U.S. Department
of Transportation
United States
Coast Guard

SHIP STABILITY

&

NAVAL ENGINEERING TOPICS

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Naval Architecture & Marine Engineering Section
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NOTABLE QUOTES

Know Your Ship

"Steps must be taken to insure that commanding officers of all vessels, particularly destroyers and smaller craft, are fully aware of the stability characteristics of their ships, that adequate security measures regarding watertight integrity are enforced, and that effect upon stability of free liquid surfaces is thoroughly understood." (Adm. Chester Nimitz letter to the fleet after a typhoon capsized 3 ships and caused major damage to 9 other ships with a total loss of 790 lives on 18 Dec 1944.)

After Damage

"After damage, there will be no time for making computations, nor will ship's personnel be in any frame of mind for careful analysis. Knowledge gained before damage, ... will enable use of good judgement in deciding what corrective measures are called for when the time for decision arrives." (NSTM Ch 079, Section 14, para 079-14.6)

"When the situation does not look good, remember... it can get worse. Determine how it can get worse and take steps to prevent it from happening."

Toughen the Ship to Resist Flooding

"It has been said that 90 percent of the work of damage control, the important part, is accomplished before damage, and only about 10 percent after the ship has been hit." (NSTM Ch 079, Section 14, para 079-14.2)

Overloading

"Overloading will seriously reduce the ship's power of survival." (NSTM Ch 079, Section 14, para 079-14.21)

"All members of the ship's company invariably want more than their allowances of material. The result is a slow reduction of the reserve buoyancy." (NSTM Ch 079, Section 14, para 079-14.19)

Ballasting Fuel Tanks

"There are no adverse effects of ballasting which cannot be overcome with good engineering practice. Sea water taken aboard as ballast must be pumped out before refueling with an attendant reduction in stability. It should be realized that the ship's resistance to damage is reduced during this period." (NSTM Ch 079, Section 14, para 079-14.28)

"There is a transient free surface created while ballasting. This is not dangerous if the athwartship width of the tank is less than one-half the beam of the ship and if the tanks are pressed full on completion." (NSTM Ch 079, Section 17, para 079-17.14)

Jettisoning Topside Weight

When stability is critical, booms and cranes should be used only to drag heavy weights across the deck. When a weight is lifted off the deck and swings free, its point of application is raised to the head of the boom, not the heel. This produces the same effect on GM as raising the weight all the way from the deck to the boom head." (NSTM Ch 079, Section 17, para 079-17.13)

Grounding

"I've spent 40 years learning how not to run aground; no one ever told me what to do if I did." ("A Ship Aground: The Do's and Don'ts", *Proceedings*, March 1974)

"Lightening of a newly stranded vessel is one of the worst and, unfortunately, one of the most common actions that can be taken. The removal of weights ... should never be attempted until the grounded condition is fully understood ..." ("A Ship Aground: The Do's and Don'ts", *Proceedings*, March 1974)

"However, one good kedge is worth three or four tugs." (NSTM Ch 079, Section 19, para 079-19.3)

Training

There is no substitute for intensive training and repetitive drills which provide the baseline knowledge that allows common sense, quick thinking and innovation to successfully combat a catastrophic situation. . . . Cross training is essential, especially in the minimum manned ships, in order to maintain the flexibility to handle any contingency. . . <u>All hands</u> must be proficient in damage control and fire fighting skills as any one at any time can be called upon to save a ship during a major conflagration." (COMNAVSEASYSCOM Washington DC msg on the lessons learned from the mine hit on USS SAMUEL B. ROBERTS, April 1988)

13 February 1945

From: Commander in Chief, U. S. Pacific Fleet
To: Pacific Fleet and Naval Shore Activities, Pacific Ocean Areas
Subj: Damage in Typhoon; lessons of

1. On 18 December 1944, vessels of the Pacific Fleet, operating in support of the invasion of the Philippines in an area about 300 miles east of Luzon, were caught near the center of a typhoon of extreme violence. Three destroyers, the HULL, MONAGHAN, and SPENCE, capsized and went down with practically all hands; serious damage was sustained by the CL MIAMI, the CVL's MONTEREY, COWPENS, and SAN JACINTO, the CVE's CAPE ESPERANCE and ALTAMAHA, and the DD's AYLWIN, DEWEY, and HICKOX. Lesser damage was sustained by at least 19 other vessels, from CA's down to DE's. Fires occurred on three carriers when planes were smashed in their hangars; and some 146 planes on various ships were lost or damaged beyond economical repair by the fires, by being smashed up, or by being swept overboard. About 790 officers and men were lost or killed and 80 were injured. Several surviving destroyers reported rolling 70° or more; and we can only surmise how close this was to capsizing completely for some of them. It was the greatest loss that we have taken in the Pacific without compensatory return since the First Battle of Savo.

2. In the light of hindsight it is easy to see how any of several measures might have prevented this catastrophe, but it was far less easy a problem at the time for the men who were out there under the heaviest of conflicting responsibilities. The important thing is for it never to happen again; and hence, while it is impracticable herein to go into all the factors involved and the experiences undergone, some of the outstanding lessons will be discussed.

3. Possibly, too much reliance was placed on the analysis broadcast from the Fleet Weather Central, Pearl Harbor. Weather data were lacking from an area some 240 to 300 miles in diameter (where the storm was actually centered); and the immediate signs of it in the operating area were not heeded early enough. Groups of the Third Fleet tried to avoid the storm center, but neither radically enough nor to best advantage, since their information as to its location and path was meager. Fleet damage and losses were accentuated by the efforts of vessels and subordinate commanders to maintain fleet courses, speeds, and formations during the storm.

Figure 4-2. Reprinted Nimitz Letter (Sheet 1 of 7)

Commanding officers failed to realize sufficiently in advance of the fact that it was necessary for them to give up the attempt, and give all their attention to saving their ships. There was a lack of appreciation by subordinate commanders and commanding officers that really dangerous weather conditions existed, until it was too late to make the preparations for security that might have been helpful.

4. The following conditions were typical during the typhoon:

a. Visibility zero to a thousand yards.

b. Ships not merely rolling, but heeled far over continually by the force of the wind, thus leaving them very little margin for further rolling to leeward.

c. Water being taken in quantity through ventilators, blower intakes, and every topside opening.

d. Switchboards and electrical machinery of all kinds shorted and drowned out, with fires from short circuits. Main distribution board in engine room shorted by steam moisture when all topside openings were closed to keep out water.

e. Free water up to two or three feet over engines or fireroom floor plates, and in many other compartments. It apparently all came in from above; there is no evidence of ships' seams parting.

f. Loss of steering control, failure of power and lighting, and stoppage of main propulsion plant. Loss of radar and of all ability to communicate.

g. Planes on carriers going adrift, crashing into each other, and starting fires.

h. Wind velocities and seas that carried away masts, stacks, boats, davits, and deck structures generally, and make it impossible for men to secure gear that had gone adrift, or to jettison or strike below topside weights when the necessity had become apparent. Men could not even stay up where they would have a chance of getting clear of the ship.

i. Maneuvering up to the time of sinking, in the attempt to maintain station, by all ships that were lost. DEWEY, saved by apparently a narrow margin, had given up the attempt.

j. The storm "taking charge" and making impossible various evasive and security measures which might have been effective at an earlier stage.

k. Testimony that the ships lost took a long roll to leeward, varying from 50° to 80°, hung there a little while, and then went completely over, floating a short time before going down.

5. The following tabulation does not purport to be the whole story, either for the ships mentioned or for the Fleet as a whole. It does, however, show that some ships, although of the same class as those lost, and undergoing the same punishment from the weather, survived nevertheless. It also indicates some differences in their condition and in the measures taken. Nobody can say, however, how far the outcome was due to these conditions and measures (or lack of them) and how far to blind chance.

Figure 4-2. Reprinted Nimitz Letter (Sheet 2 of 7)

6. See table below.

Class	All of FARRAGUT Class				Both FLETCHER Class	
	HULL	MONAGHAN	DEWEY	AYLWIN	SPENCE	HICKOX
Outcome	Sunk	Sunk	Survived	Survived	Sunk	Survived
Fuel on hand (approx.)	70%	76%	(?)	80%	15%	14%
Water ballast	No	No	Yes	(?)	Very little	Fully ballasted
Fuel to high side	No	No	Yes	Yes	No	(?)
Condition "A" taken*	Yes	(?)	Yes	(?)	No	(?)
Top weight jettisoned or below	No	(?)	Yes	(?)	(?)	(?)
Free water in ship	Yes	(?)	Some	Yes	Yes	Some
Rolled over and recovered	70°	(?)	75°	70°	Hung at 50°, then capsized	70°

*Condition ZEBRA

7. Various weaknesses were brought to light in our forecasting and dissemination of weather information, in structural details which permitted flooding with consequent loss of power, short circuiting, etc., and in the stability of some of our destroyers. Measures to correct these faults are being taken as far as possible. Yet the Commander in Chief, Pacific Fleet wishes to emphasize that to insure safety at sea, the best that science can devise and that naval organization can provide must be regarded only as an aid, and never as a substitute for the good seamanship, self-reliance, and sense of ultimate responsibility which are the first requisites in a seaman and naval officer.

8. A hundred years ago, a ship's survival depended almost solely on the competence of her master and on his constant alertness to every hint of change in the weather. To be taken aback or caught with full sail by even a passing squall might mean the loss of spars or canvas; and to come close to the center of a genuine hurricane or typhoon was synonymous with disaster. While to be taken by surprise was thus serious, the facilities for avoiding it were meager. Each master was dependent wholly on himself for detecting the first symptoms of bad weather, for predicting its seriousness and movement, and for taking the appropriate measures to evade, if possible, and to battle through it if it passed near to him. There was no radio by which weather data could be collected from over all the oceans and the resulting forecasts by expert aerologists broadcast to him and to all afloat. There was no one to tell him that the time has come to strike his light sails and spars, and snug her down under close reefs or storm trysails. His own barometer, the force and direction of the wind, and appearance of sea and sky were all that he had for information. Ceaseless vigilance in watching and interpreting signs, plus a philosophy of taking no risk in which there was little to gain and much to be lost, was what enabled him to survive.

Figure 4-2. Reprinted Nimitz Letter (Sheet 3 of 7)

9. Seaman of the present day should be better at forecasting weather at sea, independently of the radio, than were their predecessors. The general laws of storms and the weather expectancy for all months of the year in all parts of the world are now more thoroughly understood, more completely catalogued, and more readily available in various publications. An intensive study of typhoon and Western Pacific weather was made over a period of many years by Father Depperman at the Manila observatory, and his conclusions have been embodied in the material available to all aerologists. What Knight and Bowditch have to say on the subject is exactly as true during this war as it was in time of peace or before the days of radio. Familiarity with these authorities is something no captain or navigator can do without. The monthly pilot charts, issued to all ships, give excellent information as to the probable incidence and movement of typhoons. Stress on the foregoing is no belittlement of our aerological centers and weather broadcasts. But just as a navigator is held culpable if he neglects "Log, Lead, and Lookout" through blind faith in his radio fixes, so is the seaman culpable who regards personal weather estimates as obsolete and assumes that if no radio storm warning has been received, then all is well, and no local weather signs need cause him concern.

10. It is possible that too much reliance is being placed on outside sources for warnings of dangerous weather, and on the ability of our splendid ships to come through anything that wind and wave can do. If this be so, there is need for a revival of the age-old habits of self-reliance and caution in regard to the hazards from storms, and for officers in all echelons of command to take their personal responsibilities in this respect more seriously.

