16. Draft increases at light displacement:

A. *KB* increases faster than *BM* increases.
B. *KB* increases faster than *BM* decreases.
C. *KB* increases slower than *BM* decreases.
D. *KB* increases slower than *BM* increases.

17. Draft increases at near full load displacements:

A. *KB* increases faster than *BM* increases.
B. *KB* increases faster than *BM* decreases.
C. *KB* increases slower than *BM* decreases.
D. *KB* increases slower than *BM* increases.

18. A small angle of inclination for a typical merchant form vessel is usually no more than about:

A. 3° B. 5° C. 10° D. 20°

19. It is assumed that a typical merchant form hull will have its metacenter behave similarly to that of a vessel with a cylindrical cross section during which of the following conditions:

A. Any angle of inclination
B. Small angles of inclination only
C. Large angles of inclination only
D. None of the above

20. The metacenter of a typical merchant vessel will initially fall and then commence to rise as draft increases from the initial light displacement condition.

A. True B. False

4
Calculating *GM*

For the ship's officer stability is mainly a problem of finding the height of the vessel's center of gravity above the keel, *KG*, (discussed in Chapter 2) and obtaining the height of metacenter, *KM* (discussed in Chapter 3). Subtracting *KG* from *KM* produces *GM*, metacentric height.

Note that *GM* is properly called metacentric height, and *KM* is properly called height of metacenter. See Figure 24. The amount of *GM* will directly indicate the ship's initial stability and how it will behave at sea (discussed in Chapter 1).

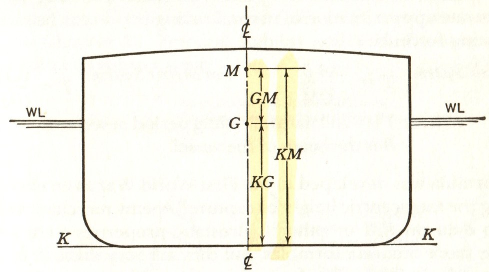


Figure 24. *KM* minus *KG* is equal to *GM*.

Stability Versus Stowage

Obviously a vessel cannot always be loaded in such as way as to produce a good *GM* or ideal amount of stability. In Chapter 1 we learned that excessive stability is just as dangerous as too little stability. *What is meant by a good* GM *or ideal stability is having a minimum stability consistent with safety.* The minimum required *GM* versus displacement or draft curve in the vessel's stability book is the guide to the minimum stability with which you are allowed to sail consistent with safety. Chapter 12, Practical Stability and Trim Considerations, discusses what a good *GM* is at length. The nature of many pieces of cargo may make it imperative to place a considerable number of heavy weights in the lower hold or on deck, thus producing a stiff or tender vessel. This means that you do all within your power to obtain as nearly ideal a stability as you can under the circumstances.

Stability calculations should be made if possible while the stowage plan is being made. It is easy to change the stowage on paper in order to produce good stability but, if the calculations are made while the ship is being loaded or after she is loaded, it may be too late to repair the damage by shifting water ballast.

Relation of *GM* to Rolling Period

We have already learned that the metacentric height, *GM*, has a definite relationship to the rolling of a vessel. That is, a stiff vessel, one with a large metacentric height will roll quickly whereas a tender vessel, one with a small metacentric height, will roll slowly.

After calculating the ship's *GM*, it is customary, and in some cases company policy, to calculate the vessel's *T*, (natural rolling period). A fairly accurate approximation of natural rolling period can be made from the following formula:

For English System: $T = \frac{.44\,B}{\sqrt{GM}}$ *For Metric System:* $T = \frac{0.79697\,B}{\sqrt{GM}}$

where: *T* is a full natural rolling period in seconds
B is the beam of the vessel.

This formula was developed in the First World War as an easy method of finding the metacentric height of captured enemy merchant vessels for which no data on *KM* or other hydrostatic properties were available. There are more accurate formulas, but they are very difficult to use and take a great deal of time; for these reasons, it is felt that the ship's officer has no need of them.

What is *T*, the natural rolling period? If a vessel were inclined in still water and released, the time it would take for the vessel to roll from port to starboard and back to port again would be its *T*, natural rolling period.

What is actually measured when a ship is underway at sea is the vessel's apparent rolling period. The apparent rolling period differs from the natural rolling period because at sea the vessel is not in still water and encounters waves. This results in the error or difference in the value between the *T* calculated and that measured by observation. This is why it is necessary to use other formulas.

