Estimation of stability for a fishing vessel and some considerations

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Abstract. An important aspect of the operation of every ship is navigational safety, particularly on the open sea. This aspect becomes more important in fishing vessels, which, unlike other ships loaded in the port, are loaded by working on open sea, off the coast, often in severe weather conditions. Currently, there are a large number of vessels in the fishing fleet, poorly equipped with reference to the technical documentation required, which are unaware of the vessel’s stabilizing behaviour condition and which therefore get classified by the Albanian Shipping Register. In this paper, the author will present a case study concerning the stability analysis of a fishing vessel operating in Adriatic and Ionian Seas. Once the measurements for determining the ship’s offsets have been carried out, geometric modelling of fishing vessel hulls in CAD software is done as well as the verification of intact stability criteria using the stability software. This procedure would be very useful for other similar cases. Several considerations have been given for three types of stability loss: dead vessel conditions, broaching to and variation of righting arm, including pure loss of stability and parametric roll.

1. Introduction
The fishing sector is one of the most dangerous activities with a high mortality rate. Fishing vessels, especially small fishing boats, make up the largest number of vessels. Though they are among the most recently built, they still pose safety concerns for three factors: crew, ship, and environment. The main task is to assess the stability of these vessels. These vessels, unlike ordinary boats loaded into the harbour, are loaded into the sea while working off the coast, often in difficult weather conditions. According to Soares (2004 and Francescutto (2007) [3] accidents on board occur mainly due to: dynamic stability of the marine vehicle, meteorological conditions, vehicle location, seasons, and vehicle characteristics.

Modelling of vessel behaviour is difficult to do nevertheless with the help of computer technologies the stability of fishing vessels can be constantly monitored:

• Initially, an assessment of the intact stability of the vessel should be carried out.
• Physics of three types of loss of stability: (dead vessel conditions, broaching and variation of righting arm, including pure loss of stability and parametric roll) should be numerically estimated.

In 1985, the IMO adopted the meteorological criteria for stability. In October 2007, the MSC (Maritime Safety Committee) endorsed the Intact Stability Code to which was to come into force from 1 July 2010.

In experimental tests carried out with small fishing vessels under the real conditions of full-load operation, there are many difficulties in the fulfilment of the IMO stability criteria, but the vessel does...
not overturn. This means that in order to find a solution to the problem of the unsuitable fishing vessel stability, the criteria need to be reviewed, [1, 4].

It is important to consider the recommendations on the meteorological criteria and the fishing gear equipment. “The combined effect of all probable factors affecting the heeling moment on fishing vessels such as the one resulting from the wind rolling, trapping water on deck, hauling or pursing a fishing gear, direction of the force when trawling, structural damage due to steep waves, crew mistakes, etc. are involved in a fishing vessel failure” [3].

2. 3D-CAD Modelling of the Ship Hull

3D-CAD model was made by using the process of Reverse Engineering. The physically measured point coordinates were used so that the hull lines and surfaces were taken. Then, the optimized model of the fishing vessel hull was achieved by means of the interpolation and optimization processes [6].

Rebuilding of the hull is directly carried out with the help of Maxsurf program. All the surfaces were checked in order to respect the geometric boundary conditions. Building surfaces were grouped into three main groups: the bow region, the stern region and the central region. [6].

In addition, to rebuild the 3D model of the vessel hull based on real measurements, as the following steps have to be taken [7]:
1. The necessary measurements in the line of keel, extreme parts of the hull and its sections were taken.
2. Surfaces were built individually for each region of the hull (bow, stern, central body).
3. It became the union of individual surfaces designed before taking preliminary hull form.
4. It underwent the checks of initially conditions of the hull previously designed with geometric data of physical measurements made on the vessel.
5. The smoothing of the surface of the CAD model lasts until the required level of compliance with hydrostatic characteristics is achieved.
6. The drawing of the CAD model of the modelled hull is carried out.

