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Study on U hull modifications with concave design to improve the tourist ship stability

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Abstract: Stability is an important aspect that was studied in ship design as it relates to the safety of the ship when facing ocean waves. The tourist ship needed to have a good image in order to attract tourists to use its services. Good stability of the tourist ship was crucial in enhancing the image of the ship and attracting tourists to utilize its services. This research aimed to investigate the effect of concave on the U hull to improve ship stability. The study compared the stability test results of two hull designs: U hull with concave and without concave. The stability tests of both ship models were conducted through simulation methods. The simulations were performed under two conditions: when the tourist ship was empty and when it was fully loaded with passengers. The simulation results indicated that the design of the U hull with concave had a positive influence on ship stability, leading to improved stability. The concave design enhanced the ship's ability to return to its original position when encountering waves. Even in the presence of small waves, the tourist ship did not experience instability.

Keywords*:* U hull, concave, tourist ship, stability

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1. Introduction

In ship hull design, there are two main criteria to consider: resistance and stability. Ship resistance is related to the engine power and fuel consumption, while stability is concerned with the safety of the ship during sailing. Tourist ships must have an optimal design that takes into account both stability and resistance. Stability is of utmost importance for tourist ships because they must provide safety and comfort to passengers during their travels. The safety and comfort of passengers are directly linked to the image and trust of tourists in using the services of the tourist ship. Therefore, in the design of tourist ships, the consideration of ship stability is crucial.

The International Maritime Organization (IMO) has established regulations for ship stability criteria (IMO, 2008). These regulations serve as a reference for ship design decisions made by engineers and the issuance of ship sailing permits by authorized institutions. The objective of these IMO stability regulations is to enhance ship safety (IM & CHOE, 2021). Numerous studies on ship stability have been reported, with many referring to the criteria set by IMO as the basis for assessing the feasibility of the researched hull designs. Examples of such studies include the analysis of stability in semi-trimaran flat hull ships (Putra et al., 2017) research on the stability of flat hull ships for fishing tourism (Nabawi et al., 2020), and a study on the stability of high-speed crafts with variations in step hull angles (Afriantoni et al., 2020).

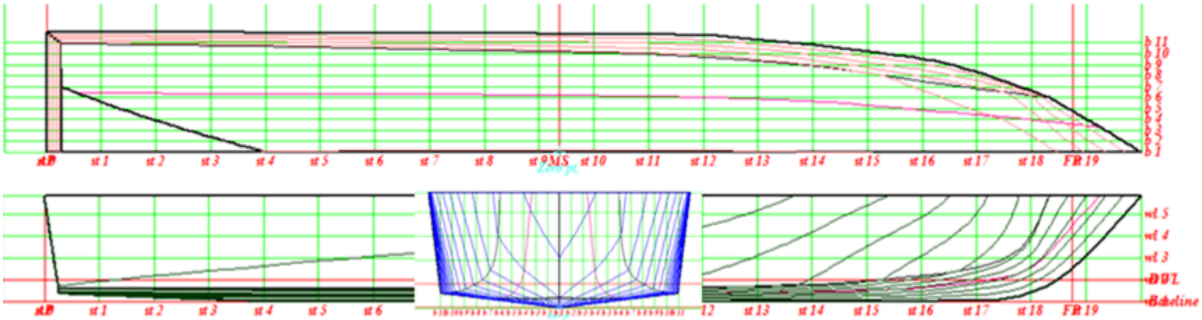
This research aims to uncover the influence of concave design on the stability of tourist ships used the U hull type. Typically, improving the stability and roll motion of ships is achieved through the installation of bilge keels on the outer sides of the hull (Gachet & Kherian, 2008; Liu et al., 2019; Ommani et al., 2016). However, for fiberglass ships, installing bilge keels is not feasible due to their low strength if made from thin fiberglass material or the risk of hull leakage if made from metal when installed with bolt systems. Based on this problem, an innovative design approach is adopted for fiberglass ships, which involves creating concave structures on the hull sides. It is expected that these concave structures will enhance stability and reduce the roll motion of the ship.

2. Methods

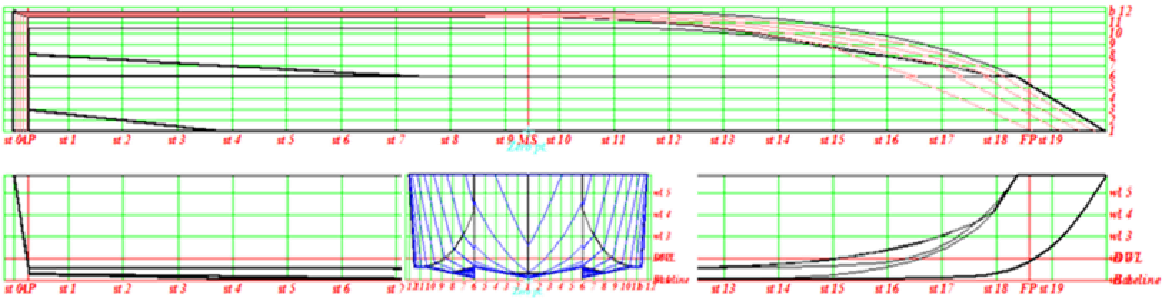
The stability analysis of the tourist ship hull design is conducted using simulation methods with Maxsurf Stability software. The cargo conditions are designed and arranged to match the conditions of the tourist ship during sailing. Two ship designs are created, consisting of a U hull without concave presented in Figure 1(a) and a U hull with concave presented in Figure 1(b). The dimensions of the tourist ship hull are presented in Table 1.

Tabel 1. Ship dimensions

Item	Size (m)
LOA	10
LWL	9.21
Depht	0.95
Beam	2.2



(a)



(b)

Figure 1. (a) Line plane U hull whitout concave and (b) U Hull with concave

The simulation results are evaluated based on the ship stability criteria listed in the IMO Code A.749(18) (IMO, 2008), which states that:

1. At an angle of heel (φ) of 30°, the area under the righting lever curve (GZ Curve) must be at least 0.005 m.rad.
2. At an angle of heel (φ) of 40°, it must be at least 0.09 m.rad.
3. At angles of heel between 30° and 40°, it must not be less than 0.03 m.rad.

4. At angles of heel equal to or greater than 30°, the righting lever (GZ) shall be at least 0.2 m.
5. The maximum righting lever shall occur at an angle of heel not less than 25°.
6. The initial metacentric height (GMo) shall not be less than 0.15 m.

The cargo conditions of the ship are divided into two scenarios: the condition of the ship without passengers and the condition of the ship with full passenger load. As for the main loads of the ship, they will be distributed among several compartments, including lightweight tonnage, propulsion systems, and fuel tanks. The ship's captain is categorized as part of the ship's permanent crew. Data regarding the ship's cargo can be found in Table 2.

Tabel 2: The ship's cargo

Load Case	Mass (Kg)	
	Case 1	Case 2
Lightship	1500	1500
Outboard Engine	100	100
Nahkoda	70	70
Fuel Tank	54	54
Passenger	-	1470
Total Mass (KG)	**1724**	**3194**

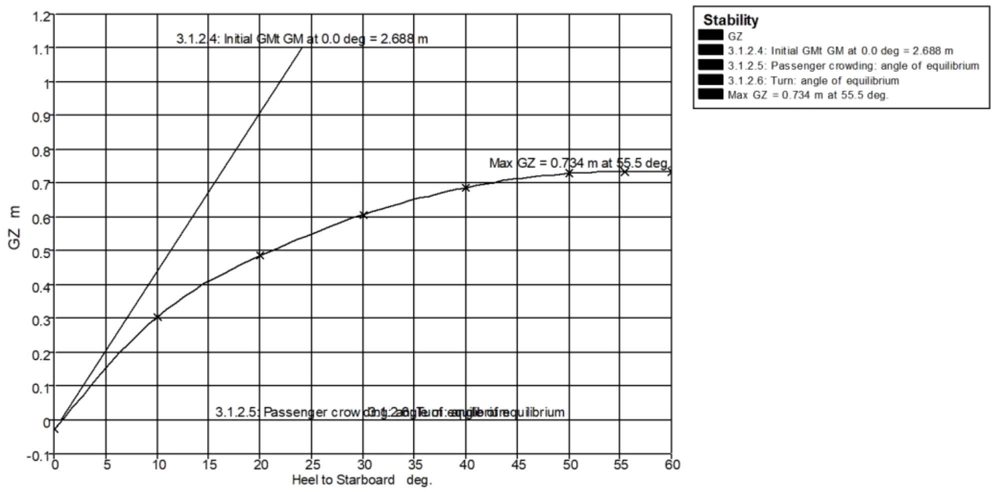
3. Results and discussion

The results of the simulation on the tourist ship under empty condition are presented in Table 3. There are six criteria presented based on the IMO standard (IMO, 2008). Based on the stability testing conducted on the passenger-free tourist ship, it can be observed that both U hull designs, whether with or without concave, meet the criteria set by the IMO. However, out of the six tested criteria, the U hull design with concave has four criteria with higher values compared to the U hull design without concave.

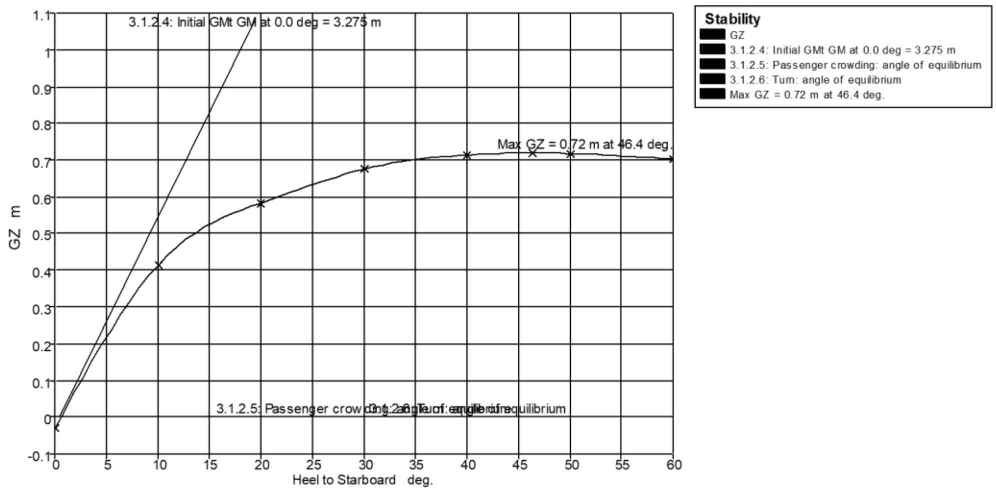
Tabel 3. The condition of the ship without passengers

IMO Criteria			U Hull		U Hull with Concave	
$\varphi = 30^0$	(m.rad)	≥ 0.055	0.1923	Accepted	0.2372	Accepted
$\varphi = 40^0$	(m.rad)	≥ 0.09	0.3058	Accepted	0.3593	Accepted
$\varphi = 30^0 - 40^0$	(m.rad)	≥ 0.03	0.1135	Accepted	0.122	Accepted
30^0	(m)	≥ 0.2	0.734	Accepted	0.72	Accepted
φ H max	(deg)	$\geq 25^0$	55.5	Accepted	46.4	Accepted
GM_0	(m)	≥ 0.15	2.688	Accepted	3.275	Accepted

At an angle of heel (φ) of 30°, the U hull design has a value of 0.1923 m.rad, while the U hull with concave has a higher value of 0.2372 m.rad. The same trend is observed at an angle of heel (φ) of 40°, where the U hull design with concave has a value of 0.3593 m.rad, while the U hull design without concave has a value of 0.3058 m.rad. Between the angles of heel 30°-40°, the U hull design with concave has a value of 0.122 m.rad, whereas the U hull without concave has a value of 0.1135 m.rad. For the metacentric height (GM0) criterion, the U hull design with concave also has a higher value of 3.275 meters compared to the U hull design without concave, which has a value of 2.688 meters. The two criteria in the U hull design without concave that have higher values than the U hull with concave are for the GZ 300 heel angle, where the U hull design without concave has a value of 0.734 meters, while the U hull design with concave has a value of 0.72 meters. Similarly, for the maximum heel angle (φ H max), the U hull design without concave has a value of 55.50 degrees, which is greater than the U hull design with concave, which is only 46.40 degrees. The stability curves for the testing under empty condition will be shown in Figure 2.



