IJNAOE
©SNAK, 2015

Int. J. Nav. Archit. Ocean Eng. (2015) 7:1~9
http://dx.doi.org/10.2478/IJNAOE-2015-0001
pISSN: 2092-6782, eISSN: 2092-6790

Stability criterion and its calculation for sail-assisted ship

Yihuai Hu[1], Juanjuan Tang[2], Shuye Xue[2] and Shewen Liu[3]

[1]*Professor, Merchant Marine college, Shanghai Maritime University, Shanghai, P. R. China*
[2]*Postgraduate student, Merchant Marine college, Shanghai Maritime University, Shanghai, P. R. China*
[4]*Manager, China Offshore Technology Center, ABS Greater China Division, Shanghai, P. R. China*

ABSTRACT: *Stability criterion and its calculation are the crucial issue in the application of sail-assisted ship. However, there is at present no specific criterion and computational methods for the stability of sail-assisted ship. Based on the stability requirements for seagoing ships, the stability criterion of the sail-assisted ships is suggested in this paper. Furthermore, how to calculate the parameters and determine some specific coefficients for the ship stability calculation, as well as how to redraw stability curve are also discussed in this paper. Finally, to give an illustration, the proposed method is applied on a sail assisted-ship model with comments and recommendations for improvement.*

KEY WORDS: Sail-assisted ship; Ship stability calculation; Ship stability criterion.

INTRODUCTION

Propelled by main diesel engine primarily and assisted by sails as auxiliary is a major application method to make the use of the wind energy on modern ships. To make the use of wind energy on modern ships primarily propelled by main diesel engines, one of the major application methods is to use sails as auxiliary power source. Under the requirement of energy conservation and emission reduction, sail-assisted technology has been rapidly developed (Meng et al., 2009). Due to the action of wind, the sail assisted ship has some different characteristics compared to the conventional powered ship in terms of stability. Means of correctly checking the stability of the sail-assisted ship correctly is one of the major problems in the application of sail-assisted technology.

Currently there are no specific rules for stability criterion of the sail assisted ship. Many researchers have proposed specifications for checking the stability of their own sail-assisted ships according to their study situation (Tsai and Haciski, 1986; Cleary et al., 1996). Some institutions in China primarily use the passenger ship criterion from the *Stability Criterion for Seagoing Ships* to check the stability of the sail assisted ship and simply correct the roll angle in order to reflect the effect of sail area (Register of Shipping of the People's Republic of China, 1980). Because the form, structure and material of the sails used on modern ships are different, it is difficult to obtain comprehensive comparison specification through limited experiments. Energy saving efficiency cannot be achieved when the wind is too weak, while the ship's turning-over risk will increase when the wind is too strong, so the sails should be used within certain wind speed range. Because the action of wind and wave to the ship will be magnified after sail installation, the moving effect of sail area is supposed to be included in the calculation of heeling moment when considering the stability of the sail-assisted ship (Yang, 1996; 1988).

Corresponding author: *Yihuai Hu*, e-mail: *yhhu@shmtu.edu.cn*

With better aerodynamic performance arc sails are easily manufactured and manipulated, and are widely used in modern sail-assisted ships. Based on the present rules of *Stability Requirements for Seagoing Ships* and referring to past experience, this paper discusses the stability criterion and calculation of the sail-assisted ships.

STABILITY REQUIREMENT ON SAIL-ASSISTED SHIP

The rules of *Stability Requirements for Seagoing Ships* are the technical regulations enacted to guarantee the safety when the ship is heeled by ocean wind and/or other external forces. The ship should have the ability to return back to the upright. Static stability and dynamical stability should be checked, besides, both initial stability at small angles and overall stability at any heeling angle should be taken into account in the ship stability calculation. Ship inclining velocity could be neglected and static stability of the ship is measured in righting moment for static stability calculation. On the contrary, in the calculation of dynamical stability, external force moment and inclining velocity of the ship should be taken into account, ship's ability to withstand the external force is measured in terms of work done by righting moment, which is numerically equal to the area enclosed by static stability curve against heeling angle.

Taking into account the damping effect of the sail, it is necessary to make correction in the calculation of rolling angle. What's more, if the sail is all unfolded on voyage, the loads applied on the sail are large and the heeling moment on the ship by wind and wave will be magnified. It is obvious that the calculation of weather criterion K depends on total moment of the ship, heeling moment by wind and waves, and rolling angle of the ship. In addition to all requirements of stability calculation mentioned above, it is noteworthy that the weight distribution of the ship will change after sail installation, which will impact the calculation of parameters and the shape of static stability curves.

The recommendatory stability criterion on sail-assisted ships includes:

1) weather criteria $K: K = M_q^* / M_f \geq 1$

2) metacentric height $GM: GM > 0.3$

CALCULATION OF STABILITY PARAMETERS

Calculation of minimum overturning moment M_q^*

Minimum overturning moment is the maximum heeling moment the ship could undertake, which also represents the limits for the ship to withstand heeling moment in the most dangerous situations. If the heeling moment reaches or exceeds this criterion, the ship will overturn.

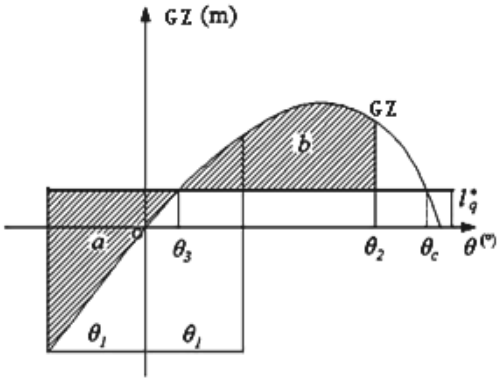

Fig. 1 Static stability curve.

The calculation of minimum overturning moment is related to rolling angle, angle of flooding and the area enclosed by static stability curve as shown in Fig. 1, where θ_1 represents the ship's maximum rolling angle in the beam sea as: