A rigorous practical method to compute the effects of the free surface in the ship for fluid weights

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Abstract

Concerning to the ship, it is very important to improve the investigation of the effect of the free surfaces due to fluid weigths in the transverse and longitudinal stability. The changes in parameters as metacentric height, heel and trim, roll and pitch, and the GZ arm for large angles of roll, are considered, and also, a correction to the mean draught for displacement purposes. Thinking in the ship's master, and in order to get a rigorous information of the free surface, this information has been covered with real data from some ships, with the final objetive of developing a practical method.

1 Introduction

It is known that the free surfaces of the fluids affect the transverse and longitudinal stability of the ship. However, the corrections made on board are only partial and approximatelly. Perhaps in the past this was enough, but nowadays we must take in account:

- The necessity to dispose of a more extensive and accurate information of the free surface effects.
- The profesionalism of the ship's master, for deciding the use of the information on board, about the level of approximation, or better, the level of accuracy for determining some parameters corresponding to a particular condition of the ship's load.

2 Influence of the free surfaces on the stability of ships

The study of the free surface effects on the transverse stability of the ships are

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the following:

- Decreasing the transverse metacentric height, GM.
- Increasing the angle of heel, θ.
- Decreasing the value of the transverse stability GZ arms.
- Decreasing the value of the dinamical stability.
- Changing the roll period of the ship.

This is the present situation with respect to the applications on board, but, as it was explained before, tha data are only partial and approximatelly.

Normally, there are no applications of the effect of free surfaces to the longitudinal stability. The more important effects are:

- Changing the trim of the ship.
- Decreasing the longitudinal metacentric height.
- Changing the pitch period of the ship.

3 Equivolume inclinations method

The method normally used for computing the value of the free surfaces correction, is by analogy with the method for computing the movement of the buoyancy centre and the situation of the transverse metacentre. The geometric considerations applied to the submerged volume are extended for any volume of a fluid contained in any tank of the ship. The centre of gravity of the liquid, changing due to a equivolume condition, and the metacentre of the fluid volume, are obtained in the same manner that the centre of buoyancy and the metacentre of the ship.

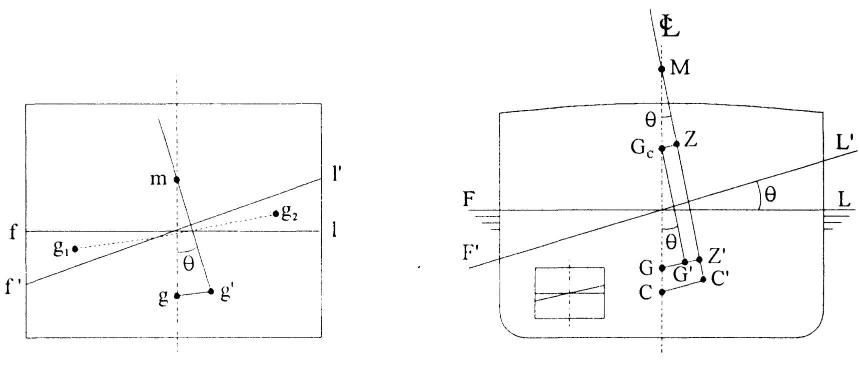

Figure 1: Parameters of the transverse stability of the ship and a tank with free surfaces.

The usual practice is to consider the effect of free surfaces in the initial stability, at small angles, or for large angles. In the first case the influence is,

$$fsc = \frac{\sum i \cdot \gamma}{D} \tag{1}$$

where, i is the moment of the transverse inertia of the free surface of the fluid about a longitudinal axis through its centre of gravity and parallel to the diametral plane, γ is the density and D, the displacement of the ship.

This correction of the free surface means that the centre of gravity is virtually supposed in the metacenter of the tank, because the small angle of heel, and in the same way, the centre of gravity of the ship is virtually positioned in,

$$KG + fsc = KG_{fsc} \tag{2}$$

Then, the free surface correction is no dependent neither of the fluid weight, nor of the tank situation. In summary, only depending of the free surface inertia and the displacement of the ship, and also of its density.

The righting moment of the GZ arm, for initial stability, can easily computed by

$$GZ = GM_{fsc} \cdot \sin\theta \tag{3}$$

having the condition that θ will be an angle that we can consider in the initial stability, and while the surface of the liquid does not reach the top or the bottom of the tank. Justifying the influence of the free surface effect on the trim of the ship, it is essential to consider if the interest exists in the calculation of the displacement as exact as possible. The corrections to be applied to the mean draught for calculating the draught in the vertical of the centre of flotation, are every time more in quantity and quality. As one specific correction for some ships or for some particular conditions of the ships, it would be interesting to take into account the longitudinal effect of the free surfaces.

