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Using trim Control to Improve energy Efficiency on High-Speed Marine Vehicles (HSMV): A Review

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Abstract: Indonesia is an archipelago made up of a large number of islands, many of which are small and isolated. For effective connection of the islands, it is crucial to have efficient and well-designed marine transportation systems. High-speed marine vehicles (HSMVs) are suitable for this purpose due to their compact size and speed. As the country continues to grow, the demand for HSMVs is increasing. However, to address the issue of climate change, these vehicles must have technological advancements that increase their energy efficiency. One way to achieve this is through trim control, a technique that can reduce the ship's resistance and improve energy efficiency. Studies have shown that if the trim control is properly configured, it can reduce the effects of ship drag and porpoising. However, the speed parameter, hull characteristics, and return moment capacity of the trim control must be properly configured. Because if the design is incorrect, resistance actually rises in comparison to not employing trim control.

Keywords: planing hull; high-speed marine vehicles; trim control; interceptor; trim tab; stern foil

1. Introduction

Energy conservation efforts have become increasingly important in reducing the carbon emissions produced by ships. Carbon emissions from fossil fuels, such as petroleum, are a major contributor to global warming[1–3]. Fossil fuels are used extensively in various industries[4–8] and transportation activities[9–13]. These fuels are burned to produce heat and pressure energy, which is then used to power engines, generators, or steam turbines on ships[14]. Finding alternative energy sources and implementing energy-efficient technologies is crucial to lowering the shipping industry's carbon footprint.

According to the International Maritime Organization (IMO), emissions from all shipping-related operations account for 2.1% of greenhouse gas (GHG) emissions and 2.2% of CO2 emissions globally, compared to all other human-made emissions[15]. This number highlights the need for decisive action to prevent emissions from increasing threefold by 2050[16,17]. However, it's important to note that reducing emissions is not a problem that can be solved by the shipping sector[18–23]. Instead, there needs to be a broader approach that involves developing and implementing green energy concepts across all industries[24–26]. The action can include using alternative fuel sources, energy-efficient technologies, and sustainable practices[27,28].

As an archipelago nation with nearly 17,000 islands[29], Indonesia presents opportunities and challenges for developing a green transportation system. The abundance of marine resources gives an advantage, but connecting all the islands with a cohesive system can be difficult[30]. Ships[31] and aircraft[32] are specifically designed for the best transportation modes for archipelagic countries with many islands. As long as there are waterways and ports, ships can transfer people or goods from one location to another. It is more feasible to construct a pier for each island rather than an airport for every island since many islands are small[29]. As a result, ships are among the most suitable modes of transportation for developing their technology.

The requirement for human mobility advances along with economic changes that alter human civilization on an island, such as a transition in society from a fishing village to a fish processing industry[33,34]. As the economy develops, higher-level occupations such as accountants,

doctors, lecturers, and other professionals are required due to the development of service facilities for education, health, and other services[35]. This kind of society unquestionably requires a faster and more practical mode of transportation, as well as one that is environmentally friendly, to prevent health problems in the future[36–40]. Additionally, high-speed marine vehicles (HSMVs) are required for various purposes such as military operations, fishing, shipping safety, surveys, leisure, and other service-related tasks[41]. These vehicles can be used for patrols (Fig. 1) for fishing or military operations[42] and for coast guard or patrol ships to keep shipping security[43]. HSMVs are also considered ambulance vessels[44,45]. These fast-moving marine vehicles are also necessary for several leisure activities[46].

Fig. 1: Patrol boat 60m built by PT. PAL Indonesia[42]

Fast boats require a lot of power, so they require high energy consumption[47]. This energy, typically used, is fuel oil[48,49]. The current situation is the main focus of efforts to stop climate change and global warming[15,16,50], so reducing emissions on HSMVs is a challenge. Several methods to reduce emissions on board include[9,51]: optimization of hull shape[52–55], weather routing[56,57], maintaining a clean hull from biofouling[58–67] use of more environmentally friendly fuels[68–72], optimization of propellers[73,74], using additional environmentally friendly energy resources[75].