11. The most difficult part of the whole heavy-weather problem is, of course, the conflict between the military necessity for carrying out an operation as scheduled, and the possibility of damage or loss to our ships in doing so. For this no possible rule can be laid down. The decision must be a matter of "calculated risk" either way. It should be kept in mind, however, that a ship which founders or is badly damaged is a dead loss not only to the current operation but to future ones, that the weather which hinders us may be hindering the enemy equally, and the ships which, to prevent probable damage and possible loss, are allowed to drop behind, or to maneuver independently, may by the very measure be able to rejoin later and be of use in the operation.

12. The safety of a ship against perils from storm, as well as from those of navigation and maneuvering, is always the primary responsibility of her commanding officer; but this responsibility is also shared by his immediate superiors in operational command, since by the very fact of such command the individual commanding officer is not free to do at any time what his own judgement might indicate. Obviously no rational captain will permit his ship to be lost fruitlessly through blind obedience to plan or order, since by no chance could that be the

Figure 4-2. Reprinted Nimitz Letter (Sheet 4 of 7)

intention of his superior. But the degree of ship's danger is progressive and at the same time indefinite. It is one thing for a commanding officer, acting independently in time of peace, to pick a course and speed which may save him a beating from the weather, and quite another for him, in time of war, to disregard his mission and his orders and leave his station and duty.

13. It is here that the responsibility rests on unit, group, and force commanders, and that their judgement and authority must be exercised. They are, of course, the ones best qualified to weigh the situation and the relative urgency of safety measures versus carrying on with the job in hand. They frequently guard circuits or possess weather codes not available to all ships; and it goes without saying that any storm warnings or important weather information which they are not sure everybody has received should be retransmitted as far as practicable. More than this, they must be conscious of the relative inexperience in seamanship, and particularly hurricane seamanship, of many of their commanding officers, despite their superb fighting qualities. One division commander reports that his captains averaged eight years or less out of the Naval Academy and this is probably typical.

14. It is most definitely part of the senior officer's responsibility to think in terms of the smallest ship and most inexperienced commanding officer under him. He cannot take them for granted, give them tasks and stations, and assume either that they will be able to keep up and come through any weather that his own big ship can, or that they will be wise enough to gauge the exact moment when their task must be abandoned in order for them to keep afloat. The order for ships to be handled and navigated wholly for their own preservation should be originated early enough by the seniors and not necessarily be withheld until the juniors request it. The very gallantry and determination of our young commanding officers need to be taken into account here as a danger factor, since their urge to keep on, to keep up, to keep station, and to carry out their mission in the face of any difficulty, may deter them from doing what is actually wisest and most profitable in the long run.

15. Yet if the OTC is to be held responsible for his smaller vessels, he must be kept aware of their conditions, and the onus of this rests on the commanding officers themselves. Each of them must not only do whatever he is free and able to do for his ship's safety, but must also keep his superiors in the chain of command fully informed as to his situation. If there is anything in his ship's particular condition or in the way she is taking the weather that worries him, he should not hesitate to pass the information to his seniors. To let this be regarded as a sign of fairheartedness is to invite disaster, and seniors should indoctrinate their commanding officers accordingly. Going still further, it has been shown that at sea the severity of the weather may develop to a point where, regardless of combat commitments of the high command, the situation will require independent action by a junior without reference to his senior. This becomes mandatory if grave doubts arise in the mind of the junior as to the safety of his vessel, the lives of crew, and the loss of valuable government property and equipment.

Figure 4-2. Reprinted Nimitz Letter (Sheet 5 of 7)

16. The commanders of all echelons in the Pacific Fleet will impress upon their subordinates the necessity for giving full consideration to the adverse weather likely to be encountered in the Western Pacific, particularly the presence of tropical disturbances and the formation and movement of typhoons. In this connection, each commanding officer should refresh himself on Knight and Bowditch, not only as to the "Laws of Storm," but also as to ship-handling in heavy weather. In order to know what outside weather reports are broadcast and what he should be getting, each commanding officer should be familiar with Radio Weather Aids to Navigation (H. O. 206), and its confidential supplement, H. O. 206-C-S (A). This publication, as well as the Navy Weather Forecast Code No. 1 (CSP-946) should be on all DD's and DE's, etc. Even more important, a commanding officer should check up on his own ship's system of handling dispatches, to make sure that every incoming dispatch about prospective weather is viewed and understood by himself or some other officer with experience enough to grasp its significance. It should by no chance get buried in files and overlooked. This applies even more strongly to local observations. Preoccupation with the job in hand, or a desire not to disturb the skipper, should never result in disregard of a rapidly falling barometer.

17. Steps must be taken to insure that commanding officers of all vessels, particularly destroyers and smaller craft, are fully aware of the stability characteristics of their ships, that adequate security measures regarding watertight integrity are enforced, and that effect upon stability of free liquid surfaces is thoroughly understood. For preparing the ship against expected heavy weather, the basic written authorities are:

a. Damage Control Book for ship concerned.

b. Ballasting Instructions issued by the type Maintenance Administration concerned.

c. Notes on Stability of Ships in a Seaway (Pacific Fleet Maintenance Confidential Letter No. 7-44).

d. Booklet of Inclining Experiment Data for either ship or class. Issued by BuShips.*

e. Damage Control Instructions (FTP 170-B).**

f. "Derangement of Electrical Equipment Caused by Ventilation Conditions." NAVSHIPS Bulletin of Information No. 12, p. 9.

g. Stability and Compartmentation of Ships (C&R Bulletin No. 14).***

*BuShips is now NAVSEASYSCOM.

**These instructions no longer exist.
See NWP 62-1, Surface Ship Damage Control.

***This bulletin no longer exists.

Figure 4-2. Reprinted Nimitz Letter (Sheet 6 of 7)

STABILITY
(PCO/PXO)

UNIT OBJECTIVES

INTACT STATIC STABILITY:

• Recall and comprehend stable, neutral, and unstable equilibrium, the transverse righting arm, and the metacentric height as they relate to initial transverse stability.

• Recall and comprehend the method and purpose of performing an inclining experiment and the determination of the ship's actual vertical position of the center of gravity.

• Recall and comprehend the righting moment and its dependence on the metacentric height.

• Recall and comprehend the cross curves of stability and apply them to the construction of a static stability curve.

• Recall and comprehend the range of stability, the location of the maximum righting arm obtained from a static stability curve, and their significance relative to the ship's transverse stability.

• Recall and comprehend the static stability curve and apply corrections to the curve for vertical and transverse changes in the position of the ship's center of gravity.

• Comprehend the signifcance of lolling.

DAMAGED STABILITY:

• Recall and comprehend free surface, pocketing, surface permeability, and free communication as they relate to the transverse stability of a ship.

• Apply the effects of free surface and free communication as corrections to the static stability curve.

• Recall and comprehend the effects of grounding (and docking) on the ship's stability.

INTACT DYNAMIC STABILITY:

• Recall and comprehend heeling moment, heeling energy, righting moment, and righting energy as they relate to dynamic stability and the construction of the dynamic stability curve.

• Apply the concepts of dynamic stability to the determination of the dynamic stability characteristics of floating ships.

SITUATION ASSESSMENT AND CORRECTIVE MEASURES:

• Recall and comprehend risks associated with negative GM and list.

• Recall and comprehend the cause and behavior of the combination of negative GM and off-center weight.

• Recall and comprehend measures to improve GM and overall stability.

DRYDOCKING AND CONTRACT ADMINISTRATION

- Recall and comprehend drydock calculations
- Understand timeline and development of specification

ENVIRONMENTAL COMPLIANCE

- Recall and understand procedures and concerns when dealing with hazardous materials.
- Refresh environmental issues.

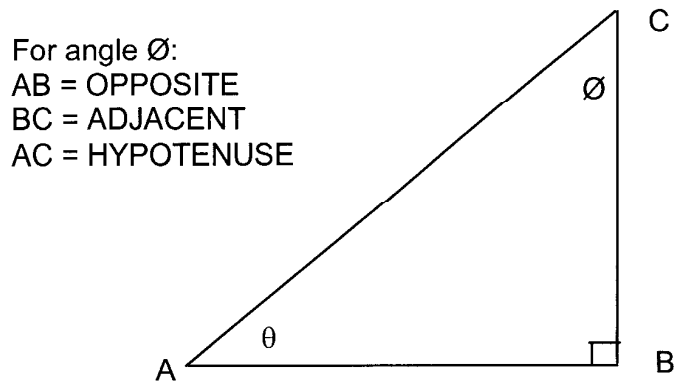
ENGINEERING ADMINISTRATION

- Understand engineering programs

Chapter One
Fundamentals

A. Trig Review
B. Basic Principles
C. Buoyancy
D. Reserve Buoyancy
E. Center of Gravity
F. KG Worksheet
G. Movement of G
H. Limiting KG Diagram

A. TRIGONOMETRY REVIEW



Cosine (θ) =		Cosine (Ø) =	
Sine (θ) =		Sine (Ø) =	
Tangent (θ) =		Tangent (Ø)	

Why do we review it for stability class?

Trigonometry is the means by which we can say that (1) GM is a measure of a ships initial stability, (2) it is the means by which we correct righting arm curves for actual loading conditions, (3) and it is the means by which we can determine angles of list caused by off-center weights.

A typical example of trigonometry in action is the use of the stadimeter to determine the distance to another ship.

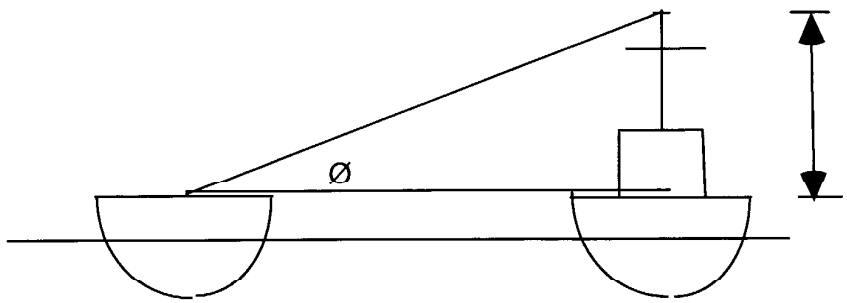


Figure 1-1 Stadimeter

The masthead height of the other ship is known, the stadimeter measures the angle from your ship to the top of the masthead. Using the relationship:

$$\frac{[\text{masthead height}]}{[\text{distance between the ships}]} = \text{tangent of } Ø$$

the distance between the ships can be determined.

The stadimeter does the calculation internally after you enter the masthead height of the other ship and it produces readout of the distance between the ships.

The value of the sine of an angle varies from 0 to 1 as the angle goes from 0 to 90 degrees. The value of the cosine varies from 1 to 0 as the angle goes from 0 to 90 degrees. If you get the sine or cosine of an angle equal to something greater than 1, you have done something wrong and should recheck your work (or buy a new calculator).

How to find values of sine, cosine, tangent:

- Use table 079-1 in NSTM
- Handheld calculator
- Sometimes provided with cross curves of stability (sine only)

B. Basic PRINCIPLES

1. **Force**: Push or pull. It tends to produce motion or a change in motion.

   Units: Long Tons (LT), pounds (lbs)

   The two basic forces primarily used in ship stability are the weight of the ship (W or D) acting vertically downward and the buoyant force (F_b) acting vertically upward.

2. **Weight**: A force.

   Units: Long Ton = 2240lbs.

   Abbreviated as tons. Tons are used to define how much weight is added, removed or shifted onboard. Displacement is also measured in tons.

3. **Distance**: Used to define position relative to a fixed reference point, like the keel. Also used to describe dimensions.

   Units: feet.

4. **Moment**: A **force** (weight) multiplied by a distance.

Units: foot-tons.

A unit that measures the effect caused by the position of a weight. Moments will be used to find the center of gravity of objects. The effect of a moment is to cause rotation of the object about some point.

5. **Weight/Volume Constants**: Used to find the weight of a volume of liquid when its dimensions are known. Used to find the weight of flooding or liquid cargo

Units: Cubic feet per ton, gallons per ton, pounds per cubic feet, pounds per gallon..