2.1. Real measurements to build the drawing hull lines that will be modeled

The significant impact on the outcome of the 3D-CAD modelling process of a vessel is the realization of real measurements of the vessel hull, vessel main dimensions in table 1 and general arrangement in figure 1, that will be modelled. The measurement process is carried out in physical bulkheads of the vessel, in order to obtain accurate results of the measurement of the semi-breadths of coordinates. Upon completion of measurements in relation to the ordinates, profile line, and extreme parts for getting database in MS Excel, the opportunity for setting up a dimensionless half-breadths of the model that we need to build is created [7].

| Table 1. Main dimensions of the fishing vessel “ECLIPSE” |
|----------------------------------------------------------|
| Length Overall | LOA = 32.70 m | Crew Number | 6 |
| Length between perpendiculars | LBP = 00.00 m | Main Engine: CATERPILLAR 620 HP |
| Breadth Overall | BOA = 8.40 m | Construction Material: Steel |
| Depth | D = 4.00 m | Year of Reconstruction: 2000 |
| Draft | T = 2.40 m | Place of Construction: Egypt |
Based on the database created in MS Excel with the help of the MaxSurf software, the 3D modelling process of this vessel is realized (figure 2).
The design process of the hull surface goes into three phases:
1. Modelling of initial hull curves
2. Building of the hull surface
3. Smoothing of the hull surface
After its visualization, identify possible errors in it during the insertion of the coordinates, making appropriate modifications and file record that contains all the coordinates of the points needed to generate the hull [5].
3. Evaluation of Stability of the fishing vessel “Eclipse”

3.1. Generation of hydrostatic curves

Hydrostatic curves are calculated (figure 3) with the help of Maxsurf and Hydromax Software [5, 8]. Below we will show the data of the vessel with full load (table 2), that correspond waterline DWL=2.40m.

Table 2. Hydrostatic DATA of the fishing vessel “ECLIPSE”.

| Draft Amidsh. M | DWL=2.40 | Block Coeff. |
|----------------|----------|--------------|
| Displacement tonne | 267 | 0.50 |
| Draft at FP m | 2.40 | Midship Area Coeff. |
| Draft at AP m | 2.40 | Waterpl. Area Coeff. |
| Draft at LCF m | 2.40 | LCB from zero pt. (+ve fwd) m |
| WL Length m | 27.24 | 15.23 |
| WL Beam m | 8.00 | 15.03 |
| Wetted Area m^2 | 223 | 1.85 |
| Waterpl. Area m^2 | 180 | Prismatic Coeff. |
| Immersion (TPc) tonne/cm | 1.85 | 0.75 |
| MTc tonne.m | 3.1 | |

The vertical center of gravity of the vessel is calculated as KG = VCG = 2.63m taking into account that:

- Maximum number of crew is 6 people on board. The weight of each average individual is estimated as 75 kg.
- The height of gravity center for passenger measures 0.3 m above the seat.
Figure 3. Graphic representation of hydrostatic curves of the fishing vessel “ECLIPSE”.

3.2. Stability data calculations
Stability data (table 5) are calculated with the help of Maxsurf and Hydromax Software [5,8]. It is shown below (table 3 and figure 4) only the KN diagram depending on displacement (Δ) for any heel angle (φ).

Table 3. Values of KN depending on Δ for any heel angle φ.

| Displacement (t) | KN in different heel angles |
|------------------|----------------------------|
|                  | 0  | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 |
| 200              | 0.00 | 0.82 | 1.55 | 2.19 | 2.68 | 2.97 | 3.10 | 3.09 | 2.94 | 2.68 |
| 220              | 0.00 | 0.81 | 1.54 | 2.18 | 2.65 | 2.92 | 3.04 | 3.03 | 2.90 | 2.65 |
| 240              | 0.00 | 0.80 | 1.53 | 2.18 | 2.62 | 2.87 | 2.98 | 2.97 | 2.86 | 2.63 |
| 260              | 0.00 | 0.79 | 1.53 | 2.16 | 2.58 | 2.82 | 2.93 | 2.92 | 2.82 | 2.61 |
| 280              | 0.00 | 0.78 | 1.52 | 2.14 | 2.54 | 2.77 | 2.88 | 2.87 | 2.78 | 2.59 |
| 300              | 0.00 | 0.77 | 1.51 | 2.12 | 2.50 | 2.73 | 2.83 | 2.83 | 2.74 | 2.57 |
| 320              | 0.00 | 0.76 | 1.50 | 2.09 | 2.46 | 2.68 | 2.79 | 2.79 | 2.71 | 2.54 |
| 340              | 0.00 | 0.75 | 1.49 | 2.06 | 2.41 | 2.63 | 2.75 | 2.76 | 2.68 | 2.53 |
| 360              | 0.00 | 0.75 | 1.48 | 2.02 | 2.37 | 2.59 | 2.71 | 2.73 | 2.66 | 2.51 |
| 380              | 0.00 | 0.75 | 1.47 | 1.98 | 2.32 | 2.54 | 2.67 | 2.70 | 2.64 | 2.50 |
| 400              | 0.00 | 0.74 | 1.44 | 1.93 | 2.27 | 2.50 | 2.63 | 2.67 | 2.62 | 2.49 |
Figure 4. KN diagram depending on $\Delta$ for any heel angle $\phi$.