At times the vessel is forced out of her apparent rolling period by waves which have a period remaining constantly different from that of the

rolling period of the vessel. This condition is known as forced rolling. It seldom continues for long periods of time, but it characterized by unexpectedly large hard rolls.

When the period of the ocean waves and the apparent rolling period of the vessel are exactly the same, synchronous rolling occurs. This results in very heavy rolling and, if maintained for a time, might result in the capsizing of a vessel. Synchronous rolling can be eliminated by: changing course; or, in some cases, changing speed; or altering the vessel's natural rolling period by ballasting or deballasting thus changing *GM*.

For example, a North Atlantic storm wave has a period of 8 to 10 seconds. It is desirable for a vessel to have a rolling period that is not equal to the wave period. Thus the tendency is to keep the *GM* as small as possible to result in a rolling period that is not equal to the wave period. You should inspect the rolling period formula to see how period changes as *GM* changes. If the frequency of occurrence of wave period is graphed with the frequency of occurrence of rolling period as shown in Figure 25, there will be an overlap (the cross-hatched area shown). This represents the occurrences of forced rolling. It can be seen that if the ship's rolling period is about equal to the wave period, the cross-hatched area will become larger and occasional forced rolling will turn into synchronous rolling. In Chapter 12, Practical Stability and Trim Considerations, we will deal with this subject again.

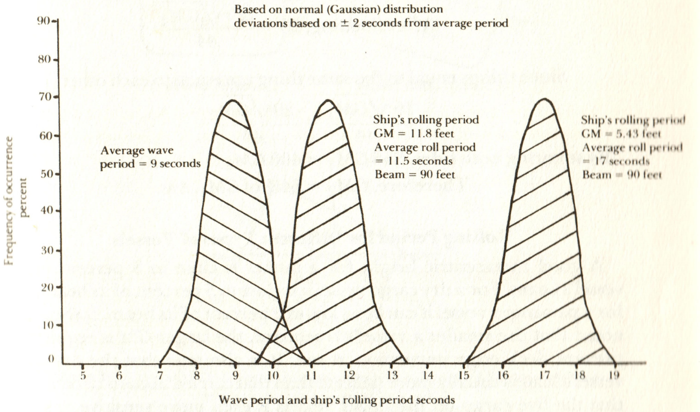


Figure 25. The wave period and the ship's rolling period. Note the cross-hatched area indicates forced rolling.

To obtain an approximation of a vessel's metacentric height, time as many rolls as possible, and do this at several different periods of the day. For example, in the morning take the total time elapsed for the vessel to make 20 complete rolls, that is, from starboard to port and back to starboard. Divide by 20 to get the average rolling period. Repeat this at noon and again at night. Average these results, and a rolling period which will be very close to the natural one should be obtained. By substituting this averaged natural rolling period for the ship into the formula, a fairly accurate *GM* can be obtained.

Proportionate Loss of Stability

The rolling period formula can be modified and used to obtain an idea of the proportionate loss or gain of stability. This principle can be best illustrated by an example as follows:

A vessel has a rolling period of 16 seconds. Her beam is 50 feet. Striking a submerged object, No. 3 hold is flooded. Her rolling period is now 20 seconds. What is the proportionate loss of stability?

$$T = \frac{.44\,B}{\sqrt{GM}} \text{ can be expressed as } B = \frac{T\sqrt{GM}}{.44}$$

$$\text{Before flooding, } 50 = \frac{16\sqrt{GM_1}}{.44}$$

$$\text{After flooding, } 50 = \frac{20\sqrt{GM_2}}{.44}$$

Since things equal to the same thing are equal to each other,

$$\frac{16\sqrt{GM_1}}{.44} = \frac{20\sqrt{GM_2}}{.44}$$

By squaring both sides, $256\,GM_1 = 400\,GM_2$

Therefore, $GM_2 = 64\%$ of GM_1. *Ans.*

Rolling Period for Different Types of Vessels

A good metacentric height for a tanker is close to 8 percent of the vessel's beam. For a dry cargo vessel it is close to 5 percent of its beam; and for a passenger vessel it can be as low as 2 percent of its beam. It should be noted that the smaller a vessel's freeboard, the larger *GM* is required to prevent deck edge immersion at sea. It is also true that the dry cargo vessel's load is usually more delicate than that carried aboard tankers, and that the live cargo on passenger vessels is even more sensitive to stress. Fortunately, as the *GM* is decreased angular accelerations on the ship are also decreased so stress on passenger ship's cargo and dry cargo vessel's

cargo can be reduced. Thus, the rolling periods for these vessels would be approximately:

Type of vessel	Beam (feet)	*GM* (feet)	Good rolling period (from formula)
Dry cargo	60	3.0	15 sec.
Tanker	70	5.6	13 sec.
Passenger	80	1.6	28 sec.

