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Stability and redesign of the Sungkur fishing boats with the towed method in the coastal waters of South Kalimantan

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Abstract. This study investigates the static and dynamic stability of the Sungkur fishing boats, proposing a redesign. The study was conducted from February to April 2018. The research used a case study method. Data collection was carried out through observations, measurements, simulations and field experiments. Data analysis was carried out with simulations and numeric methods, using naval architecture formulas. The equipment used includes cameras, a GPS, measuring tools (waterpass, callipers, measuring threads, pendulum) and a computer. The results were interpreted descriptively. The results show that the Sungkur fishing boat with the towed method has good static and dynamic stabilities and has met the International Maritime Organization (IMO) minimum standard values. It also presents a good return energy, returning safely to its original position after destabilisation. The optimal redesign of the Sungkur fishing boat can be achieved by making several prototype changes toward improving the coefficients of fineness of the tested boats.
Key Words: coefficients of fineness, dragged gear, stability, Sungkur boat.

Introduction. The Sungkur fishing boat is usually used for catching fish and shrimp in the coastal waters of South Kalimantan, Indonesia. Typically, it is classified as a towed or dragged gear boat, which emphasises stability and speed. The Sungkur fishing boat has a slender body. The lines of the highest part of the bow and stern of the ship forms a vaked bow ('V') appearance, while the midship has an Akatsuki appearance ('U' shape). This is related to the fishing system of the ship, which focuses on the bow of the ship, starting from the net placement to the capturing process (Rusmilyansari et al 2017). Concerning the speed of the boat, the slender shape of the ship makes it able to move at high speeds. However, this is a disadvantage when considering stability, because the slender body causes the ship to easily destabilize, likely threatening the fishermen on board.

The Sungkur fishing boat prioritizes stability over speed, because the fishing gear is set in the water on the sides of the ship, a process that could destabilise it. Sometimes, a high speed is also needed in carrying out some fishing activities.

Manik (2007) states that each floating structure that moves on the surface always experiences isolation movements. Rolling is one of three types of pure isolation movements. This movement works under the return moment force, when the structure is disrupted from its equilibrium position. A boat moving on undulating waters will receive forces from the surrounding areas, where hydrodynamics forces cause other movements as a response. Therefore, the intensity of boat movements depends on the excitation torque generated by hydrodynamics forces, the direction of the waves, the damping force and the return moment force.

The stability is the ability of the ship to return to its original position after the ship has been destabilised due to other forces (Hind 1967). In contrast, Handryanto (1982) states that the stability is a combination of suitable size and division of load weight that allows the ship to follow wind strength and waves, being always able to return upright and be balanced again; or the tendency of the ship to sway left and right to return to the upright position. Furthermore, the stability is the will of the ship to return to its original position if the ship suffers outside forces. The stability is a parameter related to the ship design and coefficient of fineness. The coefficient of fineness is a reflection of the main form of the ship in the water. It includes block coefficients, prismatic coefficients, water field coefficients, coefficients of the centre and prismatic vertical coefficients.

To reach better stability, low rolling and pitching motion, and also a better yawing in bad conditions, the ship could be redesigned (Hutauruk 2012). In South Kalimantan, most of the Sungkur fishing boats are built traditionally, without naval calculations. The local shipbuilders do not understand well the calculations as required by the IMO (International Maritime Organization), how to manually calculate, or how to use a computer software. The problems approached in this study are the stability of the ship in different fishing activities, as well as the evaluation of the ship design based on the coefficient of fineness. This study aims at analysing the static and dynamic stabilities of the ship and at determining the redesign of the Sungkur fishing boat based on the coefficient of fineness. Outcomes of this study could be useful for holistic evaluations of the feasibility of the ship and a reference for similar shipbuilding in the future.

Material and Method

Study site. The study was carried out in Sungai Rasau Village, Tanah Laut District, South Kalimantan, including the measurements at the fishing base and at the fishing site. Data processing was done in the Laboratory of Fishing Boats and Equipment and the Laboratory of Navigation, from the Faculty of Marine and Fisheries, Lambung Mangkurat University, Banjarbaru. The research activity was conducted from February to May 2018.

Ship measurement. The case study method and numerical simulations were used for determining design suitability and stability. The stability of the ship was determined through naval architecture calculations and the results are interpreted descriptively. The design suitability was analysed by simulating changes in the ship design. The ship redesign process has four simulations:

1. The length size of the ship (L) was changed at a fixed width size (B) and depth size (D);
2. Changing the width size of the ship at a fixed length and depth size;
3. Changing the depth size of the ship at a fixed the length and width size;
4. Changing the width size and the depth size of the ship at a fixed length size.

