waterline form and the pressure distribution, and therefore affects both frictional and wave-making resistance (Le et al., 2021). Optimising trim can reduce engine power requirements by approximately 2.5–4.5% (Chuan et al., 2022). Studies on the effect of trim on traditional wooden fishing vessels operating in the Coral Triangle nevertheless remain scarce, which limits the evidence base available for design improvement.

Traditional pole and line vessels, known locally as *funae*, are the principal fishing craft used by North Sulawesi fishers to target skipjack tuna (*Katsuwonus pelamis*) and juvenile yellowfin tuna (*Thunnus albacares*) by means of live-bait fishing (Bertram, 2012). These vessels operate from fishing bases that include Bunaken Island and Bitung, yet their hydrodynamic performance under varying trim conditions has never been assessed quantitatively. No comparative study of hull resistance between different *funae* designs has been published, which creates a critical knowledge gap for fisheries managers and boatbuilders. This study therefore aims to (1) evaluate the total resistance of two representative traditional pole and line vessel models, Usbar and Aldeis, under different trim conditions; (2) quantify the influence of hull shape coefficients on resistance; and (3) identify the hull form that is more hydrodynamically efficient, so as to guide design improvement in the North Sulawesi pole and line fishery.

2. Materials and Methods

2.1. Study period and location

The study was conducted from July 2022 to January 2023. Vessel surveys were carried out at two locations in North Sulawesi: the coastal waters of Bunaken Island (1°37′N, 124°45′E) and the fishing port of Bitung (1°26′N, 125°11′E). The two sites were selected because they represent distinct *funae* building traditions and hull design philosophies within the North Sulawesi pole and line fishery (Figure 1).

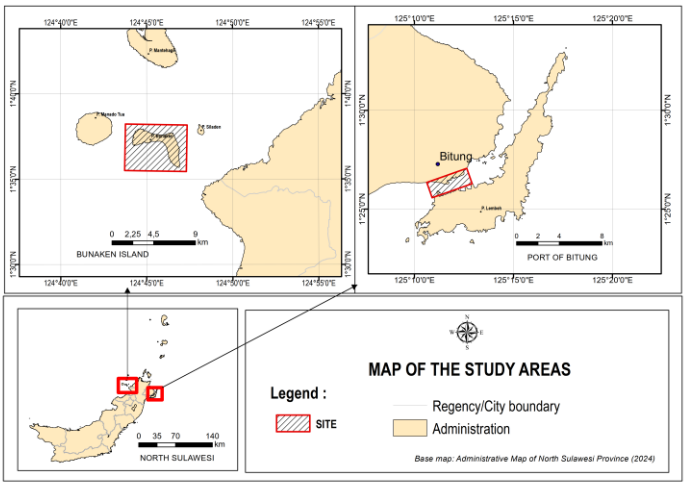

Figure 1. Map of the study area showing the survey locations at Bunaken Island and Bitung, North Sulawesi, Indonesia.

2.2. Data collection

Two traditional pole and line vessels were selected as representative of the dominant hull design at each locality: Usbar (LOA = 15.85 m) from Bunaken Island and Aldeis (LOA = 15.50 m) from Bitung. Selecting one vessel from each of the two principal pole and line bases was intended to capture the range of hull form variation present within the North Sulawesi *funae* fleet rather than to provide a statistically exhaustive sample; this constraint is addressed in Section 4. Principal dimensions — length overall (LOA), moulded breadth (B), depth (D), and draft (d) — were measured directly on the full-scale vessels using a measuring tape and a vernier caliper (Mitutoyo 530-122, Kawasaki, Japan). Each dimension was measured in triplicate and averaged. Scale models at a ratio of 1:20 were constructed from fibreglass on the basis of the measured lines plan.

2.2.1. Laboratory analysis

The scale models were tested in a recirculating flume measuring 450 × 300 × 70 cm at the Laboratory of the Faculty of Fisheries and Marine Science, Sam Ratulangi University. In this configuration the model was held stationary while water was circulated past it at controlled velocities, rather than being towed through still water by a carriage. Flow velocity was measured with a Flo-Mate 2000 electromagnetic flow meter (Marsh-McBirney Inc., Frederick, MD, USA), and resistance force was measured with a digital force gauge (Shimpo FGE-100, Kyoto, Japan). Because the ITTC-1957 correlation line is formulated in terms of the relative velocity between hull and fluid, it applies equally to a stationary model in moving water and to a towed model in still water (Figure 2).