Calculation of the ship vertical center of gravity with 20 t cargo on main deck, as shown in table 4.

| Nr | Weight Items   | Weight (t) | VCG of weights $Z_i$ (m) | Moment $M_{XY} = P \cdot Z_i$ |
|----|----------------|------------|--------------------------|-----------------------------|
| 1  | Lightship      | 180        | 2.73                     | 491.4                       |
| 2  | Fish           | 20         | 2.8                      | 56                          |
| 3  | Fuel           | 60         | 2.1                      | 126                         |
| 4  | Crew weight    | 4.5        | 5.1                      | 22.95                       |
| 5  | Total Weight   | $\Sigma_1 = 264.5$ | $\Sigma_1 = 696.35$ |

Vertical gravity center of the vessel:

$$KG = \frac{\Sigma_2}{\Sigma_1} = \frac{696.35}{264.5} = 2.63 \text{ m}$$

Lightship weight value is determined based on real measurement of draft. In this condition the measured draft of vessel is equal to 1.9 m. This value of draft from the hydrostatic data defines a weight value of lightship equal to 180 tonnes.

Table 5. Stability data according Hydromax Software calculations.

| Heel to starboard (degrees) | 10  | 20  | 30  | 40  | 50  | 60  | 70  | 80  | 90  |
|-----------------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| GZ (m)                      | 0.33| 0.62| 0.84| 0.88| 0.79| 0.64| 0.44| 0.22| -0.03|
| Displacement (mt)           | 264.5| 264.5| 264.5| 264.5| 264.5| 264.5| 264.5| 264.5| 264.5|
| Wetted area (m$^2$)         | 221.6| 220.4| 224.9| 234.0| 239.6| 243.5| 246.2| 247.6| 247.9|
The following diagram (figure 5) shows the static stability curve of the fishing vessel.

![Stability Diagram](image)

**Figure 5.** GZ diagram vs heeling angle.

### 3.3. Criteria regarding righting lever curve properties

For the purpose of assessing in general whether the IMO stability Criteria (IMO resolution A.167) are met, stability curve should be drawn for the main loading condition/s intended by the owner in respect of the vessel’s operation [8, 10].

1. The area under the righting lever curve (GZ curve) shall not be less than 0.055 meter-radians up to angle of heel $\varphi = 30^\circ$.
2. The area under the righting lever curve (GZ curve) shall not be less than 0.09 meter-radians up to $\varphi = 40^\circ$ or the angle of down-flooding $\varphi_f$ if this angle is less than 40°.
3. Additionally, the area under the righting lever curve (GZ curve) between the angles of heel of 30° and 40° or between 30° and $\varphi_f$, if this angle is less than 40°, shall not be less than 0.03 meter-radians.
4. The righting lever GZ shall be at least 0.2 m at an angle of heel equal to or greater than 30°.
5. The maximum righting lever shall occur at an angle of heel not less than 25°.
6. The initial metacentric height $GM_0$ shall not be less than 0.15 m.
7. The International Code of Intact Stability, IMO 2008 emphasizes that general intact stability criteria given in part A, 2.2.1 to 2.2.3 should apply to fishing vessels that have a length of 24 m and over, with the exception of requirements on the initial metacentric height $GM$ (part A, 2.2.4), which for fishing vessels should not be less than 0.35 m for single-deck vessels.

For the fulfilment of general criteria of righting lever curve properties, see the following table 6.