Data collection. Data was collected from the ship measurements, covering the main dimensions of the ship and the curvature of the body when it is berthing in a jetty. The fishing trial simulation of the Sungkur boat includes stability values from the fishing base to the fishing ground. The equipment used for the measurements include a camera, stationery, measuring tools, a waterpass, callipers, measuring threads, pendulums, a GPS and computers.

Data analysis. The main dimension ratios are obtained by comparing the values of the overall length (LOA), breadth (B) and depth (D). Plan lines and coefficient of fineness parameters were established by using naval architecture formulas (Gillmer & Johnson 1982; Tupper 2004). The main dimension ratios obtained were compared with previous studies (Iskandar & Pujiati 1995). The calculation for draft changes was conducted by estimating the value of changes in ton displacement based on numerical ton per centimetre (TPC) values (Istopo 1997). The stability was calculated based on the Krylov method, referring to the stability curve (Liesen & Strakos 2012).

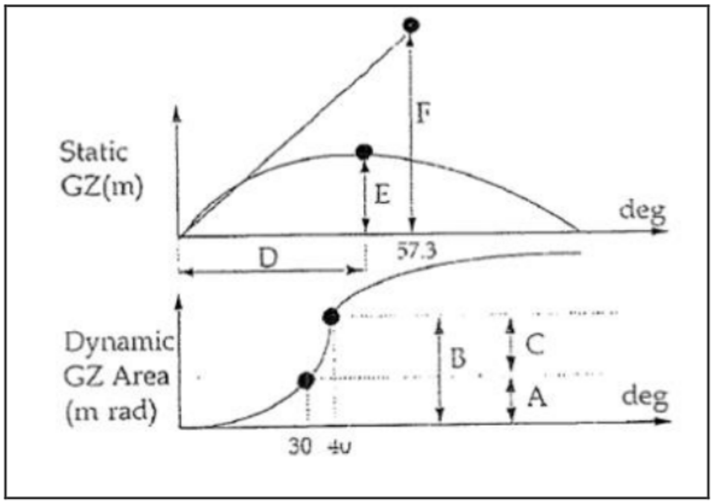

Figure 1. Illustration of the ship stability criteria curve (Hind 1982). GZ – righting arm; A - area under GZ curve up to 30° >0.055 mrad (milliradian); B - area under GZ curve up to 40° or down flood >0.09 mrad; C - area under GZ curve from 30° to 40° or down flood >0.03 mrad; D - maximum GZ to be at least 0.20 m at 30° or above; E - maximum GZ to be at an angle >25°; F - initial GM to be at least 0.15 m.

The quality of the ship stability was determined based on the criteria recommended by the International Maritime Organization (2012). The ship stability was obtained by calculating the value of GZ (righting arm) based on Attwood's method with the following formula (Hind 1982), where BR is a horizontal centre of buoyancy and BT is the total breadth of vessel:

$$GZ = BR - BT$$

The shading area is expressed as:

$$V \times hh_1 = BR \times \nabla$$

$$BR = (v \times hh1)/\nabla$$

$$BT = BG \sin \emptyset$$

Where: v - shading volume; hh1 - the horizontal change in the shading area; ∇ - the displacement volume of the ship; BG – distance from buoyancy to gravity.

$$GZ = (v \times hh1)/\nabla - BG \sin \emptyset$$

The static stability curve of GZ illustrates the height of the GZ from 0 to 80 degrees. Based on the GZ curve, an analysis of some angles was carried out. The results of the stability calculation are compared with the standard for ship stability, issued by the United Kingdom regulation of fishing vessels (Safety Provisional) Rules 1975 (Hind 1982) and the International Maritime Organization (IMO), at Torremolinos International Convention for Fishing Vessels-Regulation 28 (1977), through the GZ curve (Fyson 1985). In the redesign process, the selection criteria for an ideal design is based on dynamic stability and fineness coefficient. Redesigned boats that have dynamic stability and good coefficient of fineness are chosen as ideal alternative designs.

Results and Discussion. Overall calculations of the ship stability based on the main sizes and coefficient of fineness are presented in Table 1.