Liquid	**lbs/ft^3**	**Tons/ft^3**	**lbs/gal**	**gal/ton**
Salt water	64.0	1/35	8.56	261.8
Fresh water	62.4	1/36	8.32	268.5
Diesel fuel	52.0	1/43	6.96	322.0
JP-5	50.8	1/44	6.79	330.0
Ice (sw or fw)	57.0	1/39	7.62	294.0

Table 1-2 Important Fluid Constants

Example: a 20 feet wide by 20 feet long by 8 feet high compartment is ¾ full with salt water. What is the weight of the salt water in the compartment?

Solution: $\frac{\text{cubic feet}}{\text{cubic ft / ton}}$ = tons so $\frac{20' \times 20' \times 6'}{35}$ = 68.57 tons

Example: How much does 1000 gallons of diesel fuel weigh in long tons?

Solution: (1000 gallons) x (6.96 lbs/gallon) ÷ (2240 lbs/ton) = 3.1 long tons

or (1000 gallons) ÷ (322 gallons/ton) = 3.1 long tons

C. BUOYANCY

The principle of buoyancy was first described by "Archimedes' Principle" that states:

A solid object when immersed in a liquid experiences an up thrust equal to the weight of the liquid displaced.

This "up thrust" is the force of buoyancy.

The "Law of Flotation" states that when an object is floating freely in a fluid, the weight of the object equals the force of buoyancy acting on the object.

If we combine the above two principles we can determine the weight of a floating object by knowing what fluid it is floating in, and the volume of the object submerged in the fluid.

Object Weight = Buoyant Force = Submerged Volume x Fluid Specific Weight

or mathematically:

$$\mathbf{W} = F_b = \mathbf{V}_{subm} * \gamma$$

where:

$\mathbf{V}_{subm}$ = the submerged volume (only that portion of the floating object that is below the fluid).

γ = the "Specific Weight" (density times gravity) of the fluid and is the <u>weight per volume</u> of the fluid (i.e. g_{sw} = 64.0 lb/ft^3). The Greek symbol "gamma" is used.

<u>Example</u>: A rectangular barge 100 feet long, 40 feet wide, and having a draft of 10 feet is floating in salt water. Determine the barge's weight (also called "displacement")

<u>Solution</u>:

Submerged volume of barge = (100 ft)(40 ft)(10 ft)
= 40000 cu ft

The specific weight of salt water = 1 ton/35 cubic ft

The weight of the water displaced by the barge
= (40000 cu. ft.) x (1 ton/35 cu. ft)
= 1143 tons

Then according to Archimedes Principle and the Law of Flotation, the barge's weight is equal to the weight of the water displaced or 1143 tons.

IMPORTANT NOTE

If the barge transits into fresh water, it still <u>weighs</u> the same (1143 tons); its submerged volume will change (increase) to account for the change in the density of the fluid (decreased); i.e., the barge's draft will increase (it will sink deeper in the water).

For the above example, if the barge transits into fresh water its draft will be 10.29 ft.

1143 tons x (36 cu. ft/ton of fresh water)
= 41148 cu. ft. displaced volume

41148 cu. ft ÷ (100 ft)(40 ft) = 10.29 ft = draft in fresh water

The calculation of a ship's submerged volume is easily done by hand for rectangular barges, however for typical hull shapes the submerged volume must be calculated/estimated using computers.

On a ship's hull, the force of buoyancy is the resultant of all the forces due to water pressure (hydrostatic pressure) acting on the underwater portion of the ship's hull. All the horizontal pressure forces acting on the hull cancel each other out and the vertical forces can be combined into one force acting vertically upward at the center of the underwater volume, known as the Center of Buoyancy (B).

The resultant Force of Buoyancy always acts at the center of the underwater volume.

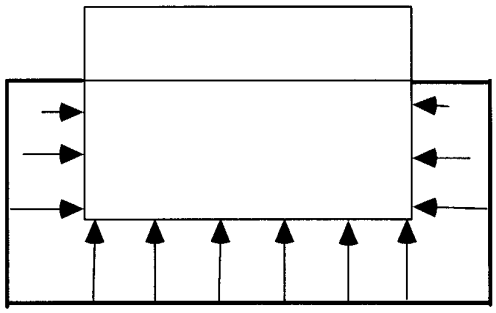


Figure 1-3 Hydrostatic Forces Acting on a Rectangular Barge

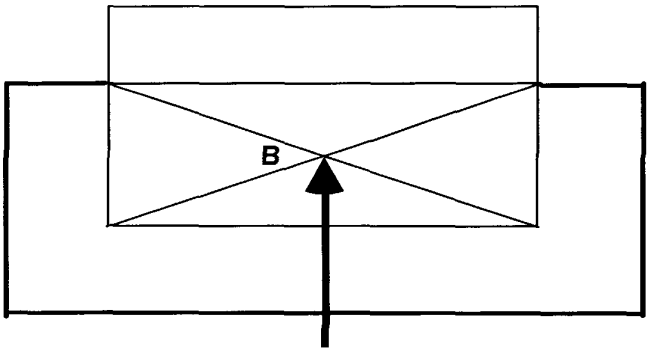


Figure 1-4 Force of Buoyancy Acting at the Center of Buoyancy (B)

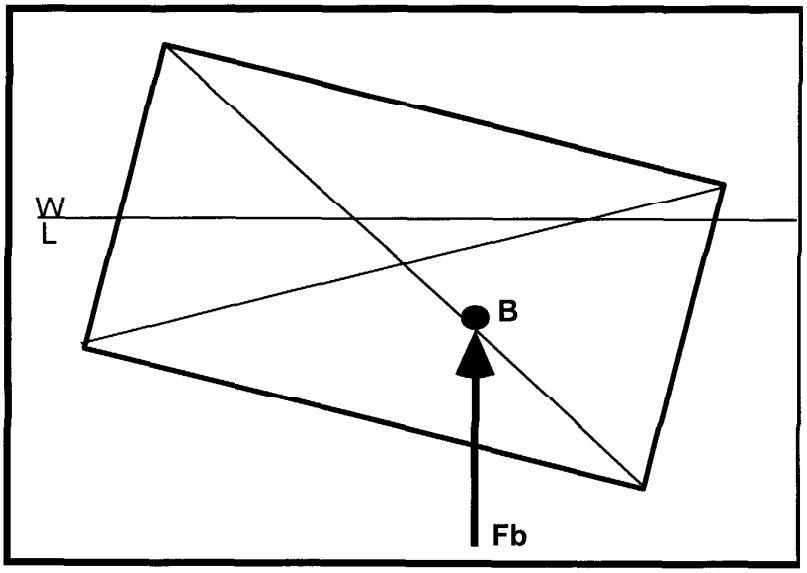


Figure 1-5 Center of Buoyancy moved to the new Center of the Underwater Volume

All objects in a liquid have a buoyant force acting on them. The weight of the object and the volume of the liquid that the object can displace determine whether they float or sink.

For Floating Objects: Weight = Buoyant Force

For Objects that Sink: Weight > Buoyant Force

Submerged Weight = Dry weight - Buoyant Force

When a weight is added to a floating ship, the ship sinks into the water to compensate; it must displace more water (increase the buoyant force) to make up for the increase in weight (drafts increase). Just the opposite happens if a weight is removed; upon removal, the buoyant force is suddenly greater than the weight and it pushes the ship up out of the water until the buoyant force decreases to equal the weight (drafts decrease).

D. RESERVE BUOYANCY

The volume of the ship's hull between the waterline and the uppermost watertight deck is known as reserve buoyancy. Expressed as a percentage, reserve buoyancy is the ratio of the volume of the above-water body to the volume of the underwater body.

Freeboard is a rough measure of reserve buoyancy. Freeboard is the distance in feet from the waterline to the weather deck edge, and unless otherwise stated is usually the freeboard amidships.

When weight is added to a ship, draft and displacement increase in the same amount that freeboard and reserve buoyancy decrease. The reserve buoyancy is the buoyant volume available to absorb added weight and/or damage. A substantial amount of reserve buoyancy is essential to the seaworthiness of a ship. If a ship is overloaded, the reserve buoyancy is reduced, and consequently the amount of damage the ship is able to absorb is also reduced. If there is not sufficient reserve buoyancy to compensate for added weight, the ship will sink.

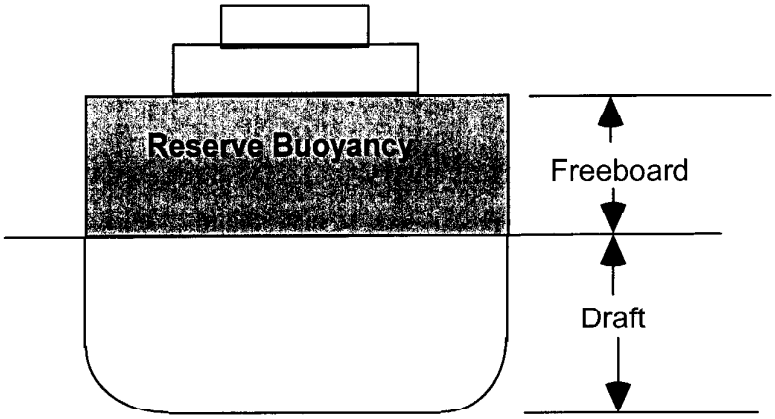


Figure 1-6 Reserve Buoyancy

E. CENTER OF GRAVITY

In a ship, the center of gravity is the point at which the force of gravity (weight) of the ship's structure and its contents may be considered to act vertically downward. The center of gravity of the ship is designated by the letter "G". The weight of the ship which acts at G is designated by "W" or "D" The center of gravity is a single point located three dimensionally in the ship.

We are primarily concerned with the vertical height of the center of gravity ("VCG" or "KG"). "K" is the "baseline" for the ship, which is usually located very close to the keel of the ship (within inches). It is just a reference point that the other points ("G", "B", etc.) are referenced to. **The vertical height of the center of gravity has the biggest effect on the stability of the ship.**

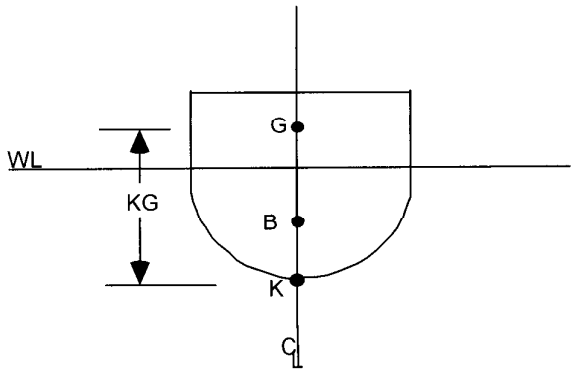


Figure 1-7 Location of Center of Gravity

We can locate the vertical center of gravity using the KG Calculation Worksheet. The vertical center of gravity for a ship is also given for some specific loading conditions in the ship's Damage Control Book or Stability and Loading Data Booklet.

The Full Load example shown is for a 270' WMEC, the Minimum Ops example is for a 180' WLB. Notice that these examples look a lot like the KG Calculation Worksheet, with items, item's height above baseline, and vertical moment for the item. The "Virtual Center of Gravity" is the KG corrected for the effects of free surface due to any liquids aboard the ship. Free Surface effect will be discussed later in the text.

F. KG WORKSHEET

Below is a typical KG calculation worksheet. The item, weight and height above a reference point (typically the baseline) must be known prior to completion. We will use a similar format to compute vessel list later in the text.

Item	Weight (LT)	Height (ft)	Vertical Moment (ft*LT)
totals		**xxxx**	

Figure 1-8 KG Worksheet

The new KG is computed by dividing the total vertical moment by the total weight.

$$KG = \frac{\text{total vertical moment}}{\text{total weight}}$$

Weights used must be consistent, and are typically in long tons. The height is measured from a reference point, typically the height above the baseline.