Effect of Negative *GM* on Vessels

If the center of gravity lies above the transverse metacenter (*G* above *M*), the vessel is in a state of unstable equilibrium, that is, she possesses a negative *GM*. There is no tendency for the vessel to right herself at small angles of inclination. An upsetting moment is formed, and the vessel will incline from the erect position. A negative *GM* does not mean that the vessel will capsize. It merely means that the vessel does not have any initial stability, and that she will incline to an angle where *B* has moved far enough toward the low side of the vessel to be once more in the same vertical line as *G*. Figure 26 illustrates this situation.

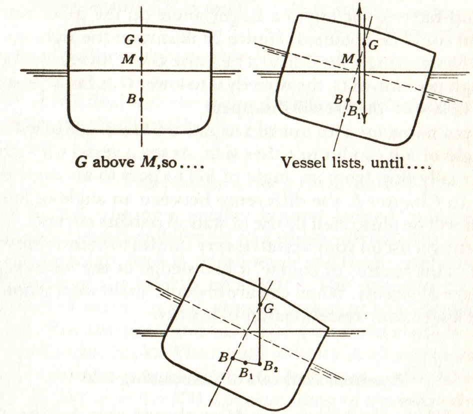
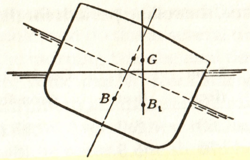


Figure 26. A negative *GM* means that the vessel will incline until *B* has moved once more in the same vertical line with *G*.

Apparently, then, a vessel can acquire a list not only by having its center of gravity off the centerline (see Figure 27) but also by having its center of



Equilibrium in an inclined position—
G and *B* in the same vertical line.

Figure 27. Center of gravity off the centerline will incline a vessel until *B* has moved in the same vertical line with *G*.

gravity too high in the vessel. This is not generally understood by ship's officers.

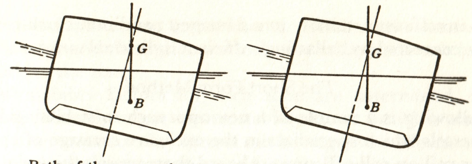
Different remedies must be applied in each of these two cases if the list is to be removed. In the case where *G* is off the centerline, the remedy is simple; shift weight over to the high side thus putting *G* back on the centerline and removing the list. In the case of a high *G* and a negative *GM*, a shift of weight from the low to the high side would be the worst thing to do. *G*, which was on the centerline, would then move over. The vessel would have to incline to a larger angle on the other side before equilibrium could be obtained. Figure 28 illustrates the right and wrong methods of correcting a list due to a negative *GM*. Obviously, if the list is due to a high position of *G*, the remedy is to lower *G* as far as possible. If *G* is lowered below *M*, the list will disappear.

The proper name for a list due to a negative *GM* is angle of loll. A vessel with an angle of loll can list to either side. At sea a vessel with a negative *GM* will actually flop from an angle of loll to port to an angle of loll to starboard. In Chapter 6, the difference between an angle of loll and an angle of list will be illustrated by use of statical stability curves.

In correcting a list on your vessel be very careful to determine the cause for the list. This means, of course, a knowledge of the location of your vessel's center of gravity. When you are in doubt about what action to take, always first lower your vessel's center of gravity.

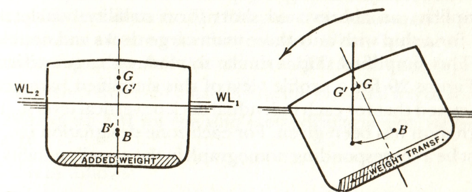
Practical Methods of Calculating *GM*

Today stability calculations are done aboard ship by one of three methods. Manual calculation is done by using either the long or short forms provided in the ship's stability booklet which must be approved by the U. S. Coast Guard or, as a third method, a stability computer made especially for the ship may be used. (Stability computers both of the electronic and mechanical types will be discussed in Chapter 10.) In this



Both of these vessels are listing because *G* was above *M* when the vessels were erect.

RIGHT WRONG



Change negative *GM* to positive *GM* by lowering *G*, and...

Shift weight to the high side. Result? Disaster, perhaps.

Figure 28. Right and wrong methods of correcting list due to negative *GM*.

chapter we will deal with the manual method of calculating *GM* by forms provided in the ship's stability booklet.

The Standard Long Form Method

Refer to the trim and stability booklet located in Appendix D. In calculating a vessel's stability by this direct method, the amount of dry cargo, reefer cargo, fuel oil, or salt water and fresh water is entered in the loading table of the booklet on sheet 7. The summary of each item is transferred to sheet 7A and summarized as to total displacement, *KG*, LCG, and free surface (both LCG and free surface will be discussed in detail later in this book). The mean saltwater draft corresponding to the total displacement is read from the hydrostatic table (sheet 3) of the stability booklet as is the *KM* corresponding to the mean draft. The *KG* subtracted from *KM* gives the *GM* of the vessel, uncorrected for free surface effects. The correction for free surface effects is obtained by dividing the total free surface by the total displacement and subtracting it from the uncorrected *GM* to give the corrected available *GM*. This *GM* should be compared with the required *GM* given on sheet 6 for the mean draft of the vessel. A *GM* available which is less than the *GM* required indicates insufficient stability in a damaged condition. Such a condition should be corrected by ballasting sufficient individual tanks.

The Short Form Method

The following is a sample of a new approach to stability calculations aboard vessels which specializes in the exclusive carriage of containers, barges, or roll-on roll-off cargo. Aboard these vessels the weights for an entire deck or level can be summed instead of individual compartments. The most confusing aspect of this relatively simpler and shorter method is the nomographs or Z-graphs introduced into the stability booklets and which are used to adjust the light ship KG to the actual KG.

For simplicity an abbreviated short form stability booklet has been prepared for a ship with only three main cargo decks and double bottom tankage. This simplified ship is similar to modern barge carriers now in use. See Figure 29 for a profile view of this simplified barge carrier. It should be noted that for each individual deck or vertical level in the ship, a *zone* designation has been given. For each zone designation the ship has, there must be a corresponding nomograph in the vessel's stability booklet.

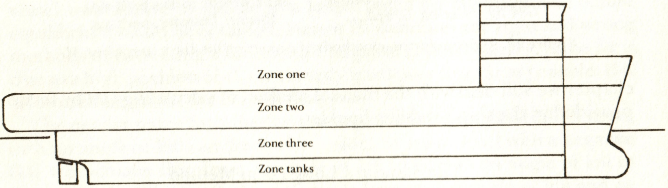


Figure 29. Profile view of simplified barge carrier used to illustrate the short form stability calculation.

The nomograph performs the calculation of GG' as described in Chapter 2. By inspection of a nomograph

$$GG' = \frac{w \times d}{\text{Displacement}} \equiv \text{Stability factor}$$

(see pages 56-57) we can easily account for displacement, Δ, and weight, w, loaded in the zone. The distance, d, is designated by the zone indication itself. GG' has actually been renamed stability factor. To use the nomograph the student should lay a transparent ruler or straight edge on the nomograph for the correct zone on which weight has been loaded. The straight edge should cross the tons loaded in the zone (left hand scale) and

cross the total displacement (canted center scale). At the intersection of the straight edge and the right hand scale, the value of the stability factor, GG', is read for the zone.

Once all stability factors for each zone are determined, they are summed algebraically to get the net stability factor (which is actually the net GG'). Note, some stability factors can be negative while others can be positive depending on assumptions of the naval architect who created the individual nomographs for the ship.

The net stability factor can be applied either to a base ship KG or a basic GM depending on the format of the short form calculations.

The Base Ship KG is either the light ship KG as determined by an inclining experiment described in Chapter 5 or an assumed value of KG chosen by the naval architect for convenience. When the base ship KG has the net stability factor applied to it, the actual KG for the ship is produced:

$$\text{Base ship } KG + \text{Net stability factor} = \text{Actual } KG \text{ of ship}$$

Then by looking up KM for the ship's total displacement, we can readily calculate GM.

Basic GM is as follows:

$$\text{Basic } GM = KM_{\text{actual}} - KG_{\text{assumed}}$$

You may obtain the basic GM by use of table, graph, or a computer printout of hydrostatic properties by entering with the total displacement of the ship in the same manner as KM is calculated. By applying the net stability factor to the basic GM, you get an actual GM as follows:

$$\text{Basic } GM + \text{Stability factor} = \text{Actual } GM$$
$$\text{where: Basic } GM = KM_{\text{actual}} - KG_{\text{assumed}}$$
$$\text{Stability factor} = \text{Net } GG'$$
$$\text{Actual } GM = KM_{\text{actual}} - KG_{\text{actual}}$$
$$\text{Prior to this we proved: } KG_{\text{assumed}} + \text{Stability factor} = KG_{\text{actual}}$$

So, you see that a basic GM is a disguised KM and must be determined by the ship's officer in a similar manner, such as entering a table or graph with the vessel's draft or displacement.

We account for the weight of the light ship, crew, and stores by using the nomograph designated as Zone 0 (or Zone Base Ship). We account for free surface in the ship's tanks also by using a nomograph which designates the free surface correction. Free surface (see Chapter 7) causes a virtual rise in the ship's center of gravity due to moving liquids in the ship. The free surface correction nomograph must be entered with the total sum of free surface moments (in the units of foot-tons) for the entire ship. The total free surface moments can be determined from the vessel's tank capacity and free surface data sheet.

Example of Short Form Calculation

The following example contains:

1. Instructions for the short form calculation.
2. Basic ship data sheet which includes:
   Mean draft
   Required *GM*
   Total displacement
   Basic *GM*

Note: Basic *GM* includes *KM*.

3. Nomographs for the profile of a simplified barge carrier Figure 29 which includes:

Main deck cargo	Zone 1
'Tween deck cargo	Zone 2
Lower hold cargo	Zone 3
Fuel and water tanks	Zone DT
Light ship, crew, & stores	Zone base ship
Free surface correction	Zone free surface

4. A short form stability work sheet.
5. Tank capacities and free surface data sheet. Given the following loaded condition:
   Zone 1 has 930 tons
   Zone 2 has 800 tons
   Zone 3 has 1,000 tons
   Tanks 1, 3, & 5 are full
   Tanks 2 & 4 are half-full
   Light ship, crew and stores are 9,470 tons
   Find the *GM* available, *GM* required, and *GM* in excess of required *GM* for the above loaded condition.

Instructions for Use of Short Form Stability Calculation

1. On the Short Form Stability Work Sheet (Table 4) enter the weights (long-tons) of cargo and liquid, next to the appropriate items. This breaks the loading down into the appropriate zones.

2. Enter under the Weight in Tons column (Table 4) the total displacement figure which is the sum of weights for all zones.

3. Using the total displacement figure determine the mean draft and basic *GM* from the Basic Ship Data Sheet (Table 1). Enter these values in the places provided.

4. Enter the stability factor nomographs to determine the stability factor which corresponds to each zone (Table 3) as follows:
   a. On each nomograph lay a transparent straight edge across tons loaded in the zone (left hand scale) and across total displacement (canted center scale).

   b. At the intersection of the straight edge and the right hand scale, read the value of the stability factor for that zone. Note: On the nomograph the stability factor is not designated as + or −, but the work sheet is designed to allow you to place it in only a + or − location.
   c. Obtain, in this way, the stability factor for zones 1 to 3, zone tanks, and base ship zone.
   d. In a similar way, using the total free surface moment (Table 2) for the vessel's slack tanks, and displacement, obtain the free surface stability factor to be entered in the labeled space on the work sheet.

5. The difference between + and − stability factors is the net stability factor which should be entered under the column of stability factor and under the value of basic *GM* in the summary box of the work sheet (Table 4).

6. Apply the net stability factor to the ship's basic *GM* to get the value of *GM* available.

7. The difference between *GM* available and required *GM* should be entered as excess *GM* in the summary section of the work sheet.

Table 1.
BASIC SHIP DATA SHEET

Mean Draft (feet & inches)	Required *GM* (feet)	Total Displace-ment (tons)	Basic *GM* (feet)	Mean Draft (feet & inches)	Required *GM* (feet)	Total Displace-ment (tons)	Basic *GM* (feet)
27′-00″	1.55	19,250	6.75	22′-09″	1.46	16,000	6.80
26′-09″	1.54	19,000	6.70	22′-06″	1.47	15,800	6.85
26′-06″	1.53	18,900	6.67	22′-03″	1.50	15,600	6.90
26′-03″	1.52	18,700	6.64	22′-00″	1.53	15,400	6.95
26′-00″	1.52	18,500	6.62	21′-09″	1.56	15,000	7.00
25′-09″	1.51	18,300	6.61	21′-06″	1.59	15,000	7.05
25′-06″	1.50	18,100	6.61	21′-03″	1.62	14,800	7.10
25′-03″	1.49	17,900	6.60	21′-00″	1.65	14,600	7.20
25′-00″	1.49	17,750	6.61	20′-09″	1.68	14,400	7.25
24′-09″	1.48	17,500	6.61	20′-06″	1.72	14,200	7.30
24′-06″	1.48	17,300	6.62	20′-03″	1.77	14,000	7.40
24′-03″	1.47	17,100	6.64	20′-00″	1.79	13,800	7.50
24′-00″	1.47	17,000	6.65	19′-09″	1.82	13,600	7.60
23′-09″	1.46	16,800	6.68	19′-06″	1.85	13,400	7.70
23′-06″	1.46	16,600	6.70	19′-03″	1.88	13,200	7.80
23′-03″	1.45	16,400	6.71	19′-00″	1.92	13,000	7.90
23′-00″	1.45	16,200	6.72	18′-09″	1.96	12,800	8.00

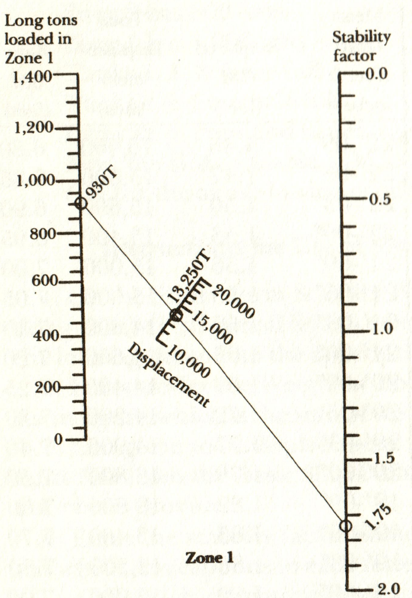
Mean Draft (feet & inches)	Required GM (feet)	Total Displace-ment (tons)	Basic GM (feet)	Mean Draft (feet & inches)	Required GM (feet)	Total Displace-ment (tons)	Basic GM (feet)
18′-06″	2.00	12,600	8.10	17′-06″	2.17	11,800	8.50
18′-03″	2.04	12,400	8.20	17′-03″	2.21	11,600	8.60
18′-00″	2.09	12,200	8.30	17′-00″	2.25	11,400	8.70
17′-09″	2.13	12,000	8.40				

Table 2.

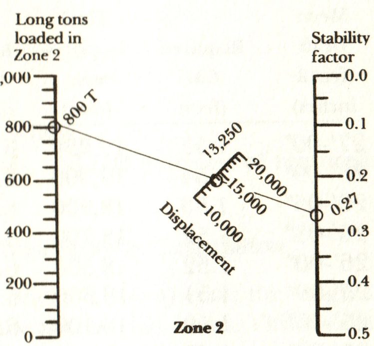
TANK CAPACITIES AND FREE SURFACE DATA SHEET

Tank	Contents	¼ Full (Tons)	½ Full (Tons)	100% Full (Tons)	Free Surface Moment* (Ft-Tons)
No. 1	Water	37½	75	150	1,000
No. 2	Fuel	50	100	200	1,000
No. 3	Fuel	137½	275	550	2,000
No. 4	Fuel	50	100	200	1,000
No. 5	Water	37½	75	150	1,000