Table 1

Offset table of the ships

	Water line					
	Base Line	1	2	3	4	5
Displacement (ton)	0	0.2751	1,063	2.146	3.476	5.02
Heel (º)	0	0	0	0	0	0
Draft at FP (m)	0	0.14	0.28	0.42	0.56	0.7
Draft at AP (m)	0	0.14	0.28	0.42	0.56	0.7
Draft at LCF (m)	0	0.14	0.28	0.42	0.56	0.7
Trim (+ Ve by stern) (m)	0	0	0	0	0	0
WL Length (m)	8.4	8.9	9,345	9,735	10,045	10.318
Beam max extents on WL (m)	0	0.625	1,019	1,228	1,359	1,476
Wetted Area (m^2)	0	4,603	8.468	11,724	14,953	18,094
Waterplane area (m^2)	0	3,858	6.61	8.45	10,072	11,344
CP	0	0.563	0.574	0.593	0.616	0.638
CB	0	0.281	0.333	0.372	0.409	0.435
Max Section area coefficient (CM)		0.5	0.581	0.628	0.663	0.681
CWP	0	0.566	0.595	0.631	0.68	0.705
LCB from amidship (+ Ve fwd) (m)	-5.35	-0,075	-0,057	-0,046	-0,035	-0,024
LCF from amidship (+ Ve fwd) (m)	-5.35	-0,064	-0,041	-0,028	-0,011	0.008
KB (m)	0	0.093	0.184	0.269	0.354	0.44
KG (m)	0.7	0.7	0.7	0.7	0.7	0.7
BMt (m)	0	0.301	0.356	0.335	0.327	0.309
BML (m)	0	65,723	31,949	22.11	17,413	14,209
GMt (m)	-0.7	-0.305	-0.16	-0,096	-0,019	0.048
GML (m)	-0.7	65,117	31,433	21,679	17,068	13,948
KMt (m)	0	0.395	0.54	0.604	0.681	0.748
KML (m)	0	65,817	32,133	22,379	17,768	14,648
Tonne/CM Immersion (TPc)	0	0.04	0.068	0.087	0.103	0.116
MTc (tonne.m)	0	-0,017	-0,032	-0,045	-0,058	-0,068
RM at 1 deg = GMt. Disp. sin (1) (tonne m)	0	-0.001	-0.003	-0.004	-0.001	0.004
Max deck inclination (º)	0	0	0	0	0	0
Trim angle (+ Ve by stern) (º)	-180	-180	-180	-180	-180	-180
Length (m)	11.2					
Breadth (m)	1.6					
Depth (m)	1					
Draft (m)	0.5					

Note: FP - fore perpendicular; AP - after perpendicular; LCF - longitudinal centre of floatation; Ve – vessel; Ve fwd - vessel by forward; WL – waterline; CP – prismatic coefficient; CB – block coefficient; CWP – waterplane area coefficient; LCB - longitudinal centre of buoyancy; KB - keel to centre of buoyancy; KG - keel to centre of gravity; BMt - buoyancy to metacentre; BML - buoyancy metacentre longitudinal; GMt - gravity to metacentre; GML - gravity metacentre longitudinal; KMt - keel to metacentre; KML - keel metacentre longitudinal; MTc - moment to change trim one centimetre; RM - righting moment; Disp. sin – displacement.

A ship is stable if it can return to its original position after aslanting. The stability of fishing boats is very dependent on the distribution of the load on board. The static stability of the Sungkur fishing boat at the fishing base, where there were no waves, and the dynamic stability of the ship when moving to the fishing areas, where the waves measured 5 m in length and 0.5 m in height, based on field data, were analysed. The results show that the Sungkur fishing boat is safe to use for fishing operations, because all the stability criteria exceed the IMO criteria, with margins of more than 50%. The results of static and dynamic stabilities are presented in Table 2.

Table 2

Static and dynamic stability parameters of the Sungkur fishing boats in Tanah Laut District, South Kalimantan Province

Value at the GZ Curve	*Standard IMO (Minimum value)*	*Ship at fishing base*	*Ship at fishing ground*
Area 0 – 40 (mrad)	0.090	0.1671	0.143
Area 30 – 40 (m-rad)	0.030	0.0703	0.064
Max GZ at ≥ 30 (m)	0.2	0.613	0.675
Angle of maximum GZ (º)	25	80	83.6
Initial GMt (m)	0.15	0.762	0.566

Note: IMO - International Maritime Organization; mrad – milliradian; Max GZ - maximum value of the righting arm; GMt - gravity to metacentre.

The Sungkur fishing boat, classified as a towed/dragged boat, should have good stability in accordance with the standard, so that the ship does not easily destabilise when utilizing the fishing gear. When it began to move forward, it experienced a boat trim tendency to descend to the surface of the water, caused by the driving force of operation of the ship.