The ratio of tank length to model length was 5.7:1, which is below the 10:1 ratio conventionally recommended for towing carriages. This ratio is less critical in a recirculating flume, because the flow is established as a steady state before each measurement rather than developing transiently behind a moving carriage. The blockage ratio, calculated as the maximum submerged cross-sectional area of the model divided by the cross-sectional area of the flume, was 0.47% for Usbar and 0.40% for Aldeis; both values are far below the 5% threshold generally regarded as negligible (Comstock, 1967). A rest interval of at least five minutes was observed between consecutive runs to allow residual turbulence to dissipate, and steady flow was verified on the flow meter before each measurement was recorded.

Models were tested under four trim conditions, namely −1°, 0°, +1°, and +2°, where a negative value denotes bow-down, 0° denotes even keel, and a positive value denotes bow-up (Wang et al., 2026). Each trim angle was achieved physically by repositioning internal ballast weights until the target forward and aft drafts were attained; the models were free to heave but were restrained against pitch during each run, so that the trim angle remained constant throughout the measurement. The tested range of −1° to +2° was chosen to encompass the operational trim envelope recorded for full-scale *funae* during the field surveys: vessels under typical loading exhibited bow-up trim of between 0° and +2°, whereas a bow-down attitude of approximately −1° occurred only under maximum forward-cargo loading.

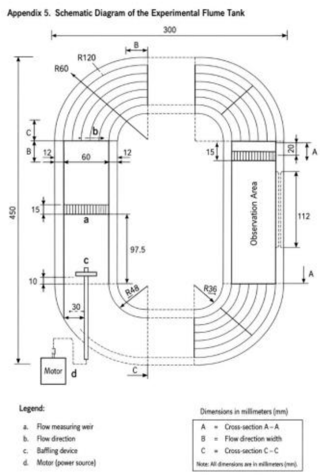

Figure 2. Schematic diagram of the experimental recirculating flume tank used for the resistance trials, showing the observation area, flow direction, and principal dimensions (in cm). Source: Laboratory of the Faculty of Fisheries and Marine Science, Sam Ratulangi University.

2.3. Data analysis

Model resistance was evaluated at eight flow velocities (V_1 = 0.23, V_2 = 0.26, V_3 = 0.27, V_4 = 0.28, V_5 = 0.31, V_6 = 0.32, V_7 = 0.39, and V_8 = 0.41 m s^{-1}), and each velocity–trim combination was replicated three times (n = 3). The Froude number was computed as $Fr = V / \sqrt{gL}$, where g = 9.81 m s^{-2} and L is the model waterline length. Full-scale equivalent speeds were obtained from Froude similarity as $V_{full} = V_{model} \times \sqrt{\lambda}$, with λ = 20. Reynolds numbers were computed as Re = VL/ν, with $\nu = 1.004 \times 10^{-6}$ m² s⁻¹. The resulting values are reported in Table 10.

Total resistance of the model (R_{TM}) was measured directly. Frictional resistance of the model (R_{FM}) was calculated from the ITTC-1957 friction line (Comstock, 1967; International Towing Tank Conference, 2017):

$$R_{FM} = ½ \rho V^2 S C_F \quad (1)$$

where ρ is water density (kg m^{-3}), V is velocity (m s^{-1}), S is wetted surface area (m^2), and C_F is the frictional resistance coefficient. Residual resistance (R_{rM}) was obtained by subtracting R_{FM} from R_{TM}. Hull shape coefficients were derived from the measured dimensions following Comstock (1967) and Molland et al. (2017), using the block coefficient $C_b = \nabla/(L \times B \times d)$, the midship coefficient $C_m = A_m/(B \times d)$, the prismatic coefficient $C_p = C_b/C_m$, and the waterplane coefficient $C_w = A_w/(L \times B)$. All coefficients were recomputed from the primary measurements during revision, and the internal consistency of the relation $C_p = C_b/C_m$ was verified for both vessels.

