الأبحاث المنشورة (1968-2001)

فى مجال اتزان السفن

للأستاذ الدكتور محمد عبد الفتاح شامة

Published Papers (1968-2001)

on Ship Stability

by

Prof. Dr. M. A. Shama

1- Shama, M. A., (UK-1968) "A Method for Calculating Ship Stability Curves", Shipbuilding and Shipping Record, Aug.
2- Shama, M. A., (UK-1969) "A Computer Program for Ship Stability Curves", Shipbuilding and Shipping Record, May.
3- Shama, M. A., (UK-1975) "The Risk of Losing Stability", Shipping World and Ship, Oct.
4- Shama, M. A., (Germany-1976) "On the Probability of Ship Capsizing", Schiff und Hafen, Sept.
5- Shama, M. A., (Egypt-1989) "Safety Requirements for Nile Tourist Vessels", Seminar on Future of Nile Tourism in Egypt, (In Arabic), Alex., Eng. Journal, Vol.28, No.2, April.
6- Shama, M. A., (Egypt-1993) "Ship Stability Assessment, Criteria & Risk", AEJ, July.
7- Shama, M. A., and others, (Egypt-2001), "Intact Stability of SWATH Ships", AEJ, Vol. 40

On the Probability of Ship Capsizing

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Summary

The variabilities of the main factors affecting the heeling and righting moments are examined. Because of the random variation of these factors, the reserve of dynamical stability is treated as a stochastic phenomenon. The mathematical model representing the random variation of the relevant parameters is assumed to follow the normal probability density function. This assumption is made because of the absence of sufficient statistical data and also to simplify the subsequent calculations. The risk of capsizing is calculated using the coefficients of variation and the results are presented graphically.

It is concluded that since the reserve of dynamical stability has a direct influence on ship safety, its variability should be carefully examined with particular emphasis on the risk of capsizing.

Introduction

Dynamical stability of ships is measured by the area under the statical stability curve. The latter is normally obtained from the cross curves of stability. Various methods are available for the calculation of these curves [1, 2, 3, 4]. These methods, however, are based on the assumption that inertia forces and hydrodynamic pressure are neglected. Therefore, experimental and theoretical methods [5,6] are proposed to determine ship stability among waves. The effects of the hogging and sagging conditions are indicated in [7]. The effect of ship speed is examined in [8].

Because of the random variation of the main parameters affecting the shape and area under the statical stability curve, the characteristics of the latter should be treated as random variables. Consequently, the reserve of dynamical stability should be associated with the risk of capsizing, since the external forces acting on a ship among waves are random in nature.

In this paper, the variability of the main parameters affecting the reserve of dynamical stability is discussed. Particular emphasis being placed on the calculation of the risk of capsizing. Because of the lack af adequate statistical data to establish the mathematical model representing the random variation of the relevant parameters associated with the reserve of dynamical stability, a normal probability function is assumed.

1. Dynamical stability

Dynamical stability is generally defined by the work done by the righting moment in inclining a ship through an angle of heel θ. It is, therefore, equal to the area under the statical stability curve [9]. Hence

$$M_D = \int_0^\theta M_R \cdot d\theta = \Delta \int_0^\theta \overline{GZ} \cdot d\theta, \qquad (1.1)$$

where:
- M_D = dynamical stability,
- M_R = righting moment,
- Δ = ship displacement,
- GZ = righting arm.

This definition, however, does not take into account inertia, hydrodynamic and friction forces. The calculations are, therefore, based on quasi-static conditions. The errors inherent in this assumption has not yet been fully identified [10].

2. Reserve of dynamical stability

In order to ensure adequate dynamical stability, the following condition must be satisfied:

$$S_D = M_D - M_H > 0 \qquad (2.1)$$

where

- S_D = reserve of dynamical stability, see fig. 1,
- M_H = work done by an arbitrary heeling moment.

The angle of dynamical equilibrium, θd, is determined from the following condition, see fig. 1:

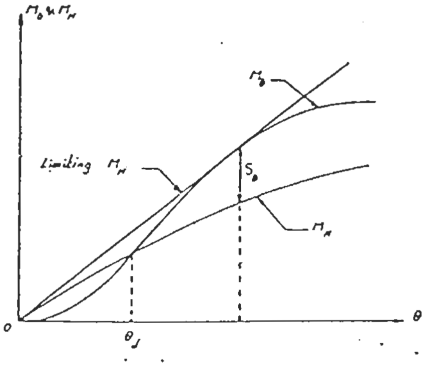

Fig. 1

$$M_D = M_H \qquad (2.2)$$

The limiting value of a heeling moment independent of the angle of heel θ could be determined as shown in fig. 1. In this case, the reserve of dynamical stability vanishes.

3. Probability of capsizing

The probability of capsizing, R, can be calculated from the probability density function, p.d.f., of the reserve of dynamical stability as follows:

$$R = P(S_D \leqslant 0) = \int_{-\infty}^{0} p(S_D) \cdot dS_D, \qquad (3.1)$$

where $p(S_D)$ = p.d.f. of S_D.