HSMVs use monohull or catamaran vessels by utilizing the planing phenomenon. This development began with intensive research related to hull planing form[76]. This planing hull can be chosen as the hull of a fast-speed marine vehicle because, along with the increase in speed, there is a hydrodynamic force that makes the hull lift (planing) so that the displacement and wet area of the hull are reduced, which then the resistance decrease[77]. Unfortunately, if the hydrodynamic lifting force is too large, it will cause the ship to experience porpoising[78]. Porpoising is the phenomenon of the ship's hull bouncing on the surface of the water[78]. Therefore, the addition of a trim-control tool needs to be applied. The trim-control device can be a stern flap or an interceptor[79]. The results showed that, apart from overcoming the porpoising phenomenon, the trim-control device could also reduce ship resistance in the right scenario[80].

In this paper, we will review the development of research on fast boat technology which has added a trim control tool with the aim intending to reduce ship resistance.

2. High-speed marine vehicle definition

A high-speed marine vehicle is a ship or boat with an operating speed of more than 30 knots or a Froude number (Fr) value above 0.4[81]. This Froude number is the ratio between the speed of the ship to its size, which can be represented by the length of the ship (L), can also be breadth (B)[47], or the cube root of displacement ($\sqrt[3]{\nabla}$). The Froude number equation is explained in Equation (1).

$$\mathrm{Fr} = \frac{U}{\sqrt{Lg}} \tag{1}$$

Where: U is the speed of the ship; L is the length of the ship; g is gravity acceleration. For HSMVs, generally, the Froude number used is not L but B or $\sqrt[3]{\nabla}$ because the value of the L will change when the ship experiences the planing phenomenon[47].

The development of high-speed craft technology indeed started in the 1950s. Damen Shipyard is one company focused on developing single-hull fast boat designs[82]. These developments aim to improve performance (reduce drag)[83] and reduce seakeeping problems[84], especially in wavy seas[85].

Designing a high-speed boat comes with its own set of unique challenges. Like a sports car, a high-speed boat's engine system takes up a significant portion of its weight and volume [47]. Additionally, due to the high resistance caused by high speeds, HSMVs require a large power installation. The resistance factor to speed is squared (V^2), while power is cubed (V^3). This means that as ship speed increases, energy consumption also increases[58]. Therefore, designing and implementing patterns that can reduce energy consumption is crucial in developing high-speed boats.

With such a large portion of machinery, the cargo capacity also poses a challenge. The engine consists of the main engine, fuel tank, and piping systems for fuel, coolant, and air. The portion of weight and volume allocated for cargo is limited. Due to the small size of high-speed marine vehicles, weight changes can significantly affect the draft and trim. Improper planing and operations can lead to disaster. Therefore, it is a significant challenge to ensure that high-speed marine vehicles can still carry many passengers while maintaining safety and stability.

Another challenge is that the ship's maneuverability becomes poor at high speed when passing through rough seas. This motion can make passengers uncomfortable. Even for waves of a certain height, the ship may have to sail below its operational speed. To reduce undesirable events of HSMVs like accidents in the sea, The International Maritime Organization (IMO) made several

regulations. The regulations consist of the International Code of Safety for High-Speed Craft (HSC Code) regulations (resolution MSC.36 (63)[86]) and improvements of SOLAS chapter X on Safety measures for high-speed craft[87].

The types of high-speed marine vehicles (HSMVs) themselves include hydrofoils, hovercraft, catamarans, monohulls, and surface effect ships (SES). Before the 1990s, most HSMVs were hydrofoils and hovercraft until catamaran and monohull models became more popular. Even passenger ferries that transport cars, buses, large trucks, and cargo are also designed as HSMVs[88].

3. Planing of hull phenomenon

The planing phenomenon generally occurs when a ship moves fast enough that hydrodynamic forces rather than hydrostatic forces support most of its weight. The ship will experience planing when it has a number Fn > 1.2[76]. When the hull moves in a straight line in still water, the hull experiences force balance and moment equilibrium, which is affected by trim angle, draft, and velocity. The hydrodynamic force in the X-axis direction becomes the ship's resistance (R_T), whereas the hydrodynamic force in the Z-axis direction becomes the lift force (F_{Zhull}). A planing hull has a very high hydrodynamic force value in the Z direction, which is what sets it apart from a displacement hull type[77]. This portion is the basis for classifying hull types; the hydrodynamic force in the planing hull is relatively significant and has an effect, whereas the lift force in the displacement type hull is so negligible that it can be assumed to be non-existent[89]. This lifting force raises the ship's hull to its equilibrium position. The equilibrium position is reached for the difference in sinking force and trimming moment (see Fig. 2)[90]. Equations (2) and (3) may explain the force balance, while Equations (4) and (5) can represent the moment balance. Where: Δ is displacement (buoyancy force); W_G is ship weight; L_{CB} is the distance from the center of buoyancy force to the stern (transom); L_{CG} is the distance from the center of ship weight to the stern; and L_H is the distance of the center of hydrodynamic forces on the hull from the stern. As a result of lifting the hull, it causes a decrease in the displacement and the hull's wet area, which causes the ship's resistance to reduce.