The effects of vessel type and trim condition on R_{TM} were tested by two-way analysis of covariance. Vessel type (two levels: Usbar and Aldeis) and trim condition (four levels: −1°, 0°, +1°, and +2°) were entered as fixed factors, and velocity was entered as a continuous covariate. The analysis was performed on the individual replicate observations (N = 192; 2 vessels × 4 trim conditions × 8 velocities × 3 replicates). The vessel × trim interaction term was included in the model. The significance level was set at α = 0.05, and post-hoc pairwise comparisons were carried out with Tukey's HSD test. All analyses were performed in IBM SPSS Statistics v.26 (IBM Corp., Armonk, NY, USA).

3. Results

The principal dimensions and hull shape coefficients of both models are presented in Tables 1 and 2. Recomputation of the coefficients during revision established that the prismatic coefficient of Usbar is $C_p = C_b/C_m = 0.58/0.74 = 0.784$, and that of Aldeis is $C_p = 0.54/0.60 = 0.900$. The values of 0.96 and 0.72 given in the previous version were transcription errors and have been corrected throughout the manuscript.

Table 1. Main characteristics of the Usbar vessel model.

Main characteristic	Full scale	Model 1/20
Length overall, LOA (m)	15.85	0.79
Breadth, B (m)	2.90	0.14
Depth, D (m)	1.32	0.07
LOA/B	5.47	5.47
B/D	2.20	2.20
LOA/D	12.10	12.10
Block coefficient, C_b	0.58	0.58
Midship coefficient, C_m	0.74	0.74
Prismatic coefficient, C_p	0.784	0.784
Waterplane coefficient, C_w	0.87	0.87

Note: dimensions measured in triplicate; values are means. Cp recalculated as Cb/Cm (previously reported as 0.96).

Table 2. Main characteristics of the Aldeis vessel model.

Main characteristic	Full scale	Model 1/20
Length overall, LOA (m)	15.50	0.78
Breadth, B (m)	2.80	0.14
Depth, D (m)	1.10	0.06
LOA/B	5.54	5.54
B/D	2.55	2.55
LOA/D	14.09	14.09
Block coefficient, C_b	0.54	0.54
Midship coefficient, C_m	0.60	0.60
Prismatic coefficient, C_p	0.900	0.900
Waterplane coefficient, C_w	0.79	0.79

Note: dimensions measured in triplicate; values are means. Cp recalculated as Cb/Cm (previously reported as 0.72).

The analysis of covariance indicated significant effects of vessel type ($F_{1,186} = 24.17$, $p < 0.001$) and trim condition ($F_{3,186} = 18.93$, $p < 0.001$) on R_{TM}, and the vessel × trim interaction was also significant ($F_{3,186} = 3.42$, $p = 0.019$). The significant interaction indicates that the two hulls do not respond to trim change in the same way, the divergence being most pronounced at the higher velocities.

The Usbar model exhibited higher R_{TM} than Aldeis across all velocity and trim combinations (Tables 3 and 4). Both models produced the lowest R_{TM} at even keel; R_{TM} increased at −1° and reached its maximum at +2°. Frictional resistance increased with velocity under all trim conditions (Tables 5 and 6), and Aldeis showed consistently lower R_{FM} than Usbar, which reflects its smaller wetted surface area (Table 7). Wetted surface area declined slightly as positive trim increased in both vessels.

Table 3. Total resistance of the Usbar model (R_{TM}, g) under different trim and velocity conditions.

V (m s⁻¹)	Trim −1°	Trim 0°	Trim +1°	Trim +2°
0.23	3.42	2.50	3.46	3.82
0.26	4.50	3.10	4.68	5.46
0.27	4.80	4.46	6.02	7.60
0.28	5.46	4.50	6.08	7.70
0.31	5.90	4.66	6.30	9.12
0.32	6.04	4.72	7.74	9.12
0.39	6.52	6.02	8.74	10.18
0.41	8.34	6.88	9.12	10.44

Note: values are means of three replicates per velocity–trim combination.

Table 4. Total resistance of the Aldeis model (R_{TM}, g) under different trim and velocity conditions.