### Table 6. Verification of general criteria of the vessel in full load departure.

| Code       | Criteria                          | Value | Units | Actual | Status | Margin % |
|------------|-----------------------------------|-------|-------|--------|--------|----------|
| A.749(18) Ch3 | 3.1.2.1: Area $0^\circ$ to $30^\circ$ | 3.151 | m.rad | 13.925 | Pass   | +342%    |
3.4. Weather criteria (wind and rolling criterion)

The ability of a vessel to withstand the combined effects of beam wind and rolling will be demonstrated with reference to the following figure 6, as follows [5, 9]:

Under these circumstances, area b shall be equal to or greater than area a, as indicated in the following table 7:

| Criteria | Value | Units | Actual | Status | Margin % |
|----------|-------|-------|--------|--------|----------|
| A.749(18) Ch3 - Design criteria applicable to all vessels | | | | | |
| 3.2.2: Severe wind and rolling | | | | | |
| Angle of steady heel shall not be greater than | 16.0 | deg | 2.0 | Pass | +87.64 |
| Angle of steady heel / Deck edge immersion angle shall not be | 80.000 | % | 7.759 | Pass | +90.3 |
| Area1 (b) / Area2(a) shall not be less than | 100.000 | % | 240.501 | Pass | +140.5 |
| Intermediate values | | | | | |
| Model windage area | | m² | 51.724 | | |
| Model windage area centroid height (from zero point) | | m | 3.283 | | |
| Total windage area | | m² | 101.724 | | |
| Total windage area centroid height (from zero point) | | m | 4.618 | | |
| Heel arm amplitude | | m | 0.067 | | |
| Equilibrium angle with steady heel arm | | deg | 2.0 | | |
| Equilibrium angle with gust heel arm | | deg | 3.0 | | |
| Deck edge immersion angle | | deg | 25.5 | | |
| Area1 (under GZ), from 3.0 to 50.0 deg. | | m.deg | 30.9949 | | |
| Area1 (under HA), from 3.0 to 50.0 deg. | | m.deg | 4.6970 | | |
Area1(b), from 3.0 to 50.0 deg. m.deg 26.2979
Area2 (under GZ), from -23.0 to 3.0 deg. m.deg -8.3391
Area2 (under HA), from -23.0 to 3.0 deg. m.deg 2.5956
Area2(a), from -23.0 to 3.0 deg. m.deg 10.9347

4. Conclusions
The study was carried out with the objective of completing the necessary technical documentation required by the Albanian Maritime Register for carrying out the activity of the fishing vessel "Eclipse".

The steps followed by real measurements on the vessel, not only help 3D modeling and 3D CAD building of vessel hulls, but they help to create a model for other similar cases.

The FORMSYS computer package assisted with considerable reliability in achieving a better hull surface of the vessel.

The fulfillment of the stability criteria has been verified according to the criteria in the IMO stability code and the normatives by the RINA classification societies, Bureau Veritas, Resolution MSC.267 (85).

5. References
[1] Resolution MSC.267(85) 2008 Adoption of the international code on intact stability (IS CODE) 12–16 20–22
[2] Albanian Maritime Administration 2009 Albanian Regulation for Ship Inspection Durres AL: AMA
[3] Francescutto A 2007 The intact ship stability code: Present status and future developments Proc. of the 2nd International Conference on Marine Research and Transportation, Naples, Italy, Session A 199–208
[4] IS-Code 2008 International Code on Intact Stability IMO London
[5] Bentley 2009 Maxsurf Australia: Formation Design Systems Pty Ltd.
[6] Girace C 2006 Rilievo di carene navali mediante tecniche di riverese engineering Napoli, Italy: Tesi di Dottorato
[7] Xhaferaj B et al 2008 Perdorimi i sistemeve te programve Maxsurf per vleresimin e cilesive lundrimore te mjeteve te transportit detar shqiptar Besuesheria e Mjeteve te Transportit Detar Vlore, Albania 52–61
[8] Lapa K 2004 Statika dhe Qendrueshmeria e Anijes Tirane, AL: SHBLU
[9] Lapa K et al 2005 The influence of Albanian sea winds on fishing-boat stability of FV 2KP-400 type Proc. of the 11th International Congress of IMAM Lisbon, Portugal 1231–1237
[10] Lapa K et al 2015 A case study on the stability analysis of passenger ship in lake Koman in Albania Proc. of the 17th International Conference on Transport Science of ICTS 2015. Portoroz, Slovenia 200–210
[11] Lapa K et al 2017 Evaluation of the fishing vessels stability in different operational conditions Proc. of the 7th International Maritime Science Conference Solin, Croatia 42–51