One of the parameters that have incidence in the trim of this ships is the moment to alter trim 1 cm, Mu, whose equation, applying the longitudinal effect for free surfaces, is

$$Mu = \frac{D \cdot GM_{L\ fsc}}{100\ L} \tag{4}$$

where $GM_{L\ fsc}$ is the longitudinal metacentric height after the correction of the free surfaces. It is to be applied, for instance, in tankers, gas carriers, or damaged ship, as flooding is calculated by the method of added weight.

3.1 The correction of the free surfaces of liquids at large angles of heel.

The heel of the ship causes the traslation of the liquid from one to the other wedge, Fig. 1. We can see that the wedge forms will depend of the tank shape and the height of the liquid level in the tank. The effect of this translation is to shift the centre of gravity of the liquid a distance parallel to the line between the centre of gravity of each wedge. As an approximation, and like the initial stability, we can find that

$$Moment\ of\ transference = i \cdot \gamma \cdot \sin\theta \qquad (5)$$

and the GZ arm

$$GZ = KN - (KG + \frac{i \cdot \gamma}{D}) \sin\theta \qquad (6)$$

Again the correction to be applied, in the case to the GZ arm, is independent of the liquid weight transferred.

If the surface of the liquid reaches the top or bottom of the tank, the moment of free surfaces will be expressed by

$$i \cdot \gamma \cdot k \qquad (7)$$

the value of k depends on the degree of fullness and the ratio depth/breadth, all of them for the tank in question, and the angle of heel. In the IMO recommendation on intact stability for passenger and cargo ships under 100 metres in length, and with the assumption that the tank is 50% full, the value of the moment of free surfaces is

$$Mfs = v \cdot b \cdot \gamma \cdot k \cdot \sqrt{\delta} \qquad (8)$$

being v, b, h and l, the total tank capacity and the maximum breadth, height and length, respectively. δ is the tank block coefficient, and k is a dimensionless coefficient to be determined from the ratio b/h and the angle of heel.

4 Method to compute the effects of the free surface liquids

A number of studies has been made with the information of different cargo ships, two of them with the characteristics that follow.

Alpha ship: length = 50,90 m, beam = 9,50 m, depth = 5,35 m, summer draught = 4,20 m, summer displacement = 1.486 Tm and dead weight = 957 Tm.

Beta ship: length = 178 m, beam = 22,8 m, depth = 14,6 m, summer draught = 10,688 m, summer displacement = 37.094 Tm and dead weight = 30.498 Tm.

The calculations were made according to the true form of the transference wedges, and also with the real arms, including the vertical arm, and parallels to the three principal axes of the ship. Therefore the shape of the ship tanks and the height of the fluid are considered.

To present some of the information calculated and the analysis of the data with influence in the stability will be the next objetive.

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4.1 Case 1. Beta ship, Figs. 2 and 3

The analysis corresponds to two symmetric upper wing tanks, slack, as it is shown in the figures, and with a heel of the ship of 15°.

The computations, the data obtained and the analysis of the deviations are as follow, being GGc the virtual vertical raised of G, the ship centre of gravity, calculated from the transverse and vertical moments.

The data are shown in a tabular form to simplify and making uniform their presentation and analysis.

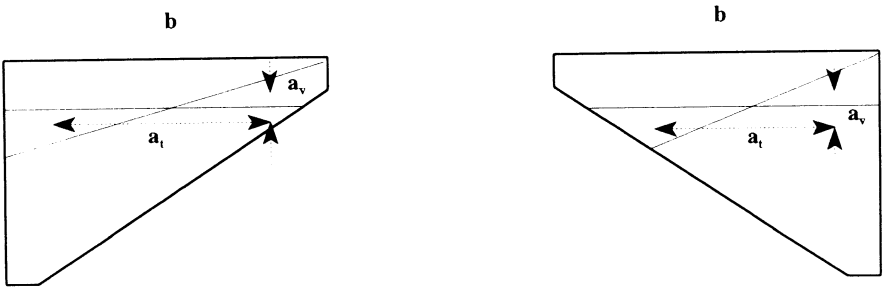

Figure 2 and 3: Upper symmetric wing tanks.

Table 1.1: Upper wing tanks.

Description	Port tank	Starb. tank
transverse surface of one wedge	1,140 m^2	0,940 m^2
length	19,200 m	19,200 m
volume	21,888 m^3	18,048 m^3
density	1,025 Tm/m^3	1,025 Tm/m^3
weight	22,435 Tm	18,499 Tm
transverse arm	3,890 m	3,590 m
vertical arm	0,440 m	0,500 m
tranverse moment, M_T	87,273 Tm·m	66,411 Tm·m
vertical moment, M_V	9,871 Tm·m	9,249 Tm·m
GGc	8,9 mm	6,9 mm
fsc from Eqn. (1)	5,4 mm	5,4 mm

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Table 1.2: Analysis of the deviations.