$$\Sigma F_Z = 0 \tag{2}$$

$$0 = \Delta - W_G + F_{Z_{hull}} \tag{3}$$

$$\Sigma M_{Y_{CG}} = 0 \tag{4}$$

$$0 = \Delta \cdot L_{CB} - W_G \cdot L_{CG} + F_{Z_{hull}} \cdot L_H \tag{5}$$

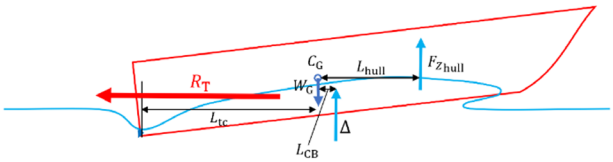

Fig. 2: An illustration of the forces on the hull during planing

The ship's planing resistance can be predicted using empirical methods[76,91], towing tank testing, and CFD simulation[92]. The most famous planing ship resistance prediction method is the empirical method from Savitsky[76]. This method is iterative, with variables that must be estimated first. The explanation of this method is explained as follows[90]:

1. It is known that the values of V, b, L_{CG}, Δ, and β, where V is the speed of the ship, b is the average breadth of the ship's chine, L_{CG} is the position of the center of gravity of the ship, Δ is the mass of the ship or displacement, β is deadrise angel;
2. Estimate the value of the length of the submerged hull (l_m), and the trim angle (τ);
3. Predict the value of the wet surface area, namely $S = l_m b \sec\beta$;
4. Calculate the value of R_F and R_A, where R_F is the frictional resistance and R_A is the air resistance. The frictional resistance can be calculated as $R_F = 0.5\rho S V^2 C_F$, for the value of C_F (coefficient of frictional resistance) can use the formula of ITTC 1957[93], namely $C_F = 0.075/(\log \mathrm{Re} - 2)^2$. Meanwhile, the air resistance can be estimated using Hadler's method[94].
5. Check the balance of moments, where $\delta M = \Delta \times L_{CG} - N \times l_p$;
6. If the value of $\delta M \neq 0$, then repeat to re-estimate the values of l_m and τ in No.2 until the value $\delta M = 0$;
7. The last step is to calculate the total resistance (R_T) based on the correct value of l_m and τ, where $R_T = T\cos\tau$, where T is thrust, ie: $T = \Delta \sin\tau + R_F + R_A$.

Total ship resistance consists of frictional and pressure resistance if air resistance is neglected. Both portions of the resistances are described in Fig. 3. Whereas the trim is increased, the pressure resistance will continue to increase, and the frictional resistance tends to decrease. The pressure resistance increases because the projected area on the X-axis exposed to water increases, and then the frictional resistance is reduced because the area of the submerged water is reduced.

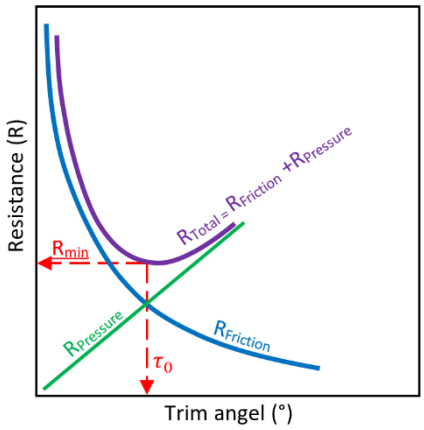

Fig. 3: Composition of pressure and frictional resistance for trim variations in planing hull[95)]

4. Porpoising phenomenon

Faltinsen[77)] defines porpoising as a fast boat's unstable heave and pitch motion. The incident of porpoising is repeatedly bouncing up and down at the surface of the water. It can also cause a slamming load[96)]. Blount and Codega[97)] provided recommendations for preventing porpoising based on the findings of Day and Haag's extensive experimental study[98)], which were later presented by Savitsky[78)]. According to the recommendation in Fig. 4, porpoising occurs when the trim angle and the force coefficient combination raise its position over the curve for each deadrise. It can be seen in the graph that if the lift coefficient increases, then one way to avoid porpoising is to decrease the trim angle value. There are several ways to reduce the trim angle, namely by moving the ship's center of gravity forward or using a trim control tool[99)]. In addition, this porpoising can also be prevented by lowering the ship's speed.