The p.d.f. of S_D can be determined from the p.d.f. of both M_D and M_H, which could be determined from the nature of their variabilities.

4. Variables of M_H and M_D

Since M_H depends largely on the wind and sea conditions, it can be treated as a stochastic phenomenon. However, in the absence of sufficient statistical data, M_H may be assumed to follow the normal p.d.f.; i.e.

$$p_X(x) = \frac{1}{\sqrt{2\pi} \cdot \sigma_X} \cdot \exp \cdot \left[-\frac{(x-\overline{x})^2}{2\sigma_X^2} \right] \qquad (4.1)$$

where: $\overline{x}$ and σ_x^2 are the mean and variance of X, X = M_H.

Since M_D depends totally on the shape of the statical stability curve, its variability must be deduced from the variabilities of the main factors affecting the statical stability curve. These factors are:

i — initial stability, GM_o,
ii — maximum righting arm, GZ_m,
iii — angle of vanishing stability, θ_v.

i — variability of GM_o

The variability of GM_o results from the variabilities of KM_o and KG, since

$$GM_o = KM_o - KG \qquad (4.2)$$

KG is a variable quantity given by

$$KG = \frac{1}{\Delta} \left[\Delta_o \cdot KG_o + \sum_{i=1}^{n} W_i \cdot Z_i \right] \qquad (4.3)$$

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where Δ_o = light ship displacement,
KG_o = height of C.G. of Δ_o from base line. It could be determined by an inclining experiment,
W_i = weight of item i,
Z_i = height of C.G. of W_i from base line,
n = total number of weight items.

The carriage of deck cargoes, as well as the presence of partially filled tanks, have a marked influence on the variability of KG.

However, the variability of KG depends on ship type and size. For certain types of ships, such as oil tankers, KG may be treated as a deterministic quantity for the particular loading condition. For other types of ships, KG must be treated as a random variable.

The variability of KM_o depends on ship size, form, geometry, sea condition, hull stiffness [11] and speed of vessel [8]. On a wave crest and in a following sea [7], KM is seriously affected. Therefore, it is possible to treat KM as a random variable.

In the absence of sufficient statistical data on the variabilities of both KG and KM_o, it may be sufficient to assume that they both follow the normal p.d.f. Since these two variables are statistically independent random variables, GM_o also follows a normal p.d.f. [12] having the following particulars:

$$\overline{GM_o} = \overline{KM_o} - \overline{KG} \quad (4.4)$$

$$\sigma^2_{GM_o} = \sigma^2_{KM_o} + \sigma^2_{KG} \quad (4.5)$$

where $\overline{X}$ =
mean value of X, (X=GM_o, KM_o and KG)

σ_X^2 =
variance of X, (X=GM_o, KM_o and KG)

It should be mentioned here that although GM_o cannot be used alone as a general measure of ship stability, a positive value must be maintained, and initial stability should be measured by the coefficient of stability, i.e. $\Delta \cdot GM_o$.

ii — variabilities of GZ_m, θ_v

The variabilities of GZ_m and θ_v result from:

a — accuracy of the method used for calculating the cross curves of stability,
b — the inevitable trim associated with the different angles of heel,
c — the effect of waves,
d — errors resulting from the presence, or absence, of watertight structures above the main deck,
e — errors associated with the presence of appendages,
f — treating the ship as a rigid body,
g — neglecting dynamic and hydrodynamic effects,
h — neglecting wind effects,
i — neglecting effect of ship speed,
j — neglecting friction forces,
k — the inaccuracy of calculating KG.

However, because of the lack of adequate statistical data needed to establish the matematical model representing the random variation of the relevant parameters affecting M_D, the latter is assumed to follow the normal p.d.f.

It should be mentioned here that the variability of each parameter affecting the reserve of dynamical stability does not vary from $-\infty$ to $+\infty$. Therefore, a truncated p.d.f. should be used in calculating the risk of capsizing. The effect of truncation could be taken into account as follows [12]:

$$f_X(x) = p_X(x) / E \quad (4.6)$$

where $f_X(x)$ = truncated p.d.f., and

$$E = \int_{-\infty}^{x_U} p_X(x) \cdot dx - \int_{-\infty}^{x_L} p_X(x) \cdot dx \quad (4.7)$$

The range of variation is, therefore, given by

$$x_L \leq X \leq x_U \quad (4.8)$$

where X = any random variable, KG, KM, ... etc.
U and L stand for upper and lower respectively.

5. Risk of capsizing

In order to calculate the risk of capsizing, R, the p.d.f. of both M_D and M_H should be known apriori. For the particular case when both M_D and M_H follow the normal p.d.f., S_D will also follow the normal p.d.f. by virtue of statistical independence.

The calculation of R could be greatly simplified by using the coefficients of variation of M_D and M_H as follows [13]:

$$\mu = \sigma_{M_D} / \overline{M_D} \text{ and } \upsilon = \sigma_{M_H} / \overline{M_H}$$

Hence, R is given by

$$R = P(S_D \leq 0) = \frac{1}{\sqrt{2\pi}} \cdot \int_{-\infty}^{w} \exp.\left[-\frac{t^2}{2}\right] \cdot dt \quad (5.1)$$

where $t = \dfrac{S_D - \overline{S_D}}{\sigma_{S_D}}$,

$$w = \frac{F-1}{\sqrt{F^2 \cdot \mu^2 + \upsilon^2}} \quad (5.2)$$

$F = \overline{M_D} / \overline{M_H} > 1.0$,

$\overline{S_D} = \overline{M_D} - \overline{M_H}$, see fig. 2,

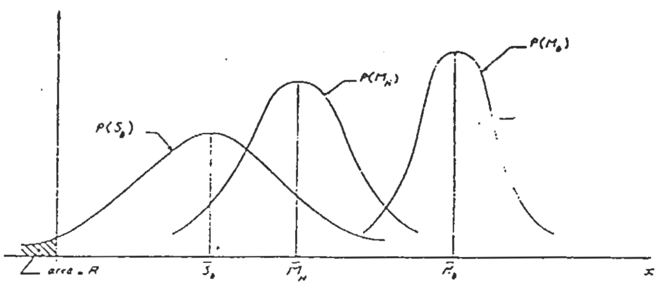

Fig. 2

$\sigma^2_{S_D} = \sigma^2_{M_D} + \sigma^2_{M_H}$,

$\overline{M_D}$ and $\overline{M_H}$ = mean values of M_D and M_H respectively,
σ^2_x = variance of x, (x = M_D, M_H and S_D).

The standard deviations of M_D and M_H could be approximately calculated as follows:

$\sigma_x \doteq$ (range of variation of x) / 6,
x = M_D, M_H.

The effect on R of variation of u, v and F is shown in figs. 3, 4. It can be seen that when:

u = 0.10, v = 0.10 and F = 1.4,

$R = \dfrac{1}{100}$.

It is evident now that the risk of capsizing is greatly influenced by the shape of the statical stability curve. The latter is normally obtained from the cross curves of stability. Therefore, improving the accuracy of calculating these curves cannot be overemphasised.

It should be mentioned here that the area under the statical stability curve does not give a correct measure of dynamical stability, as it does not take into account such factors as inertia and hydrodynamic forces, among several other factors. However, the risk of capsizing based on the area under the statical stability curve could be used for qualitative measures as well as for comparing different designs.

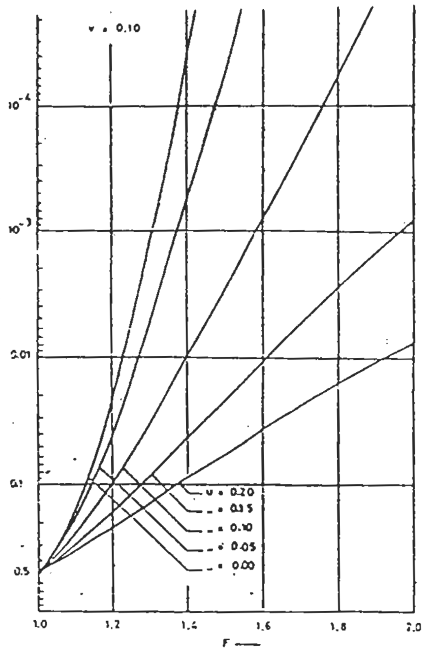

Fig. 3

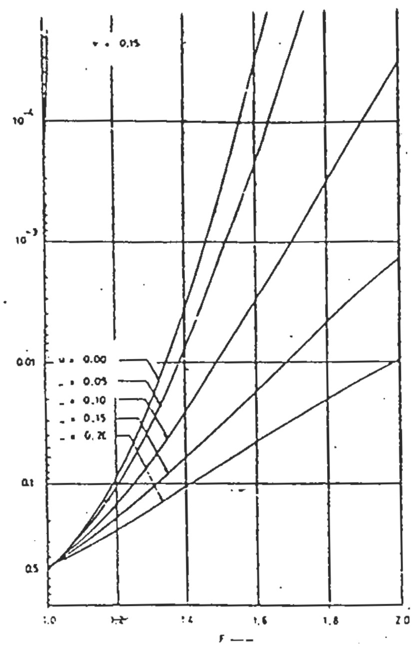

Fig. 4

6. Concluding remarks

Although there are major assumptions used in this investigation, the following main conclusions are generally valid:

1. The probability of ship capsizing is greatly influenced by the variabilities of initial stability and the shape of the statical stability curve.
2. Deficient initial stability has an adverse effect on initial and dynamical stability.
3. Stability criteria should be treated stochastically as the main parameters affecting ship capsizing are stochastic in nature.
4. Much work is needed to determine the effects of inertia, friction and hydrodynamic forces on dynamical stability.
5. Statistical data on the variabilities of the relevant parameters affecting the reserve of dynamical stability are needed.

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