GGc port tank	8,9 mm
GGc starboard tank	6,9 mm
fsc for 2 symm. tanks, Eqn. (1)	10,8 mm
difference	+ 5,0 mm
GMc minimum	300,0 mm
per cent of error	- 1,7
GZ deviation	-1,3 mm
GZ minimum	105,0 mm
per cent of error	- 1,2
number of symmmetric tanks	7
difference	35,0 mm
per cent of error	- 11,7
GZ deviation	- 9,1 mm
per cent of error	- 8,7

4.2 Case 2. Beta ship, Fig. 4

The tank is symmetric in relation to the diametral plane, and with a heel of the ship of 15°.

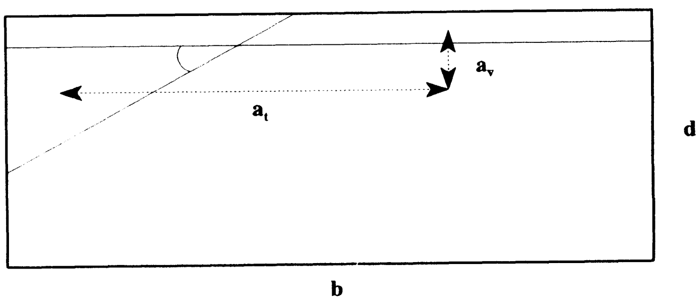

Figure 4: Symmetric tank with the diametral plane.

Table 2.1: Symmetric tank.

Data		Analysis	
GGc	27,9 mm	difference	- 11,3 mm
fsc, Eqn. (1)	39,2 mm	% error GMc, 1 tank	+ 3,8
GMc min.	300,0 mm	% error GMc, 7 tks.	+ 26,4
GZ deviation	+ 2,9 mm	% error GZ, 1 tank	+ 2,8
GZ minimum	105,0 mm	% error GZ, 7 tanks	+ 19,5

4.3 Case 3. Alpha ship

The study corresponds to a symmetric rectangular tank, when the surface of the liquid has not reached the top or the bottom of the tank.

Table 3.1: Analysis of the Mfs.

Data (heel 20°)		Analysis	
surf. wedge	0,480 m^2	GGc	14,9 mm
length	8,600 m	fsl	16,0 mm
volume	4,133 m^3	difference	- 1,1 mm
density	0,850 Tm/m^3	GMc minimum	150,0 mm
weight	3,513 Tm	per cent error	+ 0,7
transv. arm	2,166 m	$GZ_{20°}$ deviation	+ 1,5 mm
vertical arm	0,394 m	GZ minimum	200,0 mm
M_T	7,611 Tm·m	per cent error	+ 0,75
M_V	1,385 Tm·m	number of tanks	3
GGc	14,9 mm	difference	- 3,3 mm
fsc, Eqn. (1)	16,0 mm	GMc minimum	150,0 mm
$Mc_{20°}$	8115,4 Tm·m	per cent error	+ 2,2
$Mfs_{20°}$, Eqn. (8)	5890,2 Tm·m	GZ deviation	+ 4,5 mm
$GZ_{20°}$ correct.	5,5 mm	GZ minimum	200,0 mm
$GZ_{20°}$, fsc	4,0 mm	per cent error	+ 2,2

4.4 Case 4. Beta ship. Longitudinal stability

The calculations were made for a double bottom tank. Ship information from hidrostatic curves and for a cargo condition are: KM_L = 232,077 m, KC = 5,498 m, ØF = + 0,656 m, KG = 7,740 m, ψ = 1°.

Table 4.1: Longitudinal stability.

Data		Analysis	
surf. wedge	0,838 m^2	number tanks	20
breadth	10,800 m	GGc	3,5 m
density	0,930 Tm/m^3	M_L	2.266,0 Tm·m
longit. arm	13,066 m	Mu (CM_L)	472,2 Tm·m/cm
M_L	109,999 Tm·m	Mu (GM_{Lc})	460,2 Tm·/cm
vertical arm	0,114 m	t (alter)	50,0 mm
M_V	0,959 Tm·m	% trim var.	1,6

5 Conclusions

In the studies carried out, it was found a dispersion of results in comparation with the data obtained from the traditional methods of correction. This dispersion is in value and sign. The most important conclusions are:

- Tranverse stability: the deviations are important considering the percentages that it results with respect to the values of minimums from the stability criteria.

- Longitudinal stability: As it is expected, the deviations are very small, but could be necessary to take in account the effect on the trim, and its influence in the displacement of the ship.

In summary, an accurate evaluation of the free surface effects is necessary for determining the true influence on the ship stability.

6 Proposals

1. According with the conclusions, to have a better information in the ships, permiting to the master to make more accurate calculations of stability, included the evaluation of the displacement, in function of the necessities.

2. A practical method. To arrange a table with the maximum values of the free surface corrections computed as indicated before, and for some specific load conditions, e.i, full, intermediata and ballast, with the purpose to be used in a practical manner when a major approximation is not required.