Below is an example of computing a vessel's "composite" KG from several items.

Item	Weight (LT)	Height (ft)	Vertical Moment (ft*LT)
Hull	85	11	935
Gun	1	15	15
Deckhouse	10	20	200
Boat	2	17	34
Fuel	6	3	18
totals	**104.0**	**xxxx**	**1202.0**

The "composite" KG is then computed by:

$$KG = \frac{\text{total vertical moment}}{\text{total weight}} = \frac{1202.0 \text{ ft*LT}}{104.0 \text{ LT}}$$

$$= 11.56 \text{ ft}$$

This is the location above the baseline of the hull/gun/deckhouse/boat/fuel combination. As

these weights (and their locations) change (i.e. the fuel), so changes the location of KG.

Below is an excerpt from the DC book of a 270′ WMEC with the cutter at the Full Load Condition.

SUMMARY OF FULL LOAD CONDITION

WITH DIESEL OIL FOR FUEL

	TONS	KG	Vertical Moment	LCG*	Long'l Moment	Free Surface
Light Ship	1468.3	18.82	27631	1.72	2526	
Crew & Effects	12.8	25.10	321	-4.95	-63	
Provisions & Stores	17.4	17.78	309	-1.27	-22	
Ammunition	7.7	28.91	221	-57.93	-446	
Helicopter & Support	10.3	33.21	341	49.63	509	
Diesel Oil	248.3	6.91	1716	7.78	1932	290
Hydraulic & Lube Oil	7.8	7.94	62	38.15	296	2
JP-5	59.5	10.89	648	70.57	4201	104
Fresh Water	31.8	10.79	343	-46.95	-1491	45
Clean Ballast	0.0	0.00	0	0.00	0	0
TOTAL Full Load Condition	1863.8	16.95	31591	4.00	7447	441
Inclining Exp. Margin		+0.20				
Free Surface Correction (441/1863.8)		+0.24				
Virtual Center of Gravity (KGv)		17.39				

SEE FOLLOWING PAGE FOR DATA WHEN JP-5 IS FUEL

*LCG (+) AFT (-) FWD OF AMIDSHIPS

Figure 1-9 WMEC Full Load Condition

Below is an excerpt from the DC book of a 270′ WMEC with the cutter at the Minimum Operating Condition.

SUMMARY OF MINIMUM OPERATING CONDITION

WITH DIESEL OIL FOR FUEL

	TONS	KG	Vertical Moment	LCG*	Long'l Moment	Free Surface
Light Ship	1468.3	18.82	27631	1.72	2526	
Crew & Effects	12.8	25.10	321	-4.95	-63	
Provisions & Stores	5.8	17.78	103	-1.27	-7	
Ammunition	2.5	28.91	74	-57.93	-148	
Helicopter & Support	10.3	33.21	341	49.63	509	
Diesel Oil	82.8	6.73	557	43.02	3561	153
Hydraulic & Lube Oil	5.5	4.35	24	38.61	212	16
JP-5	19.9	9.18	183	68.86	1369	45
Fresh Water	21.2	10.00	211	-46.95	-992	30
Clean Ballast	138.5	6.35	879	33.40	4625	0
TOTAL Minimum Operating Condition	1767.5	17.16	30323	6.56	11587	244
Inclining Exp. Margin		+0.20				
Free Surface Correction (244/1767.5)		+0.14				
Virtual Center of Gravity (KGv)		17.50				

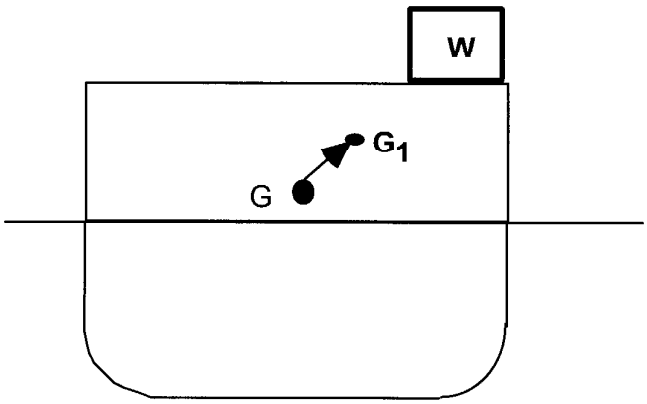
SEE FOLLOWING PAGE FOR DATA WHEN JP-5 IS FUEL

*LCG (+) AFT ( ) FWD OF AMIDSHIPS

Figure 1-10 WMEC Min Operating Condition

G. MOVEMENT OF THE CENTER OF GRAVITY

As weights are added, removed, or shifted on a ship, the center of gravity also moves. How far and in what direction the center of gravity moves depends upon the size of the weight and upon the location of the weight. When a weight is added to a ship, the center of gravity moves towards the weight addition. When a weight is removed from a ship, the center of gravity moves away from the weight removal. When a weight is shifted on a ship, the center of gravity moves parallel to, and in the same direction as the weight shift.



Figre 1-11 Movement of G due to Weight Addition

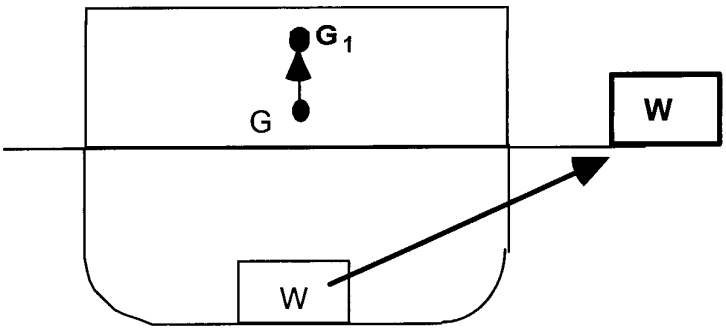


Figure 1-12 Movement of G due to a Weight Removal

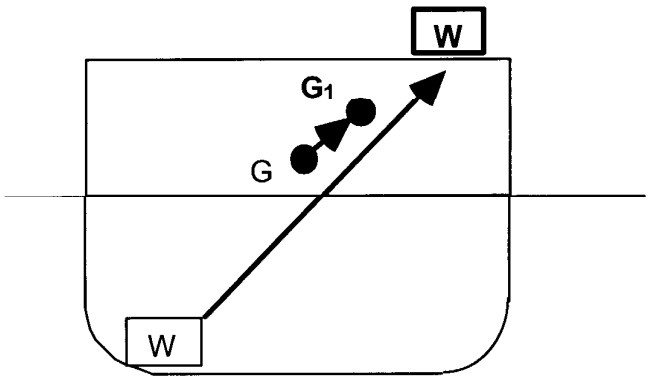


Figure 1-13 Movement of G due to a Weight Shift

We can track the vertical motion of the center of gravity (KG) using a KG Calculation Worksheet, starting at a known condition (Full Load, Minimum Ops) and adding, removing, shifting weights as necessary to get to your actual loading condition. The following examples, using the Full Load Condition for the 270' WMEC previously given, demonstrate

how to calculate the KG for a weight addition, removal, and shift. The heights of the various decks of the ship are given in the DC Book. **Use the value of KGv as your starting value because this takes into account the effects of free surface in your tanks on your stability.** Remember, this is calculating the vertical height of the center of gravity.

Let's look at three examples: a weight addition, a weight removal, and a weight shift.

Example 1: Add 500 people to the flight deck of a 270' WMEC

Item	Weight (LT)	Height (ft)	Vertical Moment (ft*LT)
270' @ full load	1824.3	17.25	31469.175
Add 500 people	33.48	35	1171.8
totals	1857.78	xxxx	32640.98

Solution:

Weight = 500 people * 150 lbs/person ÷ 2240 lbs/ton = 33.48 tons

Height= 35 ft above baseline
for flight deck (from DC Book)

Example 2: Remove helicopter and support from 270' WMEC

Item	Weight (LT)	Height (ft)	Vertical Moment (ft*LT)
270′ @ full load	1824.3	17.25	31469.18
Remove helo/support	-10.3	33.21	-342.06
totals	1814.00	xxxx	31127.11

Solution:

Weight = 10.3 tons (from DC Book)

Height = 33.21 ft above baseline (from DC Book)

Example 3: Shift 500 people from flight deck to main deck
(your starting point here is displacement and KG with people already on flight deck, i.e. example 1 above)

Item	Weight (LT)	Height (ft)	Vertical Moment (ft*LT)
270′ with 500 on flight deck	1857.78	17.57	32641.19
Remove 500 people from flight deck	-33.48	35	-1171.80
Add 500 to main deck	33.48	25	837
totals	1857.78	xxxx	3206.39

Solution:

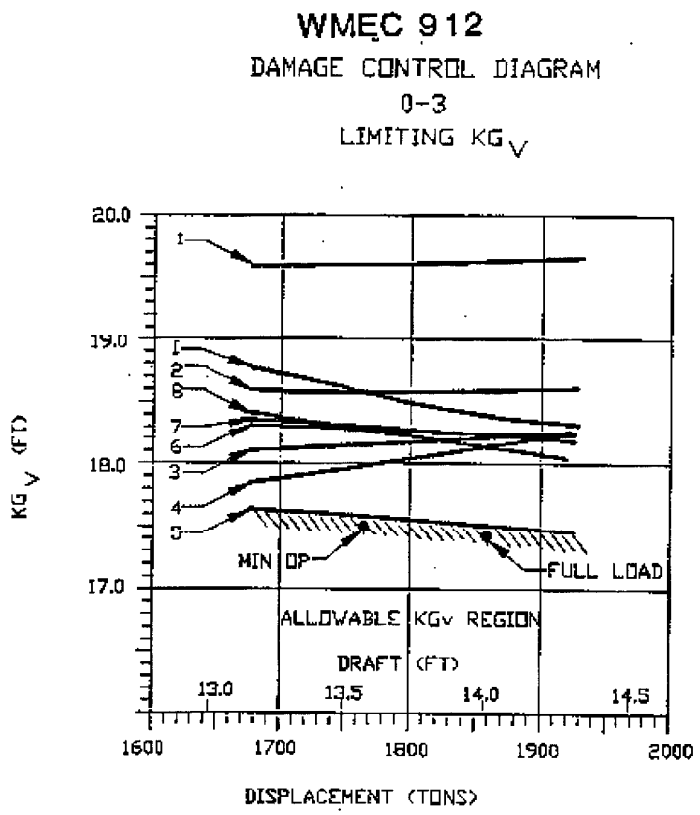
Weight = 33.48 tons

Height = 35 ft for flight deck
= 25 ft for main deck

So your center of gravity has moved... Does that movement help or hurt your stability?? What tools do we have available to help us?

H. LIMITING KGV DIAGRAM

Basically, any upward movement in the center of gravity reduces the ship's stability. (We will explain why in the next chapter). The question is...When does your stability become critical? How high can G go? The Limiting KGv diagram (or Safe Stability Diagram for some cutters) tells us how high G can go before our survivability becomes endangered. The diagram is entered with your current displacement (or mean draft) and the KG of the ship based upon its actual loading condition. That point is plotted on the diagram and if it lies <u>above</u> any of the lines for the scenarios listed, the ship will not be able to survive that scenario (either various flooding scenarios or a beam wind). The important point here is that you enter the diagram <u>prior to</u> any damage, and the diagram tells you what damage you can, or cannot, survive.



CASE	
I	INTACT CONDITION 100 KNOT BEAM WIND
	TWO COMPARTMENT FLOODING
1	FR 12-47
2	FR 26-82
3	FR 47-103
4	FR 82-165
5	FR 103-186
6	FR 165-207
7	FR 186-228
8	FR 207-AFT

Figure 1-14 Limiting KG_v Curve for 270′ WMEC

Figure 1-14 shows the position of KG after the weight addition example previously shown in this chapter (270' WMEC: add 500 people to flight deck).

