NAVIGATION AND VESSEL INSPECTION CIRCULAR No. 12-83
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Subj: Intact Stability of Towing and Fishing Vessels; Research Results

Ref: (a) Roach, C.D., "Tugboat Design," Trans. SNAME, l955.

(b) Miller, E.R., Ankudinov, V., "Evaluation of Current Towing Vessel Stability Criterion and Proposed Fishing Vessel Stability Criteria - Task III," HYDRONAUTICS, Inc. Technical Report 7311-3 (NTIS No. AD A019-831).

(c) McGowan, J. F., Meyer, R.B. ,"Has Stability Delayed the Delivery of Your Tug?," Marine Technology, SNAME, Jan. 1980.

1. PURPOSE. The purpose of this Circular is to formally publish the results of Coast Guard sponsored research on intact stability criteria of towing and fishing vessels. This Circular is not intended as regulation nor are the research findings offered as a substitute for regulation. This Circular will provide a medium for exchange of research information regarding intact stability criteria for the design and consultant community.

2. APPLICATION. The stability criteria recommended by the researcher may be applied to tugboats, offshore supply vessels, fishing vessels and other similar hull forms of approximately 90 to 180 feet in length which are engaged in towing operations. Application to vessels outside that range should not be used without further investigation.

3. BACKGROUND.

a. In the late 1960's, the Coast Guard published the "Weather Criterion" (46 CFR 170.170) for cargo and miscellaneous vessels. This regulatory standard requires a minimum metacentric height (GM) as protection against the hazard of wind heeling forces. The application of this criterion was originally intended for cargo ships of conventional size, arrangement and form.

b. A provision (46 CFR 170.173) is included in that regulation for establishing equivalent levels of safety for "special case" cargo and miscellaneous vessels to which the Weather Criterion does not apply. Such vessels are those of unusual proportion and form, those which may carry cargo above decks, and those which may be involved in special operations such as towing.

c. Since January 1974, the Coast Guard has been applying either of two towline pull criteria to vessels which are engaged in towing operations. One of those is a GM or "static" criterion which was derived from a theoretical formula by RADM C.P. Murphy which is discussed in references (a) and (c). The other alternative criterion is a required moment area or "dynamic" criterion based on the same physical principle of capsize. Both are offered as protection against the hazard of self-tripping.

d. There are no Federal regulatory stability standards for fishing vessels. The Coast Guard has been active in the development of recommended standards at the International Maritime Organization (IMO). Those international recommended standards have been published as IMO Resolution A.168 (NVIC 3-76) and the International Conference on Safety of Fishing Vessels, 1977.

e. In January 1976, a Coast Guard funded research project on the stability of towing and fishing vessels was completed. The results of that project are published in a three volume report which is concluded in reference (b).

f. The research project surveyed the U.S. towing (including tugboats and offshore supply vessels) and fishing fleet and prepared detailed stability calculations for 51 such vessels as representative samples. Four of those representative vessels were extensively model tested.

g. In the final report, reference (b), five stability criteria are recommended, all of which are published in Enclosure (1) of this Circular.

4. <u>DISCUSSION</u>.

a. Regarding the application of any stability criterion to the complexity of a vessel/seaway system, it is generally accepted that total safety or reliability is not possible to attain. The prevailing philosophy is that a vessel should be provided with sufficient stability to survive extreme case service conditions if it is handled competently by the crew and if no equipment or material failure occurs.

b. It must be understood that criteria which are based on a limited test program and analyses are necessarily tentative.

c. The following guidelines and assumptions were used by the researcher in the development of the recommended intact stability criteria:

(1) The criteria are only to apply to towing, fishing and supply vessels which are of a size and form covered by the analysis or experiments that form the basis of the criteria.

(2) Stability criteria which apply to operations at sea should result in a stability level which reduces the probability of capsize for a properly handled vessel in a defined extreme sea condition.

(3) Proper handling of the vessel includes compliance with conditions assumed in the stability calculations (i.e., openings closed, tanks pressed up) and the avoidance of local areas where unusual conditions exist such as over shoals or in surf.

(4) Only hazard situations which logically exist together, such as high winds with large waves, need to be considered. However, a margin should be added to the stability level predicted for capsize in extreme conditions to account for uncertainties in the analysis.

(5) Deterministic extreme sea conditions can be defined on the basis that, for wave lengths which are critical, the wave steepness is limited by wave breaking.

(6) The use of extreme conditions and margins in the criteria supplies a reasonable allowance for crew error or equipment failure in less than the most extreme conditions.

(7) Stability criteria which apply to normal operations, such as the towing vessel tripping criteria, should prevent capsize of a vessel which is not properly handled by its crew or which is subject to errors by others, up to arbitrarily defined limits.