(a)



(b)

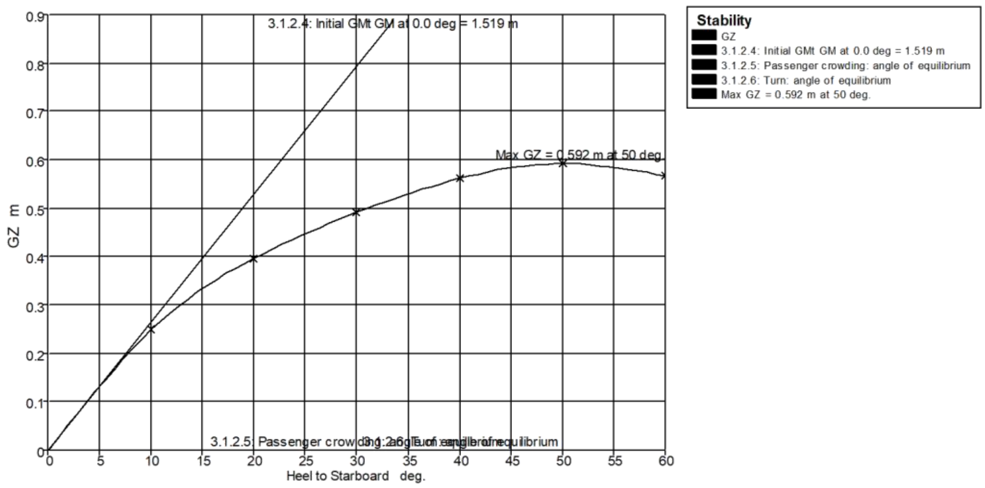
Figure 2. The stability curves for the tourist ship without passengers, (a) U hull without concave and (b) U Hull with concave

For load case 2, with the addition of passenger (tourist) load, the total weight of the ship increases to 3.19 tons. The results of the stability tested can be seen in Table 4.

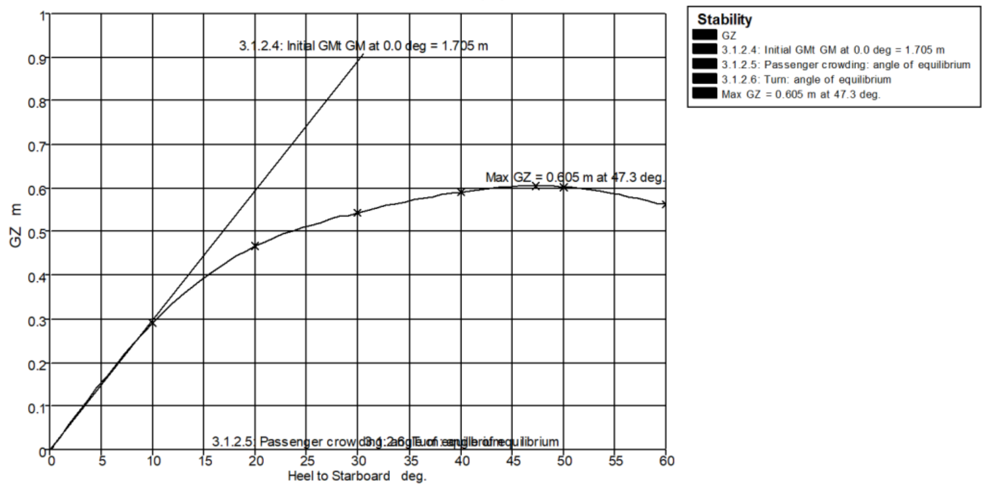
Tabel 4. The condition of the ship with full passengers