You have exceeded the limiting displacement of the ship. This means that you are cutting into the safety margin of the ship for reserve buoyancy and/or the structural strength of the ship. You have also exceeded the limiting KGv for case #5, two compartment flooding between frames 103 and 186. If you suffer damage and flood that space, it is unlikely that the ship will remain upright.

Remember, this diagram tells you what damage you can or cannot survive based on your loading condition prior to damage. If you exceed your limiting KG_v, it does not mean you are in imminent danger of capsizing. *It means that if you get damaged your stability is critical and you are likely to capsize (depending on how much you have exceeded the limit).*

Below is a different portrayal of the same information. In Figure 1-15, your vessel is "safe" so long as you remain below the plotted curves. These curves are termed "stability criteria" and they will be discussed later in the text.

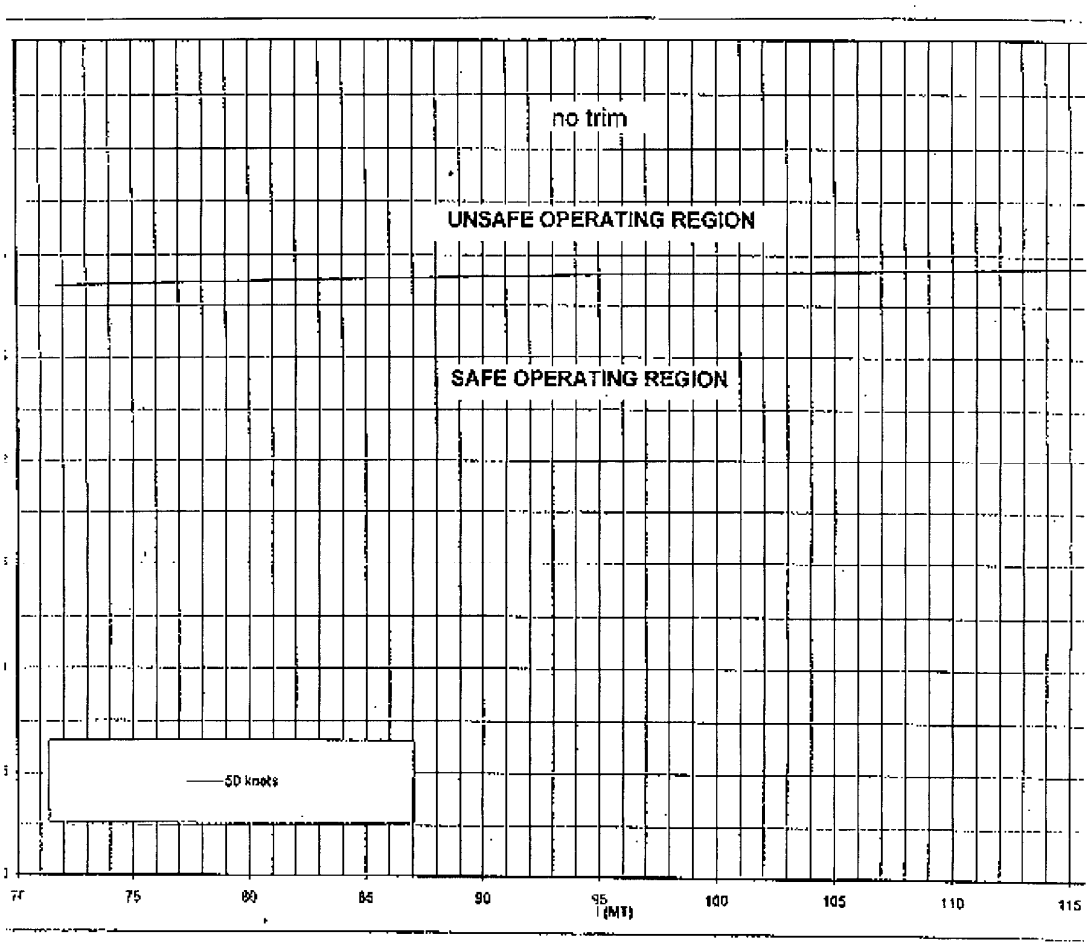


Figure 1-15 Safe Stability Diagram for WPB

When the ship is at rest, the centers of buoyancy and gravity <u>must</u> lie in the same vertical line.

What happens if they don't??...

Chapter Two
Intact Stability

A. Moments – heeling, righting and capsizing
B. Stability at Small Angles
C. Determining GM
D. Roll Period
E. Stability at Large Angles

A. MOMENTS – HEELING, RIGHTING, AND CAPSIZING

When a ship is heeled by some disturbing influence, it either tends to return to its upright position or capsize. This tendency of the ship to rotate one way or the other is referred to as the stability of the ship. This tendency of the ship to rotate is created by a moment. Hence, in order to determine the stability of a ship we need to analyze the moments acting on the ship.

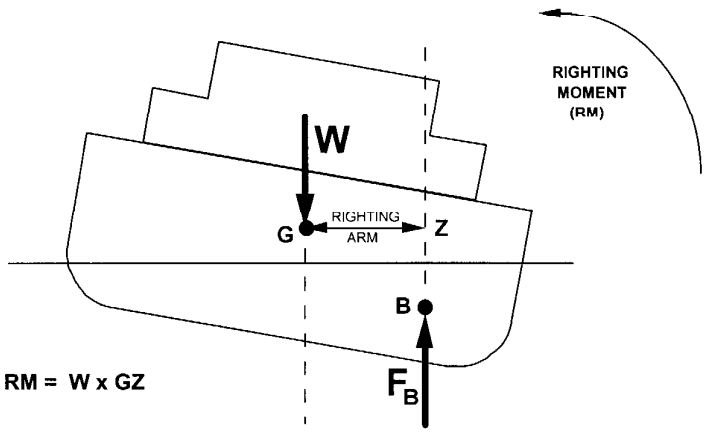
The ship may be disturbed from rest (upright) by certain influences such as:

- Waves
- Wind
- Turning forces when the rudder is put over
- Shifting of weights on board
- Addition or removal of off-center weights

These influences exert heeling moments on the ship causing the ship to heel. They may be temporary or permanent. A stable ship does not capsize when subjected to normal heeling moments. This is because when inclined, a stable ship develops a tendency to right itself. This self-righting tendency is caused by a righting moment.

For a stable ship, the interaction of the forces of weight and buoyancy create a righting moment, tending to return the ship to the upright position. As

the ship is heeled, the center of buoyancy (B) moves outboard, off centerline, due to the changing shape of the ship's underwater volume. At the same time, the center of gravity (G), is more or less stationary. It is this movement of the center of buoyancy, relative to the center of gravity, that creates a horizontal separation of the forces of weight and buoyancy, creating a *righting moment*. This horizontal distance between the forces of weight and buoyancy is called the *righting arm* (GZ).



RIGHTING MOMENT

The righting moment is equal to the ship's displacement times the righting arm:

$$RM = W \times GZ$$

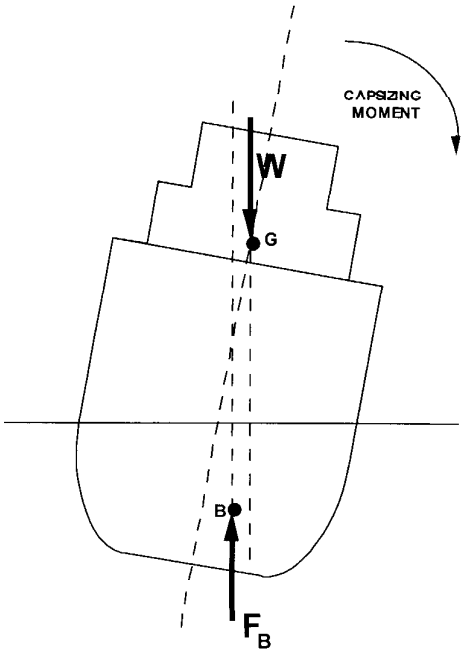
where

RM = righting moment (in foot-tons)
W = displacement of the vessel (in tons)

GZ = righting arm (in feet)

At any given angle of heel, the stability of the ship can be measured by the size of the righting moment developed. However, since displacement remains constant as a ship heels, then for a given condition of loading, the stability of the ship may be, and commonly is, measured by the size of the righting arms developed.

A narrow ship with a high center of gravity, when heeled, may create a capsizing moment instead of a righting moment. In this case, the righting arm is negative, indicating that the forces of buoyancy and gravity will act to increase the angle of heel until the forces are vertically aligned or until the ship capsizes, whichever occurs first.

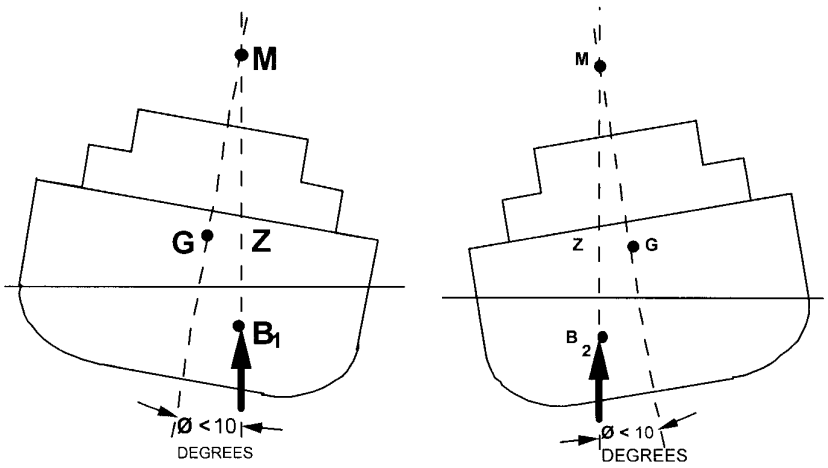


CAPSIZING MOMENT

B. STABILITY AT SMALL ANGLES

The term *initial stability* refers to the tendency of the ship to right itself when inclined to small angles of heel (less than 10 degrees).

As described earlier, the movement of the center of buoyancy as the ship heels creates a horizontal separation of the forces of weight and buoyancy, creating a righting moment. To calculate the righting arm (GZ), we need to measure the horizontal distance between B and G. However, since B is constantly moving with changing angles of heel, it is difficult to keep track of the location of B. Therefore, it would be helpful to find a stationary point through which the force of buoyancy always acts. Such a point exists at small angles of heel (0 - 10 degrees) and is called the metacenter.



LOCATING THE METACENTER (M)

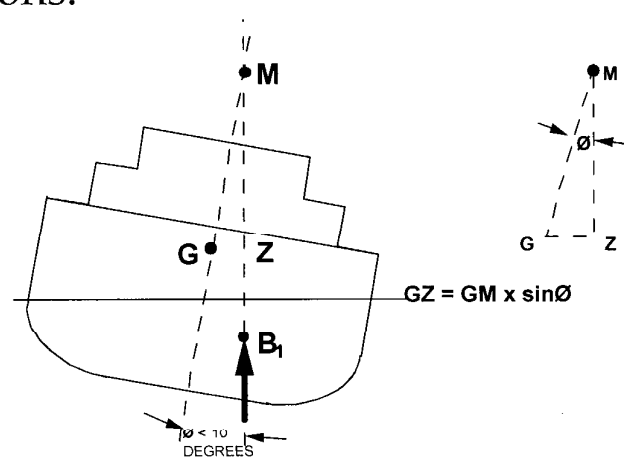
With the ship at a given draft, the *metacenter* is the point of intersection of the lines of action of the force of buoyancy as the ship is inclined through small angles. The metacenter is designated by the letter M. The location of M depends on how B moves when the ship heels, and the path of B depends on the shape of the underwater body. With typical hull shapes, the movement of B is such that M remains on the centerline and is nearly stationary for angles of heel up to about 10°. As the angle of heel increases beyond 10°, the metacenter is no longer stationary and is no longer of any use in determining the size of the righting arm (GZ).