(8) The resulting criteria should not be so stringent that large segments of the fleet could not satisfy them and still operate economically.

d. There are two basic types of stability criteria, namely general criteria and specific criteria. The general type criterion, such as Rahola and the IMO criteria, published in NVIC 3-73, is usually applied to provide protection against many capsize hazards and is based on data from the casualty history of a group of vessels. A specific type criterion is one in which the measure and level of stability is defined to prevent a certain type of capsize hazard under given environmental conditions. Specific criteria should be applied as a set to take into account those hazards that a particular vessel may be expected to encounter.

e. The recommended intact stability criteria in Enclosure (1) were developed on the concept of a set of specific criteria. The major reasons that the researcher did not choose the general criteria were:

(1) the questionable statistical base available for use in general experience criteria, and

(2) the lack of information on the effects of specific environmental conditions which is inherent with general criteria.

f. The set of specific criteria recommended are as follows:

(1) Tow Tripping Criterion - This is directed at the hazard caused by action of the tow or assisted vessel relative to the towing vessel.

(2) Self Tripping Criterion - This is directed at hazards caused by improper application of power and rudder angle by the towing vessel.

(3) Low Speed Operation with Water on Deck Criterion - This is directed at the hazard of operations at low speed in head and following seas in combination with a buildup of water on deck causing large angles of heel.

(4) Operation in Following Seas at Moderate and High Speed Criterion - This is directed at the hazards of operation in following and quartering seas at speed/length ratios of about 0.8 and higher.

(5) Wind Heel with Rolling Criterion - This is directed at the hazards of a vessel being subjected to a wind gust while rolling.

g. The following notes apply to the above criteria:

(1) All five criteria are based on GZ curves calculated assuming a constant trim moment rather than constant trim with heel.

(2) In all cases, the vessel's full range of loading conditions (including free surface) should be investigated. Reference (c) contains recommendations for minimum loading conditions to be considered on tug and tug supply vessels. Unusual loading conditions such as topside icing should be included as appropriate.

(3) Special operating conditions other then towing, such as lifting heavy weights over the side, dragging fishing nets, off-center passenger load, etc. should be checked separately if appropriate.

(4) Both the tow tripping and self tripping criteria are intended to apply to conventional tug, tug supply and fishing vessels when involved in towing operations. The criteria apply to such vessel types with single or twin screw propulsion, with or without nozzles, but they do not apply to such vessels with paddle wheels or vertical axis propellers.

(5) The downflooding point for tow and self tripping should be considered the lowest edge of an opening giving access below deck (i.e., door, tank vent, engineroom vent, etc.) not fitted with an autoclosure. Downflooding for all other criteria should be any opening not fitted with a weathertight or watertight closure. Reference (c) provides further discussion of the location and type of downflooding points of vessels that tow.

h. The recommended criteria as a set or individually may offer greater vessel design flexibility than existing general criteria. This is because each type of hazard faced and the specific design features which influence the degree of hazard are defined and tested. Therefore, for each specific criterion there are fewer unknowns and consequently a less conservative safety factor required.

i. A fleet impact analysis in reference (b) determined that the recommended criteria required, on the average, 10 percent less GM than the existing USCG "static" towline pull criterion. No comparison was made to the USCG "dynamic" towline pull criterion.

5. ACTION. Coast Guard personnel are encouraged to provide wide dissemination of these research criteria, but are cautioned not to accept them in lieu of published regulatory standards. Designers and consultants are encouraged to consider these recommended criteria for specific design applications and to compare them to present standards for towing and fishing vessels. The Coast Guard would appreciate receiving comments on any operating experience, research, or economic impact studies related to the application or suitability of these criteria.

L. N. HEIN
Acting Chief, Office of Merchant Marine Safety

End: (1) Stability Analysis Methods for Towing and Fishing Vessels.

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ZTC-68

STABILITY ANALYSIS METHODS
FOR TOWING AND FISHING VESSELS

1. TOW-TRIPPING CRITERION.

The vessel should have positive residual righting energy and a static angle of heel no greater than the angle of downflooding when comparing the righting moment curve to the constant heeling moment (K) calculated by the equation:

$$K = C_1 \times C_2 \times \frac{rho}{2} \times V^2 \times A\left(h \times \cos\theta + C_3 \times H\right)$$

where:

K =	heeling moment (ft-lbs)
C_1 =	drag coefficient (from Fig. 1)
C_2 =	correction to drag coefficient for heel angle (from Fig. 2)
rho =	mass density of water
V =	towing speed (ft/sec)
A =	projected underwater lateral area (sq ft)
h =	height of towing bitt above waterline (ft)
C_3 =	location of center of lateral force as a fraction of draft below waterline (from Fig. 3)
H =	draft (ft)
θ =	heel angle (degrees)

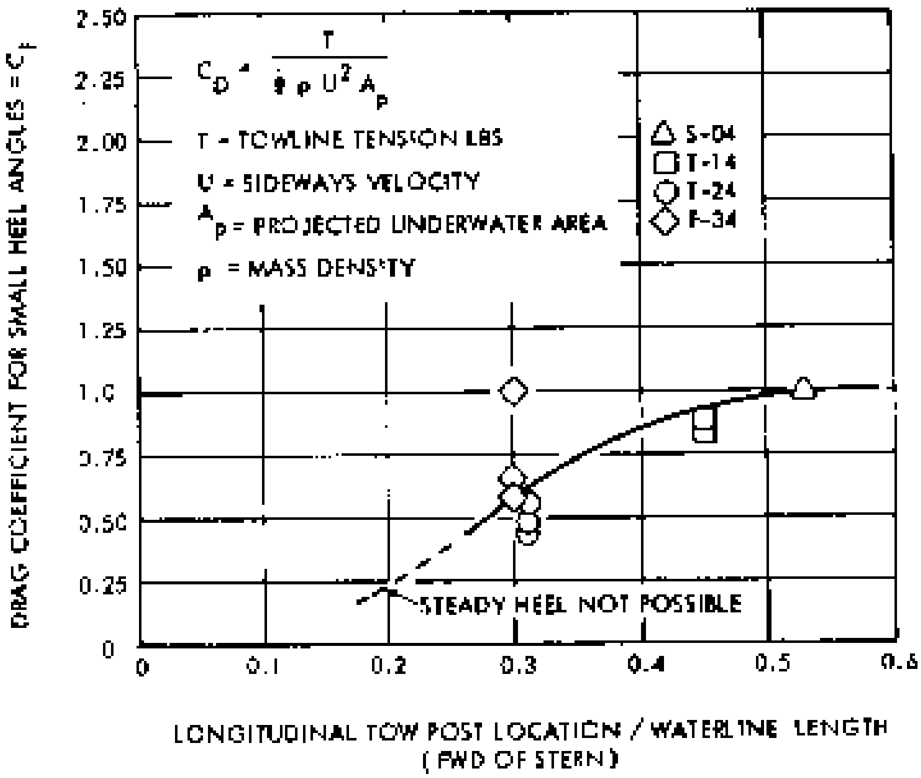


FIG. 1 - DRAG COEFFICIENT FROM TOW-TRIPPING TESTS

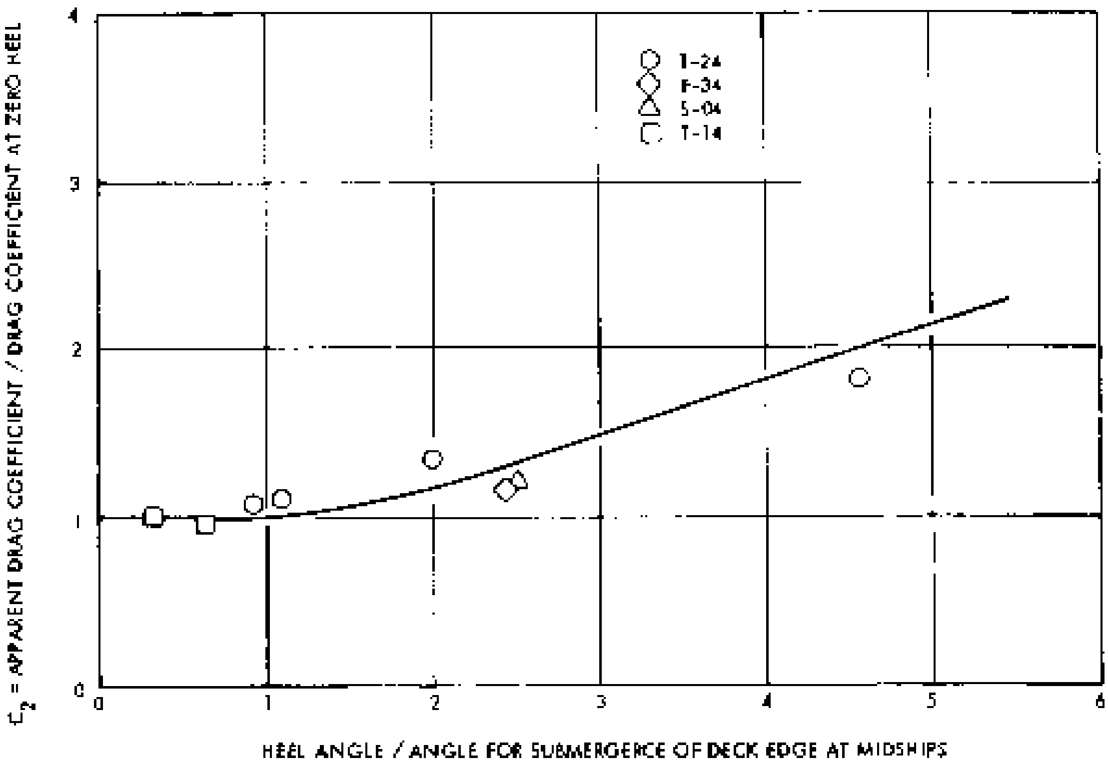


FIG. 2 - DRAG COEFFICIENT RATIO VS. NORMALIZED HEEL ANGLE

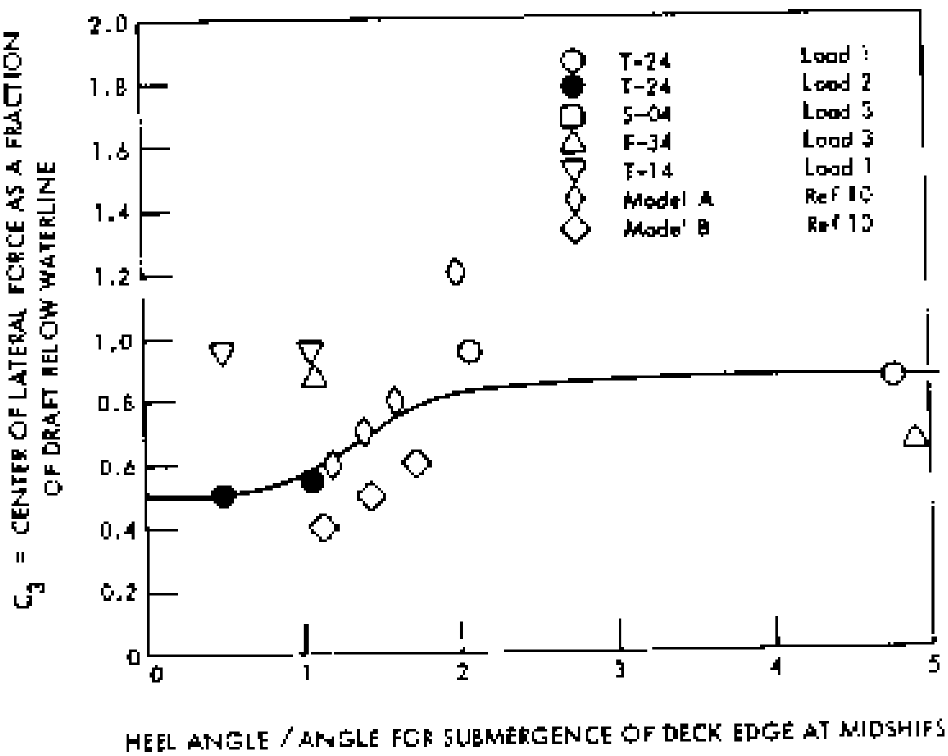


FIG. 3 - DEPTH OF CENTER OF LATERAL FORCE AS A FUNCTION OF HEEL ANGLE

Notes:

a. Model test data were used to develop a formulation for the tow tripping heeling moments.

b. The towing speed, V, selected for the criterion is critical and should be subject to further analysis. A recommended approach would be to find a number of specific tow tripping casualties and, using the proposed criteria, calculate the relative velocity necessary to cause the casualty. The criterion would then be based on the upper limit of the velocity.

c. The researcher designated 5 knots (8.44 ft/sec) as the upper limit which might be expected.

2. SELF-TRIPPING CRITERION

The vessel should have positive residual righting energy and a static angle of heel no greater than the angle of downflooding when comparing the righting moment curve to the constant heeling moment (K) calculated by the equation:

$$K = C_4 \times C_5 \times T \times \left(h \times \cos\theta + C_6 \times H\right)$$

where:

K = heeling moment (ft-lb)

C_4 = 0.70 (effective fraction of bollard thrust which can be expected on towline over the beam) - See Note "a"
C_5 = (correction factor for longitudinal location of towing bitt (Fig. 4) - See Note "a"
T = maximum bollard thrust (lbs)
h = height of uppermost part of the towing bitt above waterline (ft)
C_6 = 0.52 (effective center of resistance as a fraction of draft below waterline)
H = mean draft (ft)
q = heel angle (degrees)

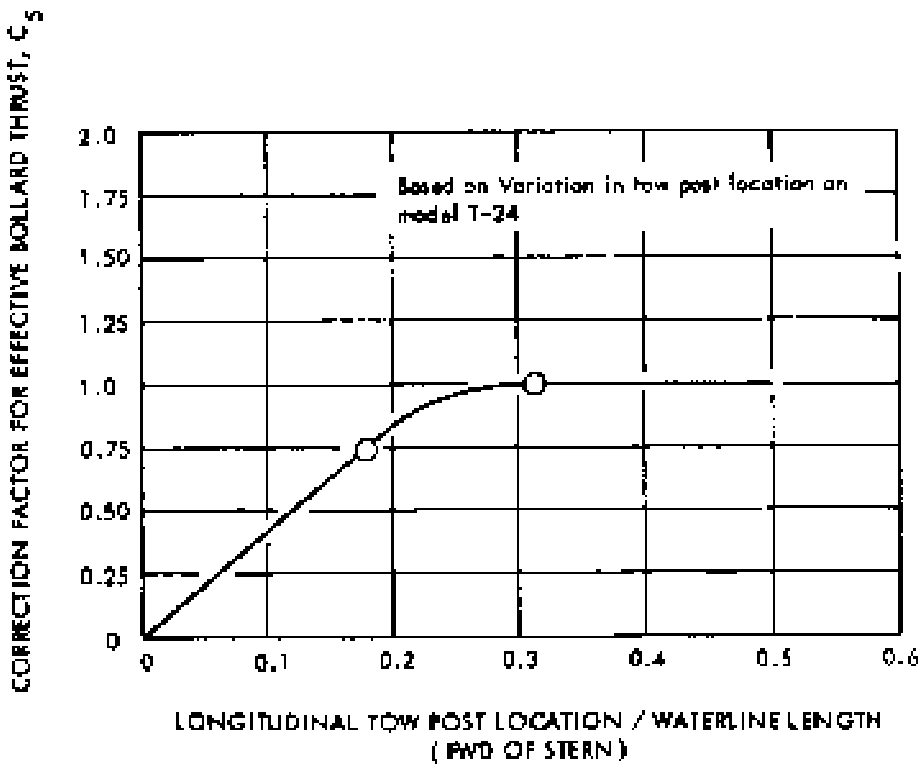


FIG. 4 - REDUCTION IN EFFECTIVE HEELING MOMENT VS. LONGITUDINAL TOW POST LOCATION IN SELF-TRIPPING TESTS

Notes:

a. Applies to conventional single or twin screw propulsion, with or without nozzles. The value of C4 and C5 for novel propulsion and steering systems should be determined on a case by case basis. The coefficient, C4, did not appear to be very sensitive to the size and location of the rudder or propeller for the models tested.

b. Model tests were used to develop towline tension forces in Fig. 4.

3. <u>LOW SPEED OPERATION WITH WATER ON DECK CRITERION</u>.

The heeling moment curve for both head and following seas calculated using the following equation should intersect the stillwater righting moment curve at 1e58 than 85 percent of the maximum righting moment and at an angle less than the angle of flooding.

$$K = 0.70\left(\frac{L}{C} - F\right)\left(A \times \frac{B}{280}\right) \times f(\text{f}) + f(T)$$

where:

K = heeling moment (ft-tons)
T = bollard thrust (tons)
L = waterline length (ft)
F = average freeboard (see Fig. 6) of exposed weather deck (ft)
A = platform area (see Fig. 6) of exposed weather deck (sq ft)
B = beam (ft)
C = 20 for following seas; 10 for head seas
$f(\text{f})$ = function of heel angle (see Fig. 5)
$F(T)$ = T(h + H/2) x sin(20 deg) for vessels that tow at sea ==> 0.0 for all other vessels
h = height to towing bitt above waterline (ft)
H = draft (ft)

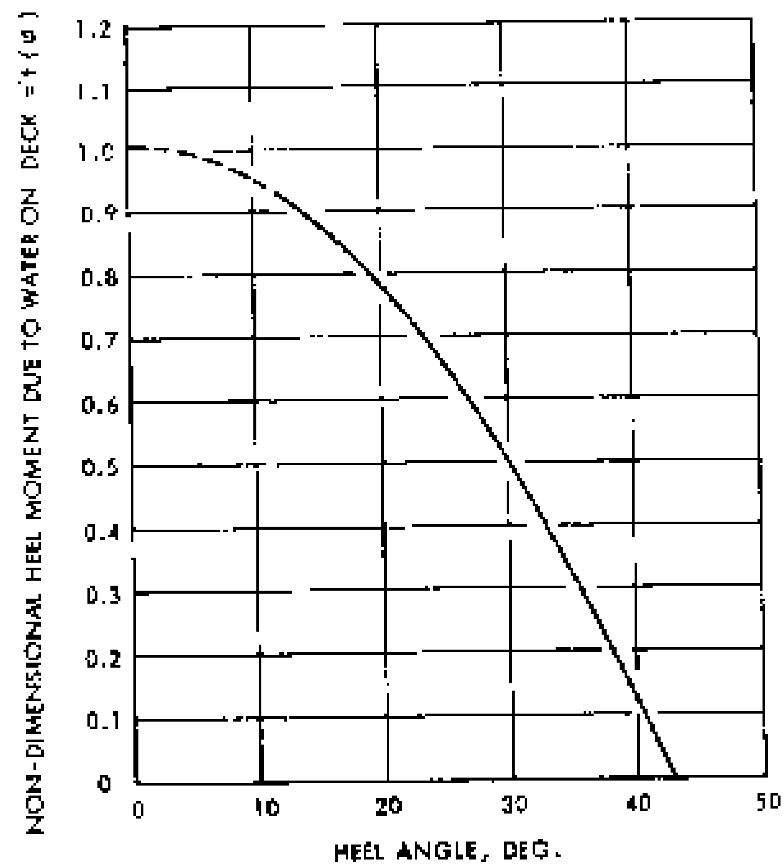
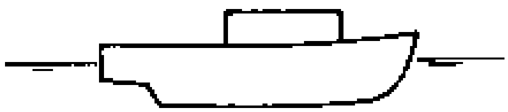
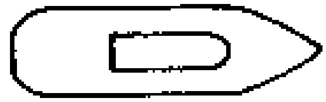


FIG. 5 - NON-DIMENSIONAL HEELING MOMENT DUE TO WATER ON DECK IN HEAD AND FOLLOWING SEAS

FLUSH DECK VESSELS





FOLLOWING SEAS

DECK AREA
Deck Area Included to
2/3 of LWL Forward of Stern
Exclude Area of House

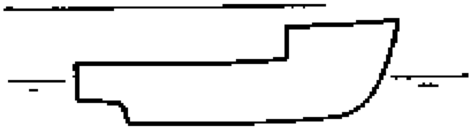
FREEBOARD
Average of Freeboard at
Stern and at Midships

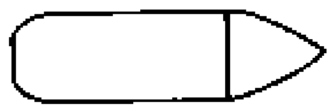
HEAD SEAS

DECK AREA
Entire Deck Area
Except area of House

FREEBOARD
Average of Freeboard at
Bow and at Midships

RAISED FOC'SLE VESSELS





DECK AREA
Deck Area Included to
Aft End of Foc'sle
Exclude Area of House

FREEBOARD
Average of Freeboard at
Stern and at Midships

DECK AREA
Deck Area is Area of Foc'sle Deck or Area of Forward Third of Vessel Which ever is Larger. In Order to be Considered a Raised Foc'sle, its Height Must be 4 Ft. Exclude Area of House on Focsle.

FREEBOARD
Average of Freeboard at Fore and Aft End of Foc'sle. If Height Less than 4 Ft. ,Use Average Freeboard at bow and Midships.

FIG. 6 - DEFINITIONS FOR USE IN LOW SPEED OPERATION WITH WATER ON DECK CRITERION

RAISED POOP VESSELS

FOLLOWING SEAS

DECK AREA
Deck Area to Include Poop Deck or Area to 1/3 of Length FWD of Stern. To be Considered a Raised Poop its Height Must Exceed 2 Ft.

FREEBOARD
Average Freeboard at Aft and FWD End of Raised Poop if Height Exceeds 2 Ft. if Lower, Average at Stern and Midships

HEAD SEAS

DECK AREA
Entire Area Excluding House Aft to Poop.

FREEBOARD
Same as for Flush or Raised Foc'sle as Appropriate

FIG 6. - CONCLUDED

Notes:

a. The phenomena of water buildup on deck are very complex. The development of a mathematical analysis was beyond the scope of this research project. The researcher's approach to the problem was to develop an empirical criterion based on model tests.

b. The influence of bulwark height and freeing port area is not well defined. In some cases the freeing port area allowed water to accumulate on deck faster than it could run off. It would be prudent to give special consideration to vessels with no bulwarks or very large freeing ports.

c. Certain assumptions made in order to determine the effective head of water on deck were arbitrary, but gave reasonable results.

d. The computer program used in calculating relative vessel motions and deck wetness used linear formulation which, while not applicable to large motions, produced reasonable agreement between measured and calculated pitch.

e. Since the calculation of the amount of water on deck is very empirical and subject to considerable uncertainty, a significant righting moment margin of safety is suggested in the criterion. The criterion requires that the intersection of the heeling and righting moment curves should occur at less than 85 percent of the maximum righting moment.

f. Wind heel could also occur simultaneously with water on deck. This has been considered in the margin allowance. However, a wind heel term can be added to the criterion if the margin is not considered to be sufficient.

4. OPERATION IN FOLLOWING SEAS AT MODERATE AND HIGH SPEED CRITERION.

The area under the righting arm curve from upright to 40 degrees heel, with the vessel poised on a wave with its crest centered at amidships must be equal to or exceed the area, E, determined by the equation:

$$E = C_7 \times V^{1/3}$$

where:

E = required area under the righting arm curve from upright to 40 degrees heel (ft-deg)
C_7 = energy coefficient determined from Fig. 7
V = vessel volume of displacement (cubic ft)