IMO Criteria			**U Hull**		**U Hull with concave**	
$\varphi = 30^0$	(m.rad)	≥ 0.055	0.1582	Accepted	0.1838	Accepted
$\varphi = 40^0$	(m.rad)	≥ 0.09	0.2504	Accepted	0.2832	Accepted
$\varphi = 30^0 - 40^0$	(m.rad)	≥ 0.03	0.0922	Accepted	0.0994	Accepted
30^0	(m)	≥ 0.2	0.592	Accepted	0.605	Accepted
φ H max	(deg)	$\geq 25^0$	50.0	Accepted	47.3	Accepted
GM_0	(m)	≥ 0.15	1.519	Accepted	1.705	Accepted

The simulation results for both U hull designs of the tourist ship with full passenger load, whether with or without concave, also show that both meet the criteria set by IMO. Out of the six IMO criteria, the U hull design with Concave has higher values in five criteria compared to the U hull without concave. At an angle of heel (φ) of 30 degrees, the tourist ship with U hull design with concave has a value of 0.1838 m.rad, while the U hull design without concave has a value of 0.1582 m.rad. Similarly, at an angle of heel (φ) of 40 degrees, the tourist ship with U hull design with concave has a value of 0.2832 m.rad, and the U hull design without concave has a value of 0.2504 m.rad. In the range of angles 30 to 40 degrees, the U hull design with concave has a value of 0.0994 m.rad, while the U hull without concave has a value of 0.0922 m.rad. At an angle of heel of 30 degrees, the righting lever GZ for U hull with concave has a value of 0.605 meters, and the U hull without concave has a value of 0.592 meters. Regarding the metacentric height (GM0) criterion, the U hull design with concave also has a higher value, which is 1.705 meters, while the U hull without concave has a value of 1.519 meters. For the criterion φ H max, the tourist ship with U hull design without concave has a higher heel angle of 50 degrees, while the U hull with concave has a heel angle of 47.30 degrees. The stability curves for the testing under full passenger load conditions are shown in Figure 3.



(a)



(b)

Figure 3. The stability curves for the tourist ship with full passenger, (a) U hull without concave and (b) U Hull with concave

The simulation results indicate that the U hull with concave design provides better stability compared to the U hull without concave. Overall, both hull types for this tourist ship meet the criteria set by IMO, whether with passengers or without. However, from these two hull types, the U hull with concave design has more instances with higher values than the U hull without concave. Concave design offers the advantage of dampening small waves or roll motions, resulting in a smoother and more comfortable ride for the passengers. This feature enhances the comfort level for the tourists onboard. Excessive roll motion can lead to the ship capsizing and subsequently sinking, making the concave design particularly beneficial in maintaining stability and ensuring the safety of the ship and its passengers. (Faltinsen, 1993).

4. Conclusions

The aim of this research is to investigate the influence of concave on the stability of tourist ships using the U hull design. The study was conducted through simulation by comparing two hull types: U hull without concave and U hull with concave. The simulation results show that the tourist ship with U hull design with concave exhibits better stability compared to the U hull without concave. The safety and comfort of the passengers are crucial aspects for any tourist ship. This research focuses on ship stability, and further studies are suggested to explore the effect of concave on U hull concerning the roll motion of the ship. Understanding how concave affects the roll motion will contribute to enhancing the overall safety and comfort of the tourist ship

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Declarations

Author contribution

Syahril made significant contributions to the development of the research concept, the writing of the article, and the interpretation of the simulation results. Rahmat Azis Nabawi played a crucial role as the designer of the ship hull, conceived the idea of adding concave to the U hull, interpreted the simulation data, and actively participated in writing the article. Aulia Zulkarnaen Nasty contributed to the creation of the ship's model, performed stability analysis, and handled the data processing.

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Conflict of interest

The authors declare no conflict of interest.

Ethical Clerance

There are no human subjects in this manuscript and informed consent is not applicable.

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