The distance between the center of gravity (G) and the metacenter (M) is called the *metacentric height,* designated by the letters GM. The distance GM is proportional to the length of the righting arm as seen in the following equations.

$$GZ = GM \times \sin Ø$$

$$RM = W \times GZ$$

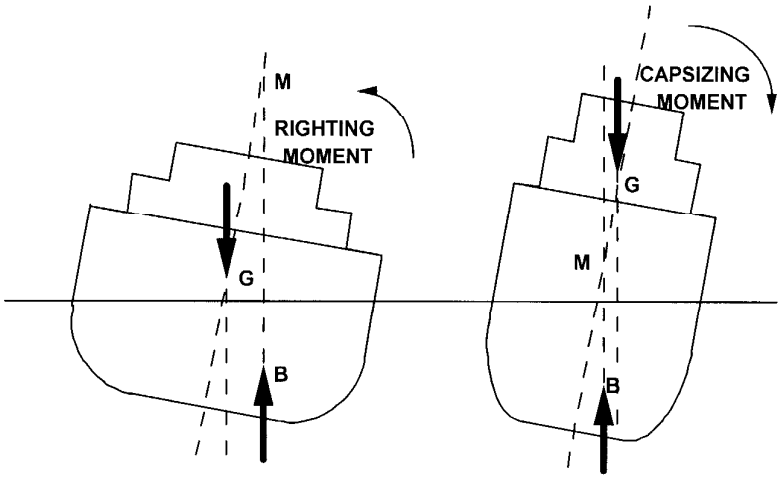
$$RM = W \times (GM \times \sin Ø)$$



Relationship Between GM and GZ

This holds true as long as M remains stationary; i.e., for angles of heel from 0 to 10°. Therefore, the metacentric height (GM) is a measure of initial stability for any given displacement, W.

The relative location of M and G determine if a ship is positively, negatively or neutrally stable. When G is below M, GM is positive and righting arms are developed tending to right the ship, indicating *positive stability*. When G is above M, GM is negative and upsetting arms are developed tending to capsize the ship, indicating *negative stability*. In the case where G and M are coincidental, making GM equal to zero, then neither righting arms nor upsetting arms are developed, indicating *neutral stability*. Thus, GM is an indicator of a ship's initial state of stability.



M ABOVE G
POSITIVE STABILITY

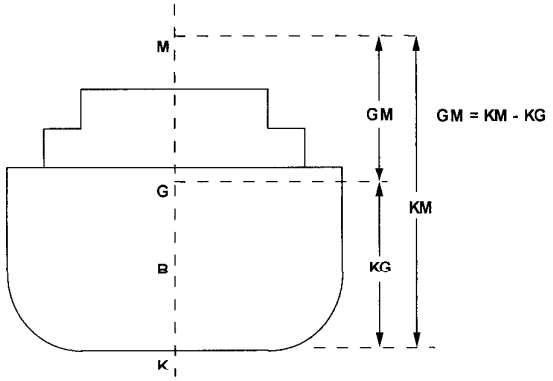
M BELOW G
NEGATIVE STABILITY

C. DETERMINING GM

The metacentric height of a ship is determined by the positions of G and M, whose locations are determined by independent and distinct causes.

The location of the center of gravity, G, is determined by the size and location of all of the weights making up the ship's structure and its contents.

The movement of the center of buoyancy establishes the metacenter, M, as the ship is heeled. Since the location of B is a function of the shape of the ship's underwater volume, then the location of M is also a function of the shape of the ship's underwater volume. Therefore, changes in displacement alter the shape of the underwater body, also altering the location of M. Hence, the position of the metacenter (M) varies with displacement, or more specifically, varies with draft.



DETERMINING THE METACENTRIC HEIGHT (GM)

The metacentric height (GM) is calculated using the following expression:

$$GM = KM - KG$$

where,

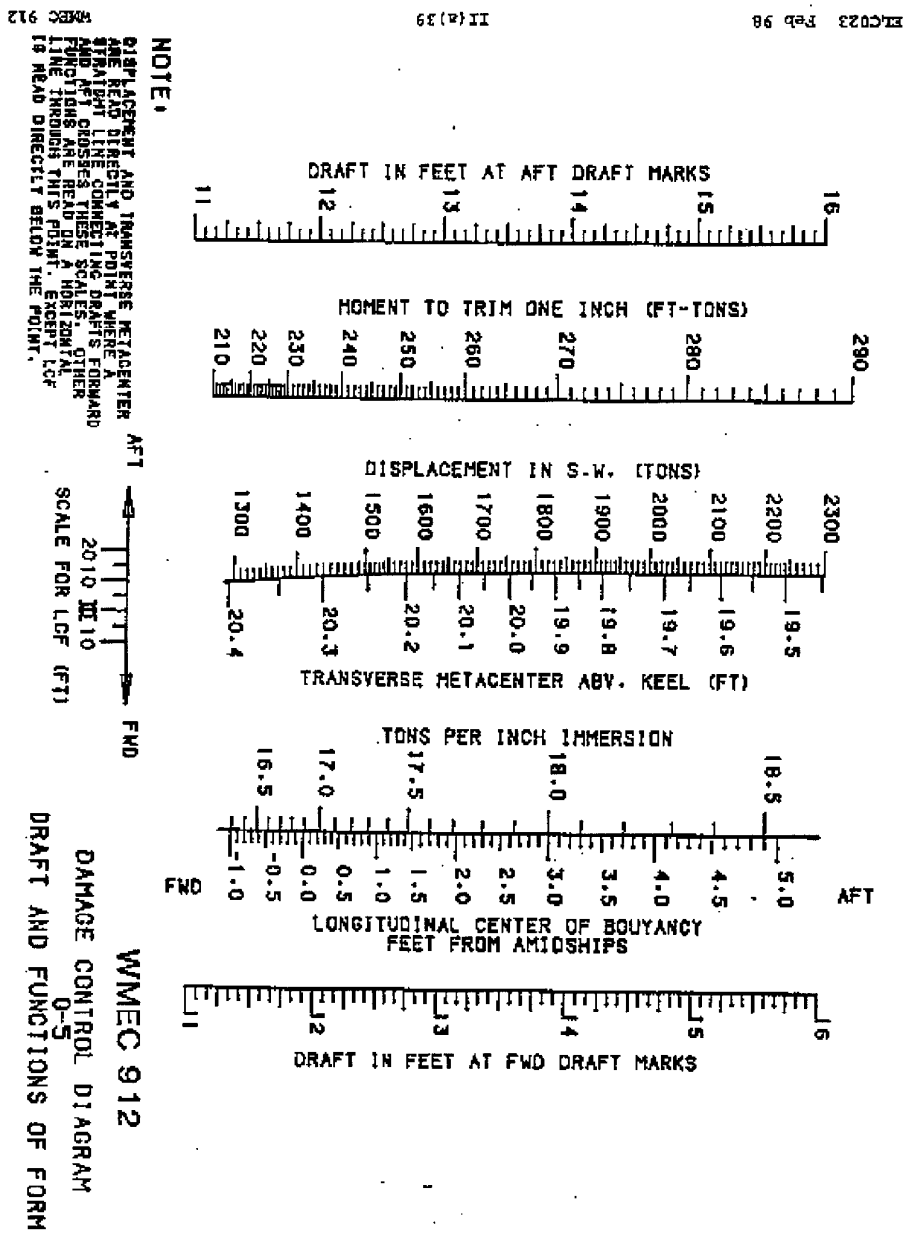
KM = height of the metacenter above the baseline (keel)
KG = height of the center of gravity above the baseline (keel)

The height of the metacenter above the baseline (KM) can be found by using the Draft and Functions of Form diagram (also called "the nomograph"). Every value found on the nomograph is a function of the shape of the underwater body and therefore can be found if the drafts of the ship are known. An example of the use of the nomograph is shown below.

Note: It is very important to read the directions on the nomograph concerning the use of the diagram and where to draw a horizontal line.

Example: 270' WMEC with a forward draft of 13 ft 6 inches and an aft draft of 14 ft.

Solution: Using the nomograph shown below we can determine the displacement to be 1810 tons and the KM to be 19.93 feet above the baseline. Nomographs for a variety of Coast Guard cutters are found in Appendix II.



(scanned 270 WMEC nomograph)

The height of the metacenter above the keel, KM, can also be determined using the following expression:

$$KM = KB + BM$$

where,

KB = height the center of buoyancy (B) above the baseline (keel)
BM = the ship's metacentric radius (the radius of curvature of the path of B as the ship heels)

Note: The method we will use to find KM is by use of the nomograph. The other method is presented to show some important effects on stability if draft or beam is varied.

For the upright ship, B lies on the centerline, and its height depends on the ship's draft. Center of buoyancy above baseline, KB, is usually a little more than one-half the draft, depending on the shape of the hull. An increase in draft will result in a larger KB.

The *metacentric radius*, BM, is the vertical distance from the center of buoyancy (B) to the metacenter (M). **The beam of the ship has a strong influence on BM and hence on GM**. For example, the metacentric radius of a perfectly square barge is calculated using the expression:

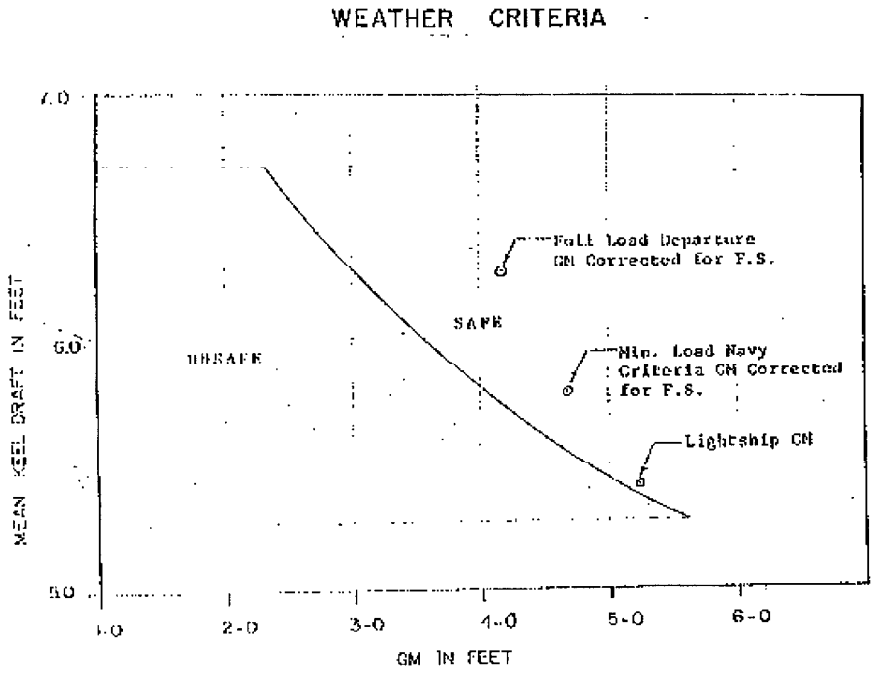
$$BM = B2/ (12*T)$$

where,

KB = height the center of buoyancy (B) above the keel
B = ship's beam
T = ship's draft

From this expression you can see the importance of beam on BM and therefore its importance on GM. Values of BM for more typical hull shapes have a similar dependence on beam (B).

Some cutters less than 200 feet have a "Minimum GM Diagram" instead of the Limiting KG Diagram discussed in chapter 1. This diagram is used in the same way as the Limiting KG Diagram; you enter it with your GM, based on your present loading condition, and either your displacement or mean draft. The diagram indicates what damage you can or cannot survive based on the loading condition you are presently in.



(scanned minimum GM diagram)

D. Roll Period

Since large values of GM correspond to large righting arms and therefore large righting moments, ships with large values of GM exhibit quick, snappy rolls, indicative of a stiff ship. On the other hand, ship's with small values of GM, reflecting small righting arms/righting moments, are tender, exhibiting slow, easy rolling.

For some ships, large values of GM and large righting arms are desirable, for they create excess or reserve stability, allowing the ship to incur some damage and still maintain good stability characteristics. On the other hand, small GM is often desirable in that it creates a slow easy roll which makes for more accurate gunfire and improved habitability. As you can see, the GM designed into a ship is the result of compromise.

Every ship, in the absence of any outside influences, will naturally roll at some characteristic period of roll. The period of roll is the time it takes the ship to roll through one full cycle, e.g. from port to starboard and back to port. This characteristic roll period is called the ship's *natural period of roll*. In still water the ship's natural period of roll can only be changed by changing the ship's initial stability (GM). Actually, the natural period of roll varies inversely as

the square root of GM. This is not true if the ship is rolling in a seaway, subject to wind and wave action.

$$T = \frac{C \times B}{\sqrt{GM}}$$

where,

T = ship's natural period of roll (in seconds)
C = ship's unique rolling constant
B = ship's maximum beam at the waterline (in feet)
GM = ship's metacentric height (in feet)

This expression has little practical value in determining a ship's initial stability (GM). However, knowledge of this relationship between period of roll and GM is useful in giving one the general feel of the ship in relation to her stability as she rolls. A ship which has a slow, sluggish roll (large value of T) has a low GM and a ship with short, snappy rolling motion, indicative of a stiff ship, has a high GM. Where this idea is most likely to become useful is if you notice the ship's, (or another's) rolling becoming noticably slower (longer period of roll) than normal. This should indicate to you that you have lost some stability and that you must investigate the cause immediately before the situation worsens. Some of the most common reasons for this happening is flooding or the accumulation of ice topsides.

A SLOW, SLUGGISH ROLL MEANS POOR STABILITY.

The term *sallying ship* refers to the procedure of getting the ship rolling and timing the period of roll in order to estimate the ship's initial stability (GM). The rolling is usually caused by the crew running from side to side in time with the ship's period. This may be accomplished by directing members of the crew to run from port to starboard on a signal. The order to run to port (or starboard) should be given about a second or two before the ship reaches the end of each respective roll. When the ship's roll reaches somewhere between 5 degrees to 10 degrees, the crew members should be ordered back to midships. The ship will now roll at her natural period of roll. Using a stop watch, time how long the ship takes to complete four or five complete rolls (port to starboard and back to port). Thus by dividing the time (in seconds) by the number of rolls timed, the period of one roll of the ship is obtained. The above procedure should be repeated a several times to assure the reliability of the results. Generally three measurements will suffice.

With the period of roll known, it is possible to determine an approximate value of GM from the following empirical formula:

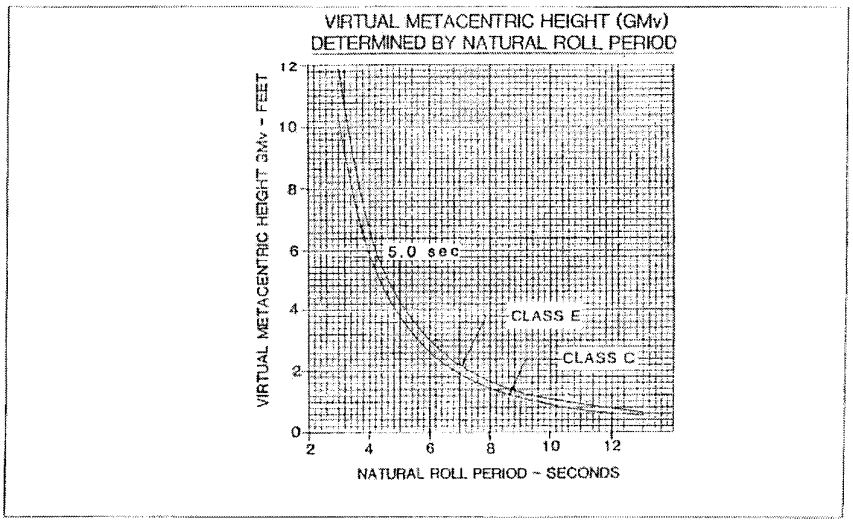
$$GM = (C * B)^2 / T^2$$

where,

GM = ship's metacentric height (in feet)
C = ship's rolling constant

B = ship's beam (in feet)
T = ship's period of roll (in seconds)

It must be remembered that the GM measured from sallying ship is approximate and that there are more exact methods available. Sallying ship may be employed as a crude method to determine the ship's initial stability. Although this method gives fairly accurate results for ships in calm water, it is not practical for use at sea or after incurring damage.



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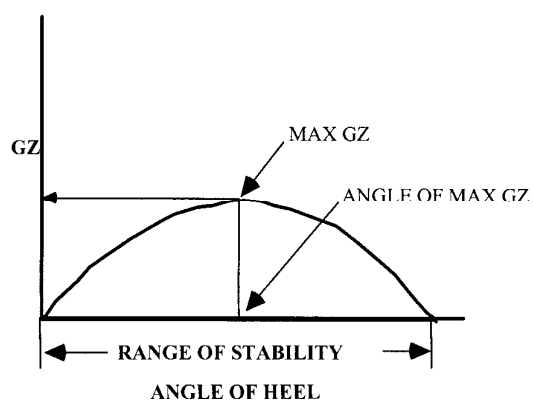
E. STABILITY AT LARGE ANGLES

Stability at large angles of heel. Up until now, we have been measuring a ship's stability by determining the ship's metacentric height, GM. However, the value of GM is not valid for angles of heel beyond 10 degrees. Therefore, we need to develop another measure of a ship's stability at larger angles of heel.

As discussed earlier, we can also use the size of the righting arm (GZ), developed as the ship heels, as a measure of the ship's stability. Thus if we plot the righting arm (GZ) versus the angle of heel, the result is called the ship's *static stability curve*.

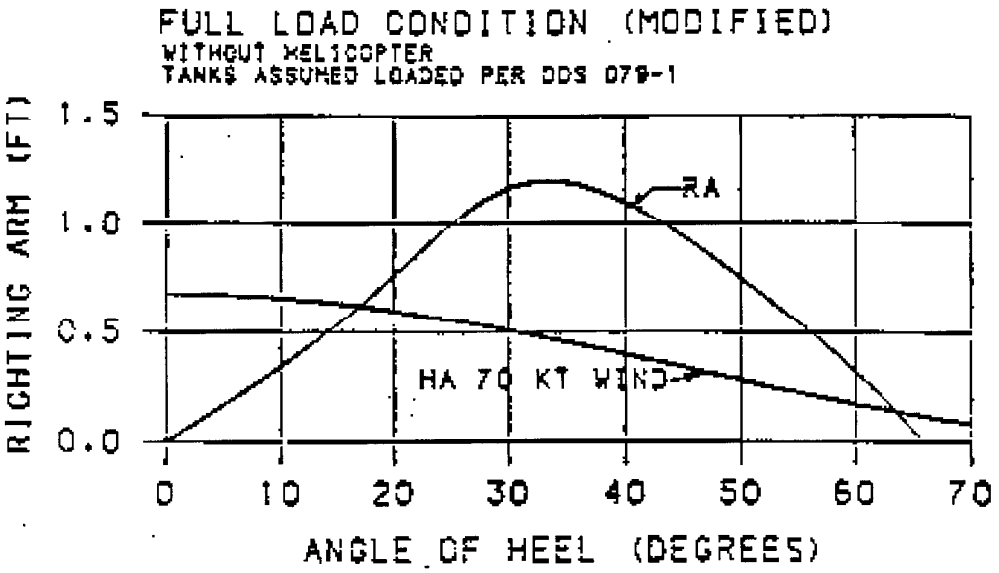
Several properties of a static stability curve are typically used to describe/compare a ship's stability at large angles of heel. They include:

- Range of stability
- Maximum righting arm (GZ_{max})
- Angle of heel at maximum righting arm



For the full load curve for a 210' WMEC shown below, these stability properties are

- Range of stability = 0° - 66°
- Maximum righting arm (GZ_{max}) = 1.2 feet
- Angle of heel at maximum righting arm = 33°



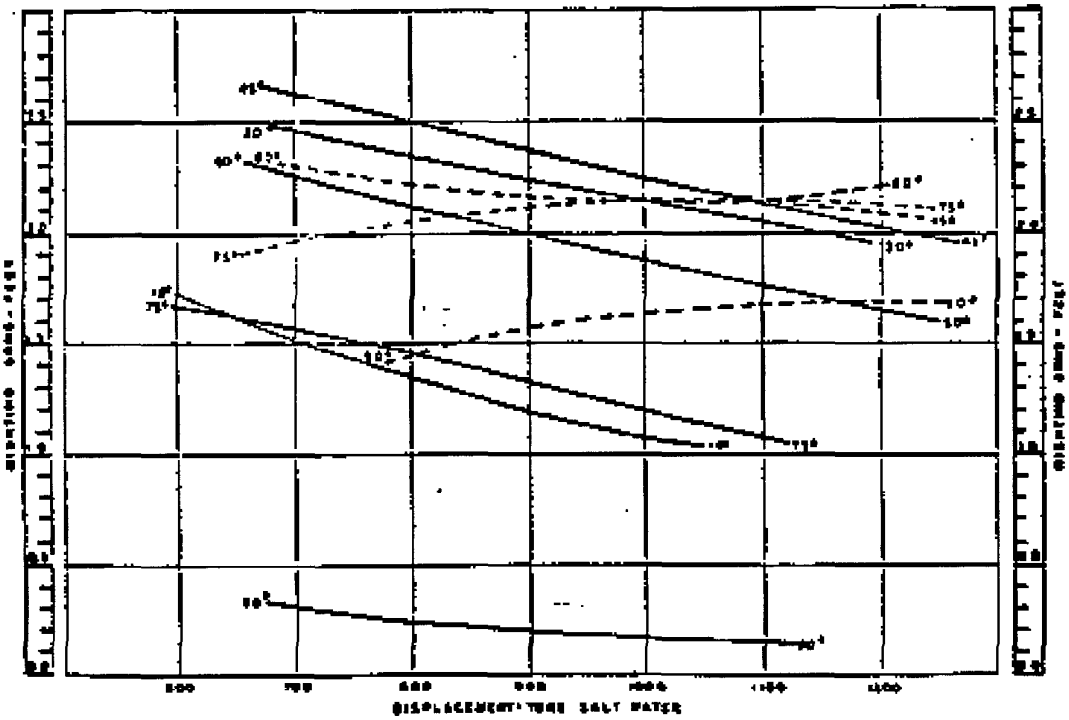
(scanned 210 SSC curve)

A change of displacement (holding KG constant) will not only cause a change in GM but will also result in altered righting arms throughout the range of stability. When draft increases (due to increasing displacement) the size and shape of the underwater body changes in such a way to reduce righting arms. This effect, sometimes referred to as loss of GZ due to reduced freeboard, results in a reduction of over-all stability.

It is common to plot righting arms (GZ) vs. displacement (W) due to the interdependence of the two parameters. This plot is called the cross-curves of stability.

CROSS CURVES OF STABILITY

TAKEN FROM COAST GUARD DRAWING NO. 618 WPC 0101-27



NOTES

1. AXIS IS ASSUMED AT 14'-0" ABOVE BASELINE.

2. VESSEL ASSUMED WATERTIGHT TO 01 DECK FORWARD OF FRAME 68½ AFT OF FRAME 68½. VESSEL ASSUMED WATERTIGHT TO MAIN DECK.

3. SOLID CURVES: DECKHOUSE AFT OF FRAME 68½ ASSUMED NON-WATERTIGHT
DOTTED CURVES: DECKHOUSE AFT OF FRAME 68½ ASSUMED WATERTIGHT TO HELICOPTER DECK.