Table 3

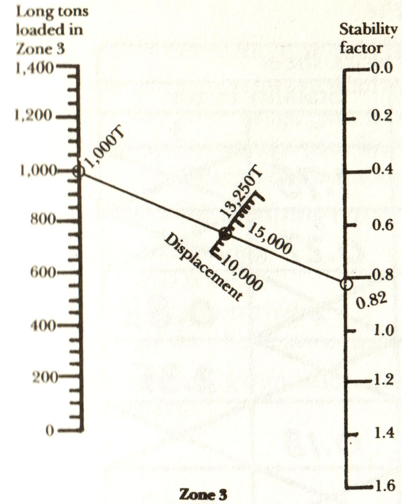


Zone 1

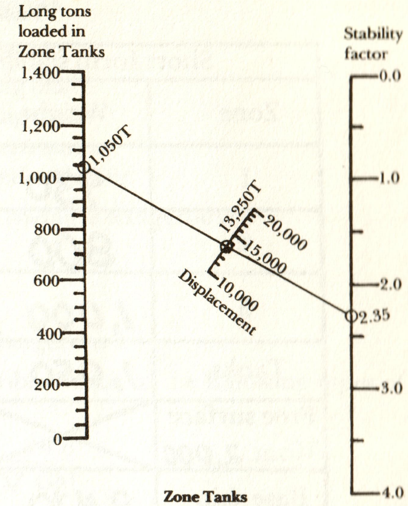


Zone 2

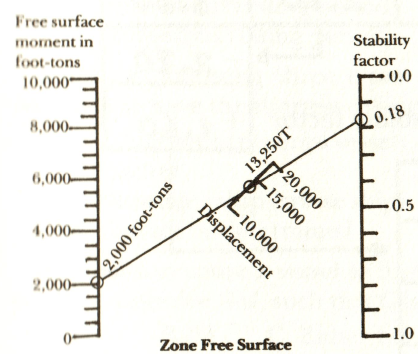
*For tanks 100% full or 100% empty use a free surface moment equal to 0.0 foot-tons.



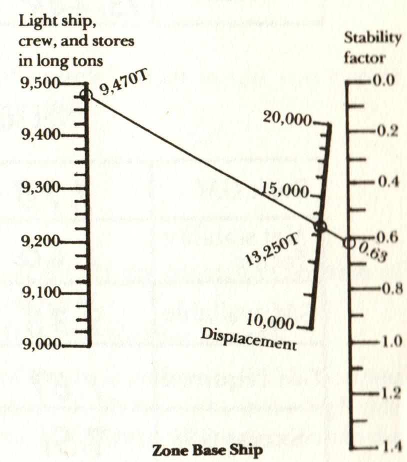
Zone 3



Zone Tanks



Zone Free Surface



Zone Base Ship

Table 4

Short form stability work sheet			
Zone	Weight	Stability factor −	Stability factor +
1	930	1.75	
2	800	0.27	
3	1,000		0.82
Tanks	1,050		2.35
Free surface Mom. 2,000		0.18	
Base ship	9,470		0.63
Totals	13,250	2.20	+ 3.80
		→	− 2.20
		Net stability factor	+ 1.60

Basic *GM*	7.78
Net stability factor	1.60
GM available	9.38
GM required	1.87
Excess *GM*	7.51

Instructions

1. Enter total weights in each zone in space provided.
2. Sum total weights to get total displacement.
3. Determine mean draft and basic GM from basic ship data sheet using total displacement.
4. Use nomographs to determine the stability factor for each zone. Enter stability factors in space provided.
5. The difference between + and − stability factors is the net stability factor. Apply this to basic *GM* to get *GM* available which is the actual *GM* corrected for free surface.

Questions

1. Stability calculations should be made:

A. Prior to the stowage plan being made
B. While the stowage plan is being made
C. After the stowage plan has been made
D. After all cargo has been loaded on board

2. Which of the following types of rolling is dangerous?

A. Natural rolling
B. Forced rolling
C. Synchronous rolling
D. All of the above are equally dangerous

3. The formula given below describes which of the following types of rolling periods?

$$T = \frac{.44\,B}{\sqrt{GM}}$$

A. Natural rolling period
B. Forced rolling period
C. Syncronous rolling period
D. Dangerous rolling period

4. Of the following three types of vessels, which would you expect normally to have the shortest rolling period?

A. Freighter (dry cargo vessel)
B. Tanker
C. Passenger ship (cruise ship)
D. Cannot be determined

5. What can cause a vessel to list? **I.** An off the centerline position of *G*. **II.** A negative *GM*, such that *G* is above *M*.

A. I B. II C. Either I or II D. Neither I nor II

6. Your vessel is listing. The cause of the list is unknown. The action you would take to correct the list would be to: **I.** Shift weight to the high side from the low side. **II.** Shift weight from a higher to a lower position in the vessel.

A. I B. II C. Either I or II D. Neither I nor II

7. If a vessel has a negative *GM* you would expect it to:

A. Be able to list to either side
B. Be able to list to one side only
C. Capsize
D. None of the above