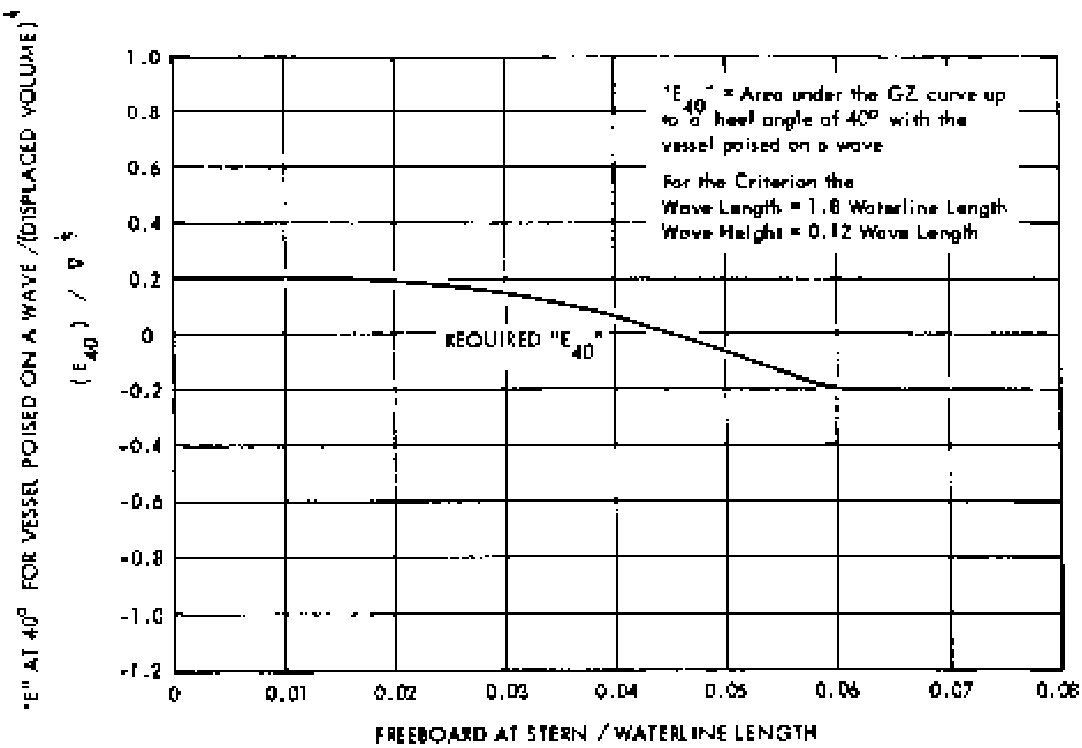


FIG. 7 - REQUIRED "E" AT 40 DEGREES WHEN POISED ON A WAVE

Notes:

a. For vessels up to about 250 feet in length on the loaded waterline, the wave used for the calculations should have a length (crest to crest) of 1.8 times the vessel loaded waterline length and a height (crest to trough) of 0.12 times the wave length.

b. The extreme wave steepness proposed for the criterion would not be sensible for vessels larger than about 250 feet in length. Consideration should be given to using modified wave dimensions on a case by case basis.

c. In extreme light load conditions, when the KG height is large relative to the draft (KG/H exceeds 1.4), large sway roll coupling moments may exist which could cause capsize. Therefore on a case by case basis, stability should be increased by requiring a greater value of the area, E, than that calculated by the criterion equation.

d. For vessels which are only expected to operate in areas of good weather or where a safe harbor is nearby, a smaller ratio of wave height/wave length could be used. This should be decided on a case by case basis.

e. If the vessel carries a cargo which can trap water (for example open pipe on the deck of a supply boat) or has a well deck structure which can trap water for significant periods, the weight of trapped water should be accounted for in the KG and the displacement used in the calculation of stability.

f. The researcher hoped to compare model test data for this criterion with the analytical capsize prediction methods developed at University of California (Paulling). However, the analytical method did not become available in time, so it was necessary to adopt a more empirical approach.

5. <u>WIND HEEL WITH ROLLING CRITERION</u>.

Each vessel should be designed so that the constant wind heeling moment line and the stillwater righting moment curve, when plotted as on Fig. 8, yields a range of positive stability to leeward (q_R) of at least 4.5 times the RMS roll angle (q_{RMS}) where:

$$q_R = \text{range of stability to leeward} = q_2 - q_1$$

q_2 = second intercept of the constant wind heeling moment line with the stillwater righting moment curve

q_1 = first intercept or mean heel angle

q_{RMS} = RMS roll angle, = $0.65 \times q_1$ in protected waters, = 10 degrees in open water

The constant wind heeling moment which defines the constant wind heeling moment line on Fig. 8 should be calculated using the equation:

$$K = 0.004 \times V^2 \times A \times h$$

where:

K = wind heeling moment (ft-lb)
V = wind speed (kts)
A = projected area above waterline (sq ft)
h = moment arm = vertical distance from the center of "A" to center of underwater lateral area or approximately one-half draft (ft)