According to Fyson (1985), the stability of a fishing boat is its ability to return to the original position after experiencing the influence of external forces. External factors include the influence of wind and waves, the presence of a fishing device in the water that can increase the tilt of the ship and reduce the ability of the ship to re-upright or reduce the righting moment. The ship has its own ability to get back upright because of either transverse stability, static stability, or longitudinal stability. This is based on the provision that fishing boats must have the initial stability not less than 0.6º.

The stability of the Sungkur boat was analysed by calculating the value of the GZ, formed on the GZ curve (Figure 2; Figure 3). These curves show that the GZ produced by the sample boat is positive, which means that the ship is able to return to its original position after experiencing destabilisation.

The static stability curve is indicated by the value of the GZ at various oblique angles (between 0º and 90º). The calculation of the GZ of the Sungkur boat using the GZ program was carried out at the fishing ground, in calm weather condition (no waves). The value of GZ has a standard set by the IMO.

As shown in Figure 2, when the ship swerved 0º and under the upright conditions the GZ equals 0 m. The GZ value on the Sungkur boat tends to increase with a tilt angle of 0º - 60º, and reaches a maximum value of 0.675 m at 80º. The intersection point between the stability curve and the heel angle lies in a big angle. This shows that when the ship is unstable to a 80% degree, it will not capsize and can return to its original position, because its GZ still has a value that is not equal to zero.

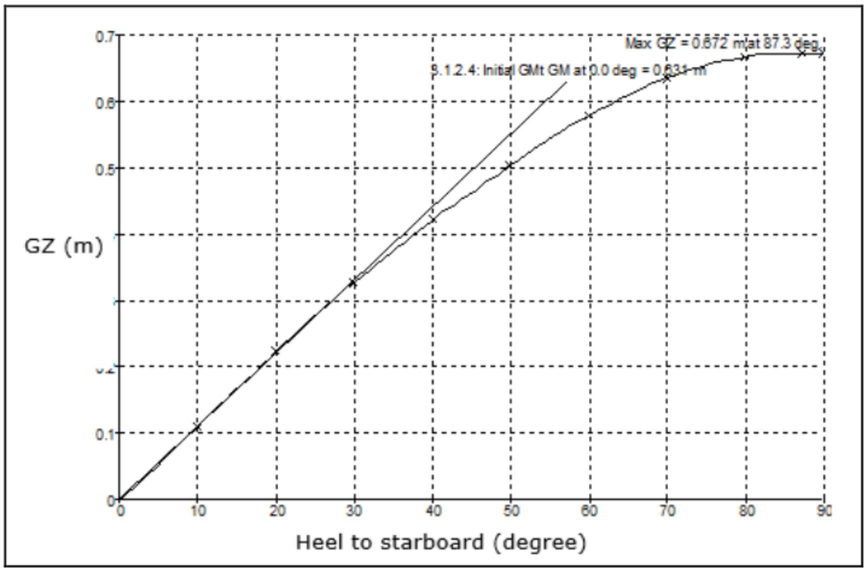

Figure 2. Static stability of the ship at fishing ground. GZ – righting arm; GMt - gravity to metacentre.

Figure 3 shows the dynamic stability measured when the Sungkur fishing boat was moving to the fishing ground. The curve displays that the GZ produced by the boat tested is positive, which means that the ship is able to stand back to its original position after experiencing destabilising. This is in line with Tailor's observations (1977), that in full condition (maximum load) the ship generates the positive GZ that is able to return the ship to its original position. Fyson (1985) explains that the calculation of the GZ value is a very important part in determining stability. This serves to avoid the entry of water into the ship. The GZ curve shows the relationship of the GZ with various angles at constant displacement.