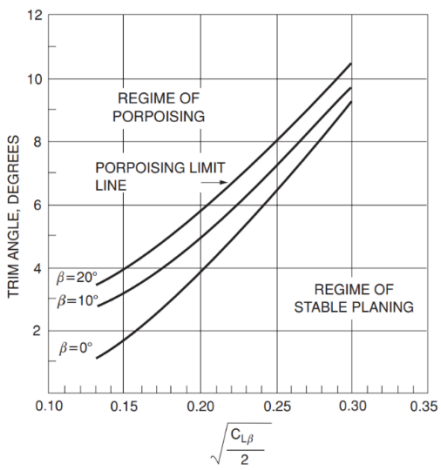

Fig. 4: Limit porpoising for prismatic planing hulls[77),78)]

A study of two models of HSMVs with deadrise angles of 10.6° and 20.5° was carried out by Day and Haag[98)] with experiments on towing tanks. From the results of their research, it was found that the critical trim value will increase with the increasing deadrise of the hull. Variations in the value of the ship's centre of gravity (LCG) were also carried out. The result is that the centre of gravity approaching the bow will reduce the occurrence of the porpoising phenomenon. Variations in LCG and deadrise angle values were also carried out by Aliffrananda et al.[100)] using the CFD simulation method. Changes in the LCG value can also reduce the ship's drag [101)]. The LCG shift can change the trim angle, which will reduce the occurrence of the porpoising phenomenon. In addition to moving the LCG, another technique is to use control trim to add anti-moment to the ship's stern.

5. Trim-control definition and function

Trim control is required since the planing phenomena worsen as ship speed rises, causing over-trim and even porpoising. There are several ways to reduce the trim angle, namely by moving the ship's centre of gravity forward or using a trim control device[99)]. The trim control functions to provide a lift force on the stern of the hull to create a return moment, see Fig. 5. With the addition of trim control, Equation (2) becomes Equation (5), and Equation (4) becomes equation (6), where: F_{Ztc} is the lift of the trim control; and L_{tc} is the distance from the trim control position to the stern.

$$0 = \Delta - W_G + F_{Z_{hull}} + F_{Z_{tc}} \quad (6)$$

$$0 = \Delta \cdot L_{CB} - W_G \cdot L_{CG} + F_{Z_{hull}} \cdot L_H - F_{Z_{tc}} \cdot L_{tc} \quad (7)$$

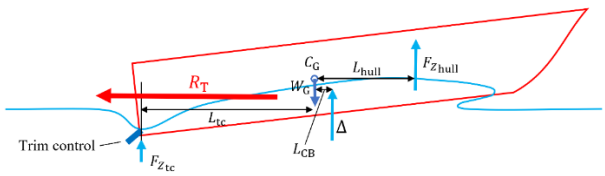

Fig. 5: An illustration of the forces on the hull during planing and with a trim control mechanism added

This trim control can be an interceptor, stern flap, or stern foil[102)]. Many studies agree that trim control can reduce unwanted trim angles at high speeds, including the interceptor[79),103–105)], stern flap[106–108)], and stern foil[109,110)]. Fig. 6 explains the difference between the placement of the trim tabs and the interceptors, as seen from the ship's side. Fig. 7, taken from Mansoori & Fernandes[102)], explains the detailed parameters for each trim tab and interceptor and their appearance from the ship's rear. Fig. 8 shows the placement of a foil at the bottom of the transom.

As seen in Fig. 9 below, this trim control aims to produce an anti-moment. The hydrodynamic force's lift force is centred, creating a moment about the ship's centre of gravity. The anti-moment produced by the force of the trim control diminishes the trim value. With the advent of

this trim control tool, it is envisaged that it would be possible to avoid the porpoising issue while also lowering drag.