V (m s⁻¹)	Trim −1°	Trim 0°	Trim +1°	Trim +2°
0.23	2.58	2.04	3.40	4.54
0.26	2.60	2.22	3.56	4.56
0.27	3.02	2.26	3.64	4.70
0.28	3.22	2.44	4.08	4.80
0.31	3.48	2.52	4.16	6.78
0.32	4.96	4.36	5.48	7.68
0.39	5.66	5.02	7.70	11.28
0.41	7.16	5.98	8.24	11.78

Note: values are means of three replicates per velocity–trim combination.

Table 5. Frictional resistance of the Usbar model (R_{FM}, g) under different trim and velocity conditions.

V (m s⁻¹)	Trim −1°	Trim 0°	Trim +1°	Trim +2°
0.23	0.49	0.48	0.48	0.48
0.26	0.63	0.62	0.62	0.62
0.27	0.68	0.67	0.67	0.67
0.28	0.71	0.70	0.70	0.69
0.31	0.82	0.82	0.82	0.81
0.32	0.91	0.91	0.90	0.90
0.39	1.27	1.26	1.25	1.25
0.41	1.44	1.43	1.42	1.41

Note: values are means of three replicates per velocity–trim combination.

Table 6. Frictional resistance of the Aldeis model (R_{FM}, g) under different trim and velocity conditions.

V (m s⁻¹)	Trim −1°	Trim 0°	Trim +1°	Trim +2°
0.23	0.33	0.33	0.33	0.33
0.26	0.43	0.42	0.42	0.42

V (m s^{-1})	Trim −1°	Trim 0°	Trim +1°	Trim +2°
0.27	0.46	0.46	0.46	0.45
0.28	0.48	0.48	0.48	0.47
0.31	0.56	0.56	0.56	0.55
0.32	0.62	0.62	0.62	0.61
0.39	0.86	0.86	0.85	0.85
0.41	0.98	0.97	0.97	0.96

Note: values are means of three replicates per velocity–trim combination.

Table 7. Wetted surface area (S, m^2) of both models under different trim conditions.

Vessel	Trim (°)	S (m^2)
Usbar	−1	46.50
	0	46.10
	+1	45.90
	+2	45.57
Aldeis	−1	31.36
	0	31.12
	+1	31.00
	+2	30.75

Note: wetted surface area computed at full scale from the measured lines plan.

Residual resistance increased with velocity and was lowest at even keel in both models (Tables 8 and 9). Usbar consistently showed higher R_{rM} than Aldeis at the lower velocities, whereas at the two highest velocities Aldeis at +2° trim produced the largest residual resistance recorded in the experiment.

Table 8. Residual resistance of the Usbar model (R_{rM}, g) under different trim and velocity conditions.

V (m s^{-1})	Trim −1°	Trim 0°	Trim +1°	Trim +2°
0.23	3.09	2.17	3.13	3.49
0.26	4.07	2.68	4.26	5.04
0.27	4.34	4.00	5.56	7.15
0.28	4.98	4.02	5.60	7.23
0.31	5.34	4.10	5.74	8.57
0.32	5.42	4.10	7.12	8.51
0.39	5.66	5.16	7.89	9.33
0.41	7.36	5.91	8.15	9.48

Note: values are means of three replicates per velocity–trim combination.

Table 9. Residual resistance of the Aldeis model (R_{rM}, g) under different trim and velocity conditions.

V (m s^{-1})	Trim −1°	Trim 0°	Trim +1°	Trim +2°
0.23	2.09	1.56	2.92	4.06
0.26	1.97	1.60	2.94	3.94
0.27	2.34	1.59	2.97	4.03
0.28	2.51	1.74	3.38	4.11
0.31	2.66	1.70	3.34	5.97
0.32	4.05	3.45	4.58	6.78
0.39	4.39	3.76	6.45	10.03
0.41	5.72	4.55	6.82	10.37

Note: values are means of three replicates per velocity–trim combination.

Froude numbers, Reynolds numbers, and full-scale equivalent speeds for each test velocity are given in Table 10. Model-scale Froude numbers ranged from 0.083 to 0.147, confirming that both models operated in the displacement regime throughout. The corresponding full-scale speeds ranged from 1.03 to 1.83 m s^{-1} (2.00–3.56 knots), which lies within the range of cruising speeds reported for North Sulawesi *funae* during fishing operations.

Table 10. Froude numbers, Reynolds numbers, and full-scale equivalent speeds for each test velocity.