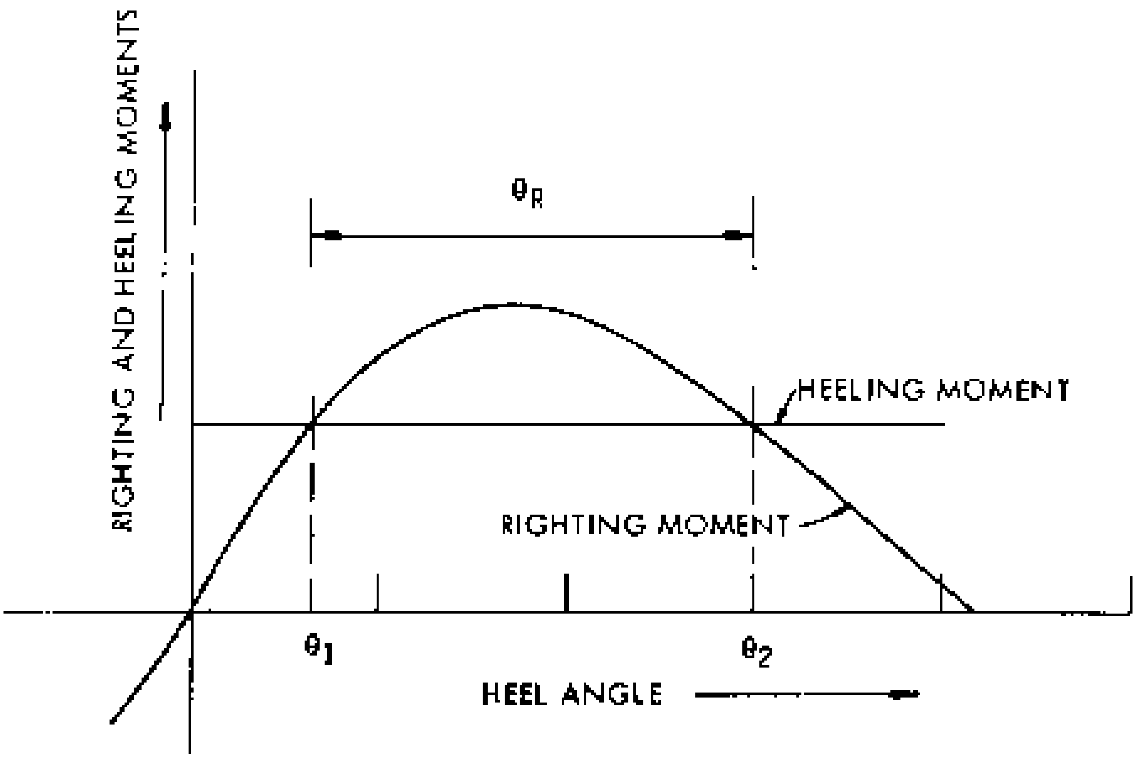


Fig. 8 - STABILITY REQUIREMENTS FOR WIND HEEL WITH ROLLING

Notes:

a. This classic wind heel criterion does not relate to the real dynamics of a ship rolling in gusting winds. It is highly idealized and very arbitrary in the selection of the initial heel angle. No model tests were conducted in the development of this criterion.

b. Computer analyses of non-linear roll equations of a ship in irregular waves and a gusting wind were used. Calculations were carried out in the time domain.

c. The effective wave slope for irregular waves was calculated from the summation of 10 sine waves with random phases and amplitudes and frequencies to approximate a Pierson-Moskowitz wave spectra.

d. Very little reliable quantitative information about wind loads varying with time was available. Therefore, it was assumed that the wind heel moment was constant for this study. It was assumed that the limiting wind variance is about 1.5 times the mean wind velocity. The wind moment was assumed to be independent of roll angle.

e. Capsizes do not necessarily occur when the vessel is subjected to a sharp wind gust after a large roll to windward. Rather, a capsize seems to be a random event which depends on the phasing of the roll, wave slope and wind gust.

f. If the vessel is expected to trap water on the lee side deck, the mean heeling moment due to this should be added to the wind heel moment.

g. The most arbitrary assumption in this criterion is the RMS roll angle selected for the criterion. This should be a function of the actual sea spectra, hull shape, roll natural period, damping devices such as bilge keels and the roll restoring moment at large heel angles. The selection of a RMS roll angle for use in this criterion deserves further study, including experimental verification.

h. IMO has developed a severe wind and rolling criterion for the intact stability of passenger and cargo vessels over 24 meters in length (SLF 28/13 Annex 5 dated 14 March 1983). That criterion supplements the criteria of the recommendation on intact stability for passenger and cargo vessels under 100 meters (Resolution A.167(ES.IV) as amended by Resolution A.206(VII)). It may be of benefit to compare stability parameters and relative levels of safety offered by these 11(0 criteria to this recommended wind heel with rolling criterion.