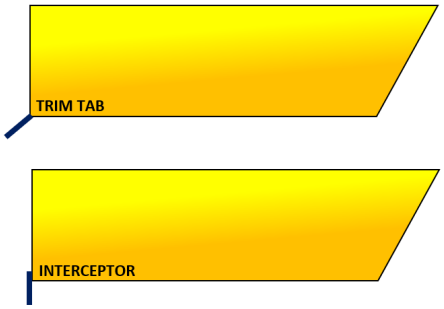

Fig. 6: The trim tab and interceptor have different positions and operations

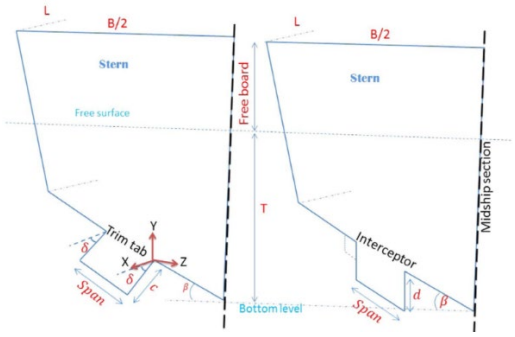

Fig. 7: Different trim tab and interceptor input parameters where this image was taken from Mansoori & Fernandes[102)]

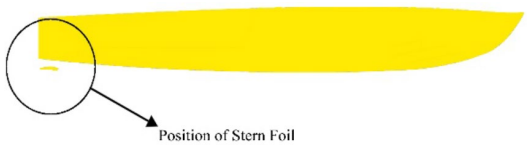

Fig. 8: Placement of stern foil (taken from Syahrudin et al.[111)])

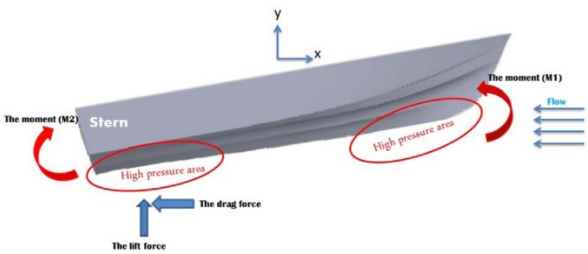

Fig. 9: M2 moment value, which becomes anti-moment to prevent porpoising[102)]

5.1 Trim tab

Fitriadhy et al.[108)] conducted CFD simulations to analyze the performance of trim tabs on high-speed vessels. This simulation aims to determine the effect of reducing pitch movement due to the addition of a trim tab to increase comfort in calm water conditions. Fitriadhy et al. [108)] vary the value of Fr and the angle of the trim tab, which produces the lift force as the anti-moment pitching. The results showed that the trim tab reduced the pitch value of the ship's movement significantly up to 76% at Fr = 1. The trim tabs generate lift, pushing the stern of the boat upwards and creating a negative moment. This negative moment causes the dynamic trim to decrease. Unfortunately, with this trim tab, the total resistance actually increases.

Ghadimi et al.[107)] examined the different variations of several trim tab parameters, namely span length from 0.3 – 0.9 m, trim tab angle from 2 – 12 degrees, and the value of the ratio of the point of gravity to the width of the ship (LCG/B). The method used is a parametric study with the existing empirical formula. The results show that the longer the span of the trimtab, the more effective it will be to reduce the trim of the hull, but the consequence is to increase the drag. Likewise, the angle of the trim tab, the greater the angle of the trim tab, the trim of the ship is reduced, but the total resistance is higher. The optimization results show a deflection angle of 5.2 degrees for the value of LCG/B = 0.71 and then an angle of 3.5 degrees for LCB/B = 1.87. Therefore, the larger the LCB/B value ratio, the smaller the optimal trim tab angle.

Budiarto et al.[106)] performed a CFD simulation to analyze the application of the stern flap to the Fridsma's hull, with a variation of Fr 0.89-1.78. The analysis findings indicate a positive impact of the stern flap on reducing ship resistance, including pressure drag and friction drag. Initially, the total drag increases, but this decreases displacement, resulting in a lower resistance value. Optimum results occurred in flaps with a span of 58% of the hull width, which reduced 10.2% of total drag and 18% of displacement compared to no stern flap.