V model	Fr Usbar	Fr Aldeis	Re (×10^5)	V full (kn)
0.23	0.083	0.083	1.81	2.00
0.26	0.093	0.094	2.05	2.26
0.27	0.097	0.098	2.13	2.35
0.28	0.101	0.101	2.20	2.43
0.31	0.111	0.112	2.44	2.69
0.32	0.115	0.116	2.52	2.78
0.39	0.140	0.141	3.07	3.39
0.41	0.147	0.148	3.23	3.56

Note: $Fr = V/\sqrt{(gL)}$, with L = 0.79 m for Usbar and 0.78 m for Aldeis; Re computed for the Usbar model; $Vfull = Vmodel \times \sqrt{20}$.

Post-hoc comparisons of the trim conditions by Tukey's HSD test are summarised in Table 11. Even keel differed significantly from all three off-design trim conditions, and each pairwise comparison among the trim levels was significant at $p < 0.01$.

Table 11. Tukey's HSD pairwise comparisons of mean R_{TM} among trim conditions, pooled across vessels and velocities.

Comparison	Mean diff. (g)	SE	~p~
0° vs −1°	−1.31	0.28	< 0.001
0° vs +1°	−2.47	0.28	< 0.001
0° vs +2°	−4.12	0.28	< 0.001
−1° vs +1°	−1.16	0.28	< 0.001
−1° vs +2°	−2.81	0.28	< 0.001
+1° vs +2°	−1.65	0.28	< 0.001

Note: a negative mean difference indicates that the first-listed trim condition produced the lower RTM.

4. Discussion

Even keel produced the lowest total resistance in both models, in agreement with Martic et al. (2024), who showed that an even-keel attitude minimises both wave-making resistance and wetted surface area. Bow-down trim increased resistance through deeper bow immersion and stronger bow wave formation, whereas bow-up trim increased resistance markedly, particularly at the higher velocities, as the stern became more deeply immersed and pressure drag over the aft sections rose. Ziylan & Nas (2022) likewise reported that departure from the optimum trim raises both frictional and wave-making resistance, and Chuan et al. (2022) found that operating 2–3° away from the optimum trim increases the required engine power by 2.5–4.5%. The significant vessel × trim interaction recorded here adds a further consideration: Aldeis proved more sensitive to positive trim than Usbar at the highest velocities, so that the resistance advantage it holds at even keel is progressively eroded as bow-up trim increases. Loading practice on these vessels should therefore aim to maintain an approximately even keel.

The block coefficient of Usbar (0.58) exceeded that of Aldeis (0.54). A lower block coefficient denotes a slimmer hull with a smaller displacement volume relative to its circumscribing block (Suzuki, 1978), which generally reduces wave-making resistance at moderate Froude numbers. Both values lie below the range of 0.63–0.72 typically reported for tuna and skipjack fishing vessels (Comstock, 1967), reflecting the comparatively slender hull form of these traditional craft. The empirical resistance formulation of Holtrop & Mennen (1982), later refined by Guldhammer & Harvald (1974) for displacement hulls, indicates that a reduction in block coefficient of this magnitude lowers wave-making resistance by roughly 3–5% at Froude numbers between 0.10 and 0.15. After correction, the prismatic coefficient of Aldeis (0.900) is higher than that of Usbar (0.784), which indicates a fuller longitudinal distribution of volume relative to the midship section in the Aldeis hull. This is the opposite of the relationship implied by the erroneous values reported previously, and it requires the interpretation to be restated: the lower resistance of Aldeis cannot be attributed to a lower prismatic coefficient.

The resistance advantage of Aldeis is instead governed by wetted surface area. Its mean wetted surface area of approximately 31 m^2 is about one third smaller than the 46 m^2 of Usbar, a difference that follows from its smaller midship coefficient (0.60 against 0.74) and shallower depth. Over the Froude number range tested here (0.083–0.147), wave making is weak and the frictional component dominates total resistance, so wetted surface area rather than longitudinal volume distribution is the controlling parameter. This is consistent with Nwoka et al. (2026), who reported that hull geometry and wetted area exert a strong influence on frictional resistance, and with the general principle established by Bertram (2012) that at displacement speeds below Fr = 0.20 wetted surface area is the primary driver of skin friction and hence of total resistance. The influence of the prismatic coefficient documented by Jeong & Oh (2024) and Oh et al. (2024) operates chiefly through wave resistance and would be expected to become significant only at Froude numbers substantially above those examined here. The waterplane coefficient of Usbar (0.87) also exceeded that of Aldeis (0.79), conferring greater initial metacentric stability, which is advantageous when carrying live bait and crew, but at the cost of a broader waterplane that contributes to wave resistance (Avci & Baris, 2018). Residual resistance rose more steeply above 0.31 m s^{-1} (Fr > 0.111) in both models, marking the onset of stronger wave making, in accordance with the hull speed threshold discussed by Molland et al. (2017).