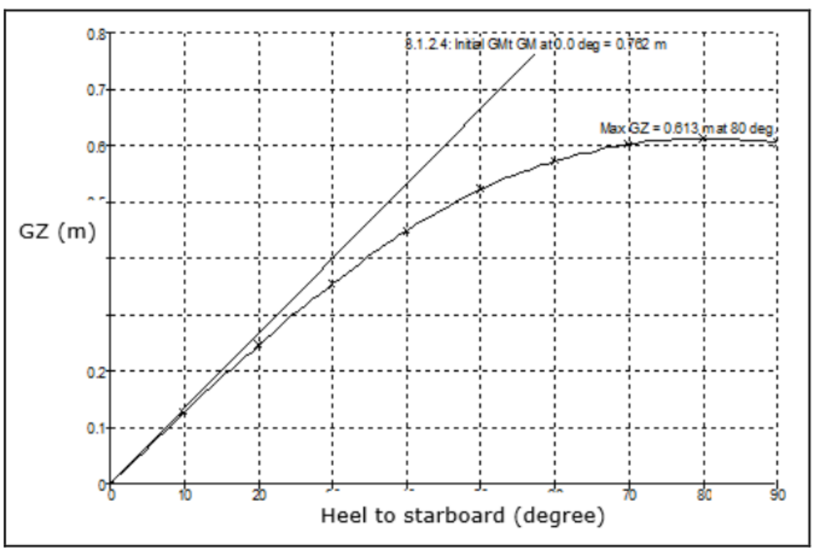

Figure 3. Dynamic stability curve of the Sungkur fishing boat. GZ – right arm; GMt - gravity to metacentre.

Fishing boats must have an initial stability not less than 0.6°, as the Sungkur boat has. Rawson and Tupper (1983) reported that stability can be explained in the form of righting moment produced from the centre of gravity when the ship becomes tilted.

The traditional Sungkur boats in South Kalimantan have various sizes because they are not constructed based on the calculations of naval architecture. Thus, the main dimension ratio is also different (Table 2). Dealing with the main dimension ratios, most of the Sungkur boats are suitable for towed/dragged gears, as stated by a previous study (Iskandar & Pujiati 1995).

Table 3

Comparative dimensions of the Sungkur fishing boats operated in Tanah Laut, District of South Kalimantan Province

Ship Dimension	*Ship 1*	*Ship 2*	*Ship 3*	*Ship 4*	*Ship 5*	*Ship 6*
L (m)	8	9	10	9	11.4	9.8
B (m)	2	2	2.5	2	1.4	1,2
D (m)	1	1	1	1	1.3	1,2
L/B (2.86-8.30)	4	4.5	4	4.5	8.1	8.1
L/D (7.20-15.12)	8	9	10	9	8.7	8.1
B/D (1.25-4.41)	2	2	2.5	2	1.7	1

Note: L - length; B - breadth; D – depth.

A small L/B value or a large B/D value provides good stability, but it can also increase the boat resistance to water. A large L/B value is especially suitable for ships with high speeds, but it reduces the ability of the ship to move and its stability. Meanwhile, a large L/D value reduces the longitudinal strength of the ship. Otherwise, a small L/D value will increase the longitudinal strength of the ship.

Figure 4. The Sungkur boat going to the fishing areas.

The redesign of the Sungkur fishing boat (Figure 4) is carried out based on the coefficient of fineness as described in Table 4.

The coefficient of fineness characterizes the shape of the ship based on the relationships among different areas of the ship and the volume of the ship and the main dimensions of the ship. The shape coefficient or block coefficient (CB) points out a comparison between the value of the displacement capacity of the ship and the volume of a rectangular field surrounding the body of the ship. For boat 1 (0.638), CB is at the upper threshold, while for boat 2 (0.325), it is at the lower threshold. This indicates that the size of the Sungkur boat varies because it was built traditionally depending on the availability of the construction materials.

Table 4
Redesign of the Sungkur fishing boat, based on the coefficient of fineness changes

Coefficient of fineness	*Boat standard of towed/dragged gear*	*Sungkur boat 1*	*Ship re-design 1*	*Sungkur boat 2*	*Ship re-design 2*
CP	0.51 - 0.62	0.435	0.579	0.539	0.578
CB	0.40 - 0.60	0.638	0.486	0.325	0.501
CM	0.69 - 0.98	0.681	0.840	0.603	0.850
CWP	0.66 - 0.77	0.705	0.674	0.574	0.666

Note: CP – prismatic coefficient; CB – block coefficient; CM – maximum section area coefficient; CWP – waterplane area coefficient.

The midship coefficient or maximum section area coefficient (CM) is the ratio of the area of the immersed portion of the midship section to the product of the breadth and the draught of the ship. Boat 1 and boat 2 with CM values of 0.681 and 0.603, respectively, meet the predetermined criteria. The water-plane area coefficient (CWP) is defined as the ratio of the water-plane area of the ship to the area of a rectangle having the same length and breadth of the ship at the waterline. The value for boat 1 (0.705) meets the criteria, but the one for boat 2 (0.574) is at the lower threshold.

The prismatic coefficient (CP) is a comparison of the displacement capacity of the ship and the volume formed by the cross-section area of the centre of the ship with the length of the ship in the water line. The CP can also be obtained by comparing the value of CB with the value of CM. The CP value of boat 1 (0.435) is below the threshold and the value of boat 2 (0.539) complies with the predetermined criteria.

The redesign of the Sungkur fishing boat was carried out by simulating changes of the coefficient of fineness parameters to meet the predetermined criteria as follows: CP = 0.578; CB = 0.486; CM = 0.840; CWP = 0.674, for boat 1 and CP = 0.578; CB = 0.501; CM = 0.850; CWP = 0.666, for boat 2. Muckle (1975) suggests that the greater the value of CB and CP at a certain speed is, the greater is the resistance produced by motion. According to Nelly (1999), the shape coefficient determines the motion resistance of the ship. In addition, the resistance of the ship increases with a higher shape coefficient. Novita (1994) stated that the resistance of the motion produced increases with a greater midship coefficient.

The relationship between these coefficients can be expressed as: CB = CP × CM. The values of these coefficients for fishing boats should follow the sequence: CB<CP<CM (Ayodhya 1972). Pangalila (2011) suggests that if the CP value increases, it will cause the ship to widen the stern section, so that it can increase stability.

In determining the optimal size of the ship, the body shape of the ship has a great effect on its stability. The body shape of the ship can be seen from the profile plan, half breadth plan and body plan. The line plan redesign of the Sungkur fishing boat is presented in Figure 5.

From the body plan, it can be clearly seen that the shape of the bow of the Sungkur fishing boat is a 'V' (V type shape). The midship is Akatsuki shaped, like a 'U', with a rigid line. This is appropriate with the operations carried out centrally on the bow of ship, like the placement of the net. The redesign results show that the value of the finesses coefficient are within the fixed standardization range.

The Sungkur fishing boat has a 'V' bottom shape on the bow and stern, and has an Akatsuki shape in the midship. Iskandar (1990) reported that the selection of a 'V' bottom in the bow is intended to cleave the water better. Kirana (2000) stated that the 'V' shape of the bow allows the ship to split the water mass in front of the ship so that the ship can move forward at high speeds. The midship base shape tends to be flat and is considered less beneficial for the fishing operations of the ship and can also increase boat resistance, which results in the ship movement being difficult when the ship is spinning (Yataningsih 1998; Sinaga 1998).

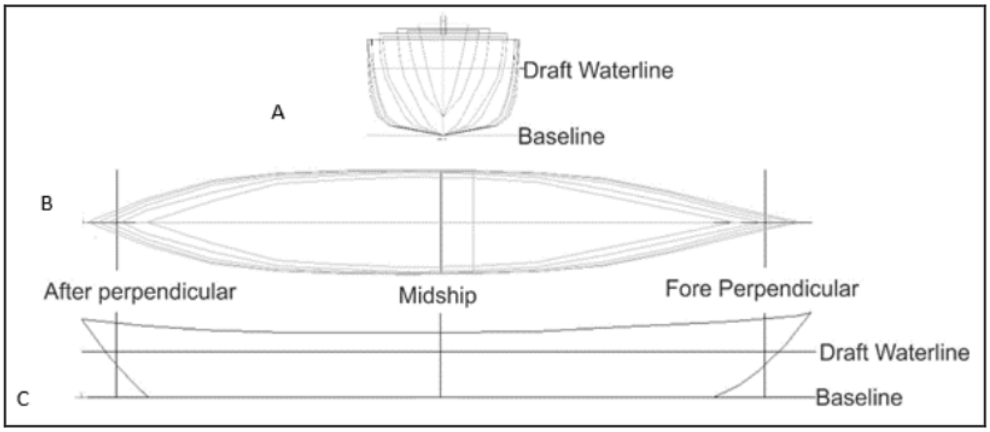

Figure 5. Line plan redesign of the Sungkur fishing boat (scale 1:75). A - body plan, front view (transversal); B - half breadth plan: top view; C - profile plan: side view (longitudinal).

Lines plan is a very important element and needs to be considered because it can affect the final design of the ship. Utomo (2010) pointed out that in projecting a good body plan, the main size and the coefficient of fineness of the ship are very important to consider.

Conclusions. From a fishing point of view, it can be concluded that the Sungkur fishing boat has good static and dynamic stabilities and meets the IMO minimum standard values. It has a good stability so that it can return to its original position when the ship is destabilized. The optimal redesign of the Sungkur fishing boat can be done by making some prototype changes toward the parameters of the coefficient of fineness.

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