Based on the trim tab application reviews, a conclusion can be drawn about its use for HSMVs. Trim tabs can reduce the trim angle, preventing porpoising and increasing comfort. But it increases drag, unlike everything in a state of quiet movement, not porpoising. However, if porpoising occurs, it is certain that the ship's movement becomes unstable and will automatically create an up-and-down drag[100)]. The value of drag that goes up and down will cause unstable thrust and lead to inefficient use of energy. However, applying a stern flap in certain optimal variations can reduce drag by reducing the ship's displacement[106)].

5.2 Interceptor

Many studies agree that interceptors can reduce unwanted trim angles at high speeds, as has been done by Avci & Barlas[103)], Karimi et al.[79)], Mansoori & Fernandes [104)] as well as Samuel et al.[105)]. However, at high speeds, the interceptor needs to be recalculated because the effect of trim that is too high makes the ship bend, and the drag starts to be higher than ships without an interceptor[103)]. Along with increasing speed, the height of the interceptor can be reduced to remain optimal in producing the right lift value[105)].

According to Avci & Barlas[103)], an interceptor of any

configuration is useless at speeds Fr < 0.5 because the interceptor provides added drag. At speeds Fr > 0.5, the interceptor proves helpful in reducing drag from 10 to 18%. However, at 0.85 < Fr <1, the effectiveness of the interceptor begins to decrease. Its drag reduction is only 6% compared to without an interceptor. Even at speeds of Fr > 1.05, the interceptor depth needs to be reduced because the effect is too significant to make the hull too bent. As per Karimi et al.[79], a drag reduction of 7% to 19% is achieved with a 2mm to 3mm interceptor. The study of Samuel et al.[105] shows that the most optimal condition occurs at Fr = 0.87 with a drag reduction of 57% compared to without an interceptor.

Increasing the interceptor span length is preferred over increasing the height to increase lift. Interceptor placement is also more effective near the keel than near the chine, according to Avci & Barlas[103]. It is different, according to Samuel et al.[105], that the placement of the interceptor that is close to the chine is the most effective. Still, this variation in location does not have a significant effect. In contrast to the results proposed by Sahin et al.[112], that is most effective, the interceptor is placed halfway between the keel and the chine.

The interceptor can change the pressure distribution. For a hull without an interceptor, the distribution of the compressive force tends to be greatest at the bow, where the water first confronts the hull. With the interceptor, the rear of the hull also gets a high compressive force, which can produce lift. The lifting force creates a negative moment, reducing the trim angle and increasing lift, decreasing the ship's drag. Thus, using interceptors on ships can be effective by considering existing factors, such as operational speed and geometry of the interceptor.

The issue is that figuring out the trim control capacity is difficult. If the lift force of the trim control is not correct, it will cause an increase in drag, although the trim decreased. Fig. 10 is an excerpt from the research results of Samuel et al.[105], taken with permission. If this is observed at Fr_L = 0.87, where the resistance (R_T/Δ) decreases, which is accompanied by a decrease in the trim (θ_V), but there is a decrease in the rise of CG (Z_V) and lift force (F_Z), where these mean that the ship's draft is getting deeper or sinking. Unfortunately, that didn't happen at Fr_L = 1.74 instead, the resistance actually increased. Therefore, it can be concluded that in order to reduce drag, many parameters play an important role, including the hull form itself. Because of this, a different hull shape necessitates a different trim value (or trim control capacity) in order to reduce resistance.

The trim control must be recalculated at high speeds since excessive trim causes the ship to nose-dive and starts to have a more significant drag than ships without an interceptor[103]. The interceptor's height can be reduced while speed is raised to maintain peak performance in producing the correct lift value[105].

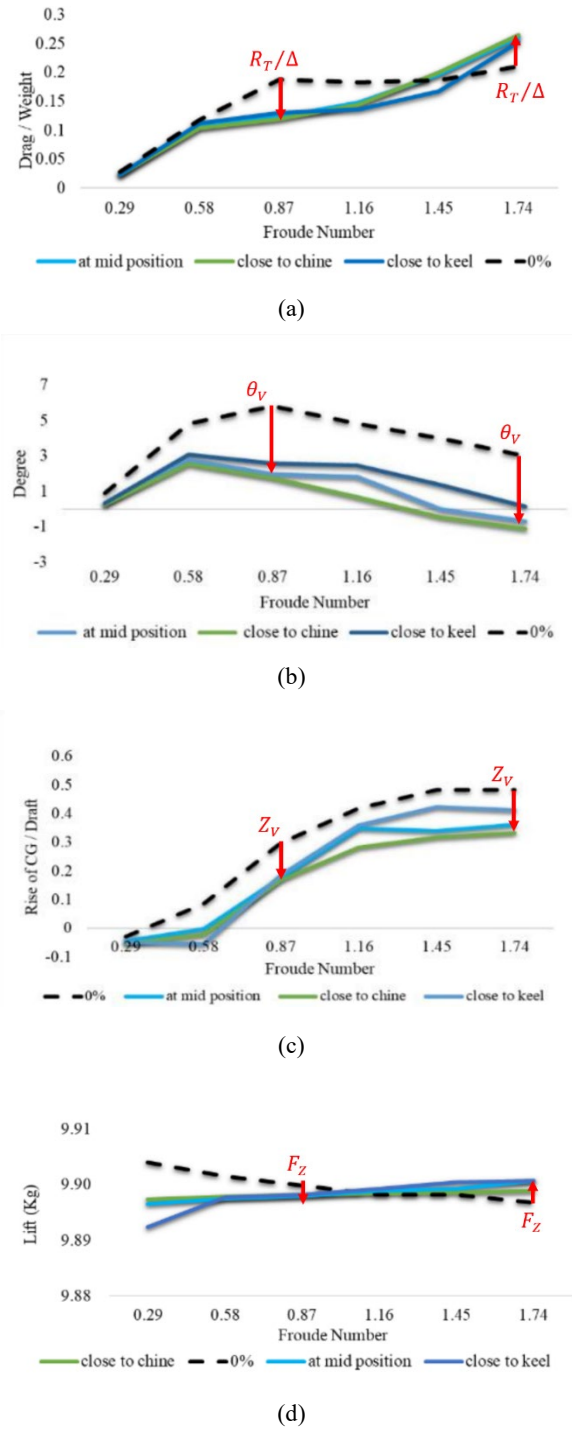

Fig. 10: The research results from Samuel et al.[105] on the application of interceptors to reduce hull planing resistance, where these Figures were taken by permission

The problem faced by the author is how to design the appropriate interceptor on the hull of a planing boat with tunnels. The planing hull with the tunnel is shown in Fig. 11, where the function of the tunnel is to provide a good fluid flow to the propeller, enabling it to generate maximum thrust. However, the installation of the interceptor creates a unique phenomenon. The interceptor

disrupts the fluid flow (wake) to the propeller, resulting in a reduction of hull efficiency for the propeller's thrust requirements. Therefore, the author conducted a parametric design study to find the optimal design of the interceptor while minimizing the wake disturbance.

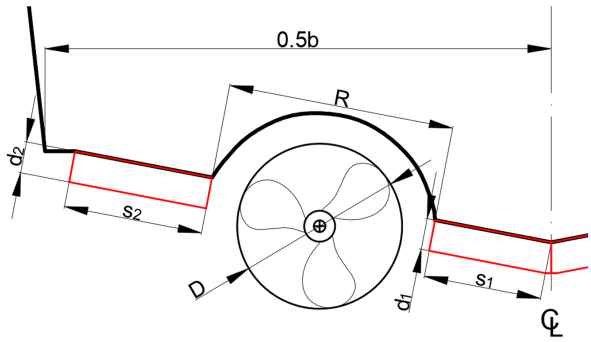

Fig. 11: An example of one of the problems related to interceptor design

5.3 Stern Foil

The application of a stern foil can lower the resistance of fast boats. The stern foil is a hydrofoil placed beneath a ship's transom, which creates dynamic lift and supplementary thrust as the ship moves in water, impacting the ship's trim and the area of the hull in contact with the water (the wetted surface area). At high speeds, it can lead to an overall reduction in the ship's total resistance. The lift force generated by the stern foil can be divided into two components: a force in the backward longitudinal direction (increasing the ship's resistance) and a force in the vertical direction (affecting the trim) to minimize the total ship resistance.