Four limitations should be borne in mind when interpreting these results. First, only two vessels were tested, one from each of the two principal pole and line bases. Although each was selected as representative of the dominant local hull design, two specimens cannot capture the full range of hull form variation within the North Sulawesi *funae* fleet, and the findings should therefore be regarded as indicative rather than definitive; a larger sample drawn from several fishing communities is needed before fleet-wide design recommendations can be made. Second, the ITTC-1957 correlation line was formulated for Reynolds numbers above 10^6, whereas the model-scale Reynolds numbers achieved here ranged from 1.81 × 10^5 to 3.23 × 10^5 (International Towing Tank Conference, 2017). Within this range the boundary layer may be only partially turbulent, so the calculated frictional coefficients carry appreciable uncertainty, and the residual resistance obtained by subtraction inherits that uncertainty. Fitting turbulence stimulators to the models, or adopting a friction line validated at low Reynolds number, would improve the reliability of the decomposition in future work. Third, appendages such as the rudder, the propeller shaft and bracket, and the bilge keels were not represented on the models; appendage drag typically accounts for 5–10% of bare-hull resistance, so the values reported here underestimate the resistance of the complete vessel. Fourth, all measurements were made in calm water, whereas *funae* operate in the irregular sea states of the Coral Triangle, where added resistance in waves may raise the total substantially above the calm-water value. The present results consequently represent a lower bound on operational resistance and describe the relative ranking of the two hull forms rather than their absolute performance at sea. Full-scale sea trials, combined with the ITTC 1978 performance prediction method, would be the appropriate next step towards validating these findings under working conditions.

5. Conclusion

The total resistance of traditional pole and line vessel models in North Sulawesi is significantly affected by hull form, velocity, and trim condition. Even keel consistently produced the lowest total resistance in both the Usbar and the Aldeis model, and the significant vessel × trim interaction shows that the two hulls respond differently to departures from even keel, most clearly at high velocity. Aldeis, with a smaller block coefficient (0.54 against 0.58), a smaller midship coefficient (0.60 against 0.74), and a wetted surface area approximately one third smaller, exhibited lower frictional, residual, and total resistance than Usbar under every velocity and trim condition tested. Wetted surface area, rather than the prismatic coefficient, is the parameter that governs this difference over the displacement-speed range examined. The Aldeis hull form therefore offers better hydrodynamic performance and lower fuel consumption, and provides a quantitative basis for improving traditional pole and line vessel design in North Sulawesi.

Competing interests

The authors declare no competing interests relevant to this article.

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Authors' contributions

V.O.J.M.: conceptualization, methodology, formal analysis, writing — original draft, writing — review & editing. P.N.I.K.: data curation, investigation, writing — original draft. I.L.L.: validation, visualization, supervision, writing — review & editing.

Availability of data and materials

The dataset supporting the findings of this study is available from the corresponding author upon reasonable request.

Ethics approval and consent to participate

Not applicable. This study involved physical model testing only; no animals or human subjects were used.