Several research results have been carried out on the use of stern foil on fast boats. According to experimental results of Budiyanto et al. [110,111], the stern foil application with an angle of attack parallel to the keel reduced the total resistance by up to 41.16% at Fr 1.3 and 28.5% at Fr 0.7-0.75. Based on the experimental results from Suastika et al.[109] at low speed (Fr < 0.45) both CFD and experimental results yield an increase in resistance of up to 13.9%. Whereas at high speeds, at Fr > 055, the ship's drag decreases by up to 10%.

Implementing a stern foil on fast boats can pose difficulties, similar to utilizing other trim control mechanisms. Incorrect configuration of parameters may result in heightened resistance, defeating the purpose of reducing resistance through the application of the stern foil.

Table 1. The results table summarizes the efficacy of using trim controls to reduce drag.

Reference	Type	Fr_L	Position	Magnitude	Efficacy to lower drags
Samuel et al.[105]	interceptor	0.29 – 0.58	mid, chine, keel	high, medium, low	no different
		0.58 – 1.45			reduced
		1.45 – 1.74		high, medium	increased
				low	slightly reduced
Avci & Barlas[103]	interceptor	0.14 – 0.5	full, keel, mid	low	increased
				high	high increased
		0.5 – 1.05		low – high	reduced
		0.14 – 0.5	chine	high	high increased
				low	slightly increased
		0.5 – 1.05		high	increased
				low	reduced
Mansoori & Fernandes[102]	interceptor	0.6 – 1.2	mid	low	reduced
				high	slightly reduced
		1.2 – 1.4		low	reduced
				high	increased
	trim tab	0.6 – 1.4		low	slightly reduced
				high	reduced
	combined	0.6 – 1.4		low	slightly reduced
				high	reduced
Luca & Pensa[113]	interceptor	1.2 – 2.4 (Fr_∇)	chine	low – high	reduced
		2.4 – 2.8 (Fr_∇)			increased
Fitriadhy et al.[108]	trim tab	0.7 – 1.3	mid	low – high	increased
Deng et al.[114]	interceptor	0.1 – 0.75	full	low – high	increased
Karimi et al.[79]	interceptor	0 – 1.25 (Fr_∇)	full	low – high	increased
		1.25 – 4.5 (Fr_∇)		low – high	reduced
		4.5 – 5.5 (Fr_∇)		low – high	increased

Ghadimi et al.[107]	trim tab	5 – 15 (knots)	full	optimum	no different
		15 – 25 (knots)			reduced
Budiarto et al.[106]	trim tab	0.6 – 1.8	mid	low – high	reduced
Sahin et al.[112]	interceptor	1.1 – 2.3 (Fr_B)	chine, mid, keel	low – high	reduced
		2.3 – 2.8 (Fr_B)	Chine, mid, keel	low – high	increased
Budiyanto et al.[110]	stern foil	0.6 – 1.1	full	low – high	reduced
Syahrudin et al.[115]	stern foil	0.6 – 1.1	full	low – high	reduced
Suastika et al.[109]	stern foil	0.35 – 0.55	full	low	increased
		0.55 – 0.75			reduced
Conclusion mostly		**0.5 – 0.85 (medium)**	**full**	**low**	**reduced**

6. Conclusion

Reviews on the application of trim control on HSMV demonstrate that trim control can reduce ship resistance within the appropriate parameters and improve operating comfort by minimizing over-trim that causes porpoising. Rather than relying on trim tabs, interceptors, or stern foils, these parameters are geometric in nature. The literature study findings presented in Table 1 indicate that several factors influence the effectiveness of trim control in reducing drag.

Speed is crucial factor to consider. Trim control becomes ineffective at low speeds where $Fr < 0.5$, resulting in increased drag. Trim control proves to be effective at relatively high speeds, with $0.5 < Fr < 0.85$. When operating at very high speeds, the interceptor height must be adjusted, ensuring that the lift force is modified to meet the anti-moment requirements. If the anti-moment is excessive, it may cause the hull to bend, leading to increased drag. This principle also applies to the application of trim tabs and stern foils.

In addition to speed, the design of the trim control also plays a role, considering its position and magnitude. The optimal position is generally full, while the optimal magnitude is typically low. Therefore, by calculating and implementing the appropriate parameters, the drag can be reduced, resulting in more efficient energy utilization and lower emissions. Consequently, further research is necessary to determine the optimal configuration that ensures the proper functioning of the trim controls with the objective of reducing drag.

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