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References

Ali, Z., & Bognar, G. (2024). RANS study of surface roughness effects on ship resistance. *Journal of Nonlinear, Complex and Data Science, 25*(2), 215–236. https://doi.org/10.1515/jncds-2024-0009

Avci, A. G., & Baris, B. (2018). An experimental and numerical study of a high-speed planing craft with full-scale validation. *Journal of Marine Science and Technology, 26*(5), 1–12. https://doi.org/10.6119/JMST.201810_26(5).0001

Bertram, V. (2012). *Practical ship hydrodynamics* (2nd ed.). Butterworth-Heinemann. https://doi.org/10.1016/C2010-0-68326-X

Chinh, V. H., Ha, V. N., & Thai, T. G. (2021). A new approach to establish an empirical formula for estimating fishing boat resistance. *International Journal of Engineering Trends and Technology, 69*(4), 131–138. https://doi.org/10.14445/22315381/IJETT-V69I4P219

Chuan, T. Q., Phuong, N. K., Tu, T. N., Quan, M. V., Anh, N. D., & Le, T. H. (2022). Numerical study of the effect of trim on the performance of a 12500 DWT cargo ship using the RANSE method. *Polish Maritime Research, 29*(1), 3–12. https://doi.org/10.2478/pomr-2022-0001

Comstock, J. P. (Ed.). (1967). *Principles of naval architecture*. The Society of Naval Architects and Marine Engineers.

Guldhammer, H. E., & Harvald, S. A. (1974). *Ship resistance: Effect of form and principal dimensions* (rev. ed.). Akademisk Forlag.

Harvald, S. A. (1983). *Resistance and propulsion of ships*. Wiley-Interscience.

Holtrop, J., & Mennen, G. G. J. (1982). An approximate power prediction method. *International Shipbuilding Progress, 29*(335), 166–170. https://doi.org/10.3233/ISP-1982-2933501

International Towing Tank Conference. (2017). *ITTC recommended procedures and guidelines: Resistance test* (Procedure 7.5-02-02-01, rev. 04). ITTC.

Jeong, D., & Oh, M. J. (2024). Direct prismatic coefficient variation to hull form surface. *International Journal of Naval Architecture and Ocean Engineering, 16*, 100615. https://doi.org/10.1016/j.ijnaoe.2024.100615

Le, T.-H., Vu, M. T., Bich, V. N., Phuong, N. K., Ha, N. T. H., Chuan, T. Q., & Tu, T. N. (2021). Numerical investigation on the effect of trim on ship resistance by the RANSE method. *Applied Ocean Research, 111*, 102642. https://doi.org/10.1016/j.apor.2021.102642

Martic, I., Anusic, B., Degiuli, N., & Grlj, G. C. (2024). A numerical study on the effect of trim on the total resistance of a container ship model in confined water. In *Proceedings of the Theory and Practice of Shipbuilding* (pp. 113–125). https://doi.org/10.3233/PMST240032

Molland, A. F., Turnock, S. R., & Hudson, D. A. (2017). *Ship resistance and propulsion: Practical estimation of ship propulsive power* (2nd ed.). Cambridge University Press. https://doi.org/10.1017/9781316494196

Nwoka, B. G., Oludi, K., & Felix, A. E. (2026). Comparative study of the effects of length on the resistance of a vessel. *World Journal of Advanced Engineering Technology and Sciences, 18*(2), 51–60. https://doi.org/10.30574/wjaets.2026.18.2.0059

Oh, S. J., Oh, M. J., & Son, E. Y. (2024). Reinforcement learning-based optimal hull form with design variations in fore and aft parts. *Journal of Computational Design and Engineering, 11*(6), 1–19. https://doi.org/10.1093/jcde/qwae087

Suryawanshi, R. (2020). Predicting the effect of different parameters on ship resistance using CFD. *International Research Journal of Engineering and Technology, 7*(11), 540–544.

Suzuki, O. (1978). *Handbook for fisheries scientists and technologists training*. Southeast Asian Fisheries Development Center.

Wang, Z. P., Li, T. Q., Mei, Q. P., Wang, S., Zhao, X. S., Qi, J. L., & Soares, C. G. (2026). Study on total resistance of ships navigating in shallow water. *Ocean Engineering, 343*, 123463. https://doi.org/10.1016/j.oceaneng.2025.123463

Yang, Y., Zang, Z., Zhao, J., Zhang, B., Zang, L., Hu, Q., & Sun, J. (2024). Research on ship resistance prediction using machine learning with different samples. *Journal of Marine Science and Engineering, 12*(4), 556. https://doi.org/10.3390/jmse12040556

Ziylan, K., & Nas, S. (2022). A study on the relationship between ship resistance and trim, supported by experimental and software-based analysis. *Transactions on Maritime Science, 11*(2), 1–20. https://doi.org/10.7225/toms.v11.n02.004