TABLE OF NATURAL SINES			
ANGLE	SINES	ANGLE	SINES
0°	.0	60°	.86603
15°	.25882	75°	.96593
30°	.50000	90°	1.0000
45°	.70711		

(scanned 210′ cross-curves)

Chapter Three
Cross-Curves

A. Cross-Curves of Stability
B. Stability While Listing

A. CROSS-CURVES OF STABILITY

The cross-curves of stability show the effect of displacement on righting arms. Righting arms usually decrease in length with increasing displacement. This can be seen by looking at the cross curves below and noticing that all the curves slope down to the right, indicating that the righting arms (GZ) are decreasing with increasing displacement.

The cross curves of stability are used to develop the static stability curve for a *particular loading condition with a known displacement and a known KG.*

CROSS CURVES OF STABILITY

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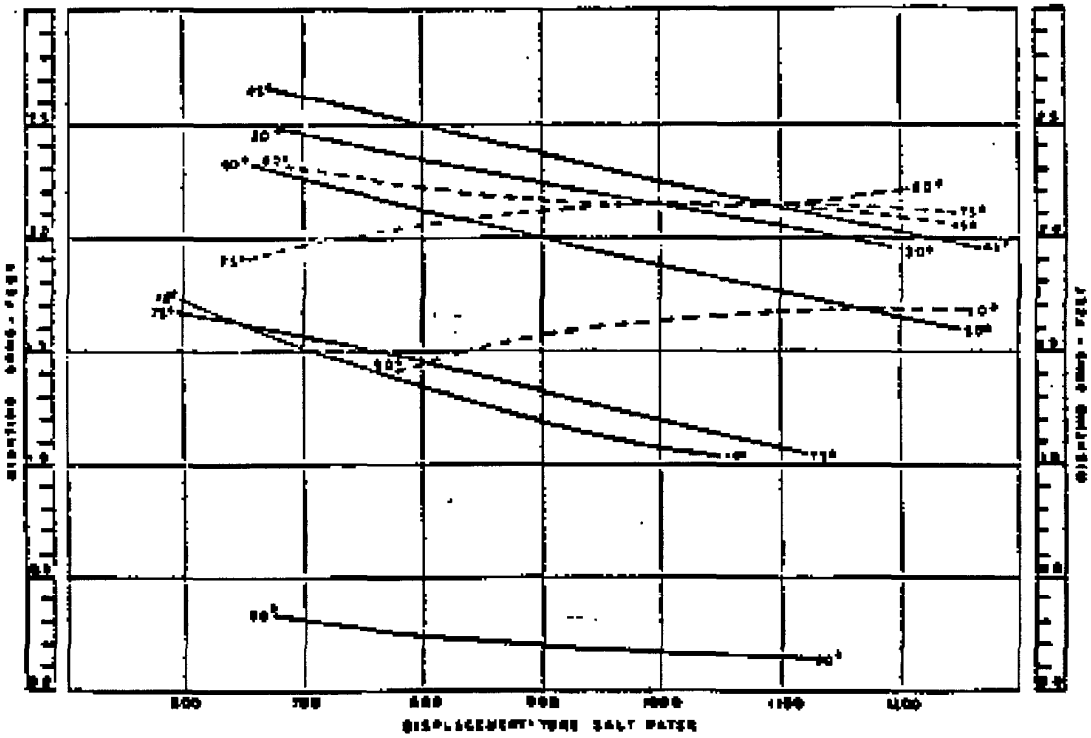

NOTES

1. AXIS IS ASSUMED AT [illegible]'-0" ABOVE BASELINE.

2. VESSEL ASSUMED WATERTIGHT TO 01 DECK FORWARD OF FRAME 68½ AFT OF FRAME 53½. VESSEL ASSUMED WATERTIGHT TO MAIN DECK.

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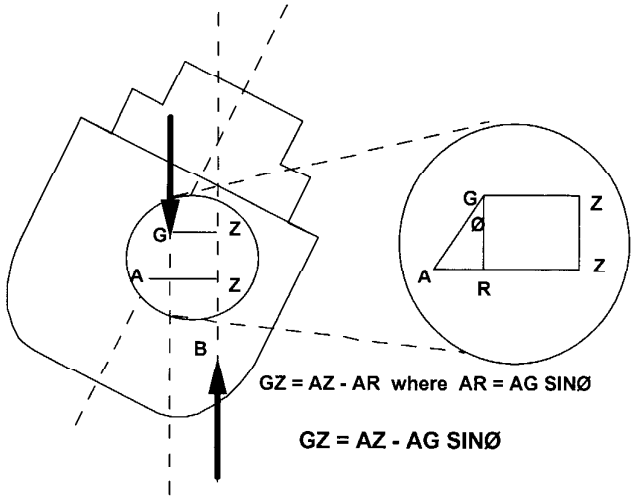
DOTTED CURVES: DECKHOUSE AFT OF FRAME 53½ ASSUMED WATERTIGHT TO HELICOPTER DECK.

TABLE OF NATURAL SINES			
ANGLE	SINES	ANGLE	SINES
0°	.0	60°	[illegible]
15°	.25882	75°	.96593
30°	.50000	90°	1.0000
45°	.70711		

(scanned 210′ cross-curves)

The uncorrected values of GZ taken directly from the cross curves are actually the distance AZ. The distance between the assumed center of gravity (A) and the actual center of gravity (G) is referred to as the distance AG.



To find corrected values of GZ, you must be multiply AG by the sine of the angle of heel and apply it to the uncorrected value of GZ (AZ). If G is above A, then the correction is subtracted, and if A is above G, then the correction is added to the uncorrected righting arms. Most commonly the correction is subtracted.

$$\mathbf{GZ_{cor} = GZ_{unc} - AG\sin Ø}$$

The following examples show how to correct and plot a static stability curve for a given KG and displacement.

Example: Draw the corrected Static Stability Curve for a 270' WMEC at full load condition.

W = 1824.3 tons KG = 17.25 ft

Solution:

1. Using the Cross Curves of Stability for the 270' WMEC shown, pick off values of righting arm (GZ) at a displacement of 1824.3 tons. These are the uncorrected GZ values.
2. The assumed center of gravity is 16 ft. The actual center of gravity is 17.25 ft. Therefore, the correction is:

$$AG * \sin ø = (17.25 - 16.0) * \sin ø$$
$$= 1.25 * \sin ø$$

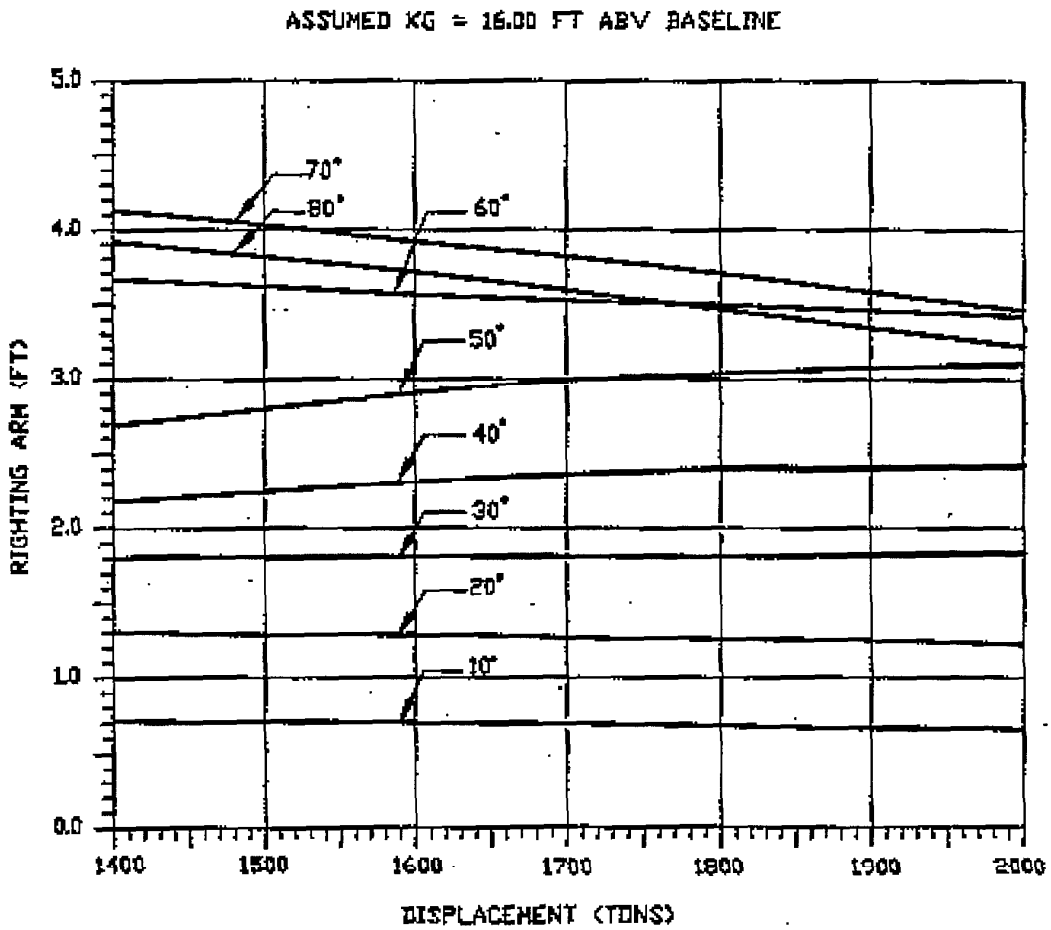
Since G is above A, the correction is subtracted from the uncorrected GZ values to obtain the corrected GZ values.

Note: If you have trouble remembering whether to add or subtract the correction, look at the big picture: is my stability better or worse than the values assumed in the cross curves? If your G is higher than A, your stability is worse (the higher G is, the less stability you have), and you should subtract the correction because your righting arms are smaller than what was assumed in the cross curves. Just the opposite is true in the rare case of G being below A; your stability is better, so add the correction to increase your righting arms.

3. $GZ_{cor} = GZ_{unc} - 1.25 * \sin ø$

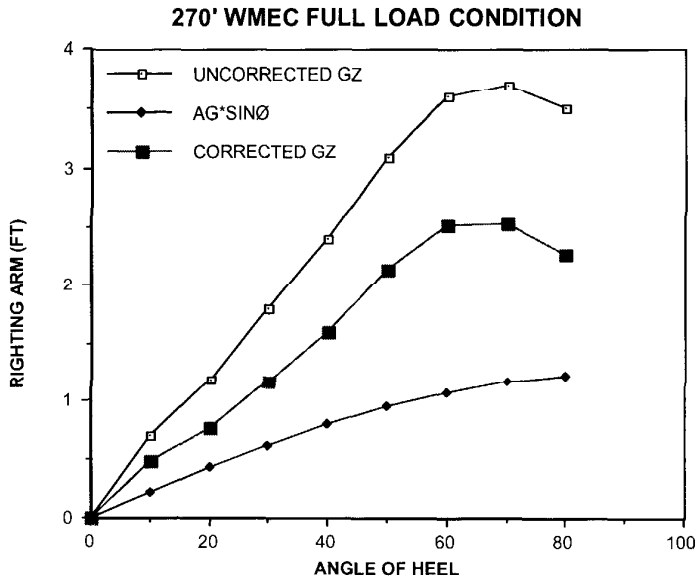
Heel Angle	**0°**	**10°**	**20°**	**30°**	**40°**	**50°**	**60°**	**70°**	**80°**
GZ_{unc}	**0**	**0.7**	**1.2**	**1.8**	**2.4**	**3.1**	**3.6**	**3.7**	**3.5**
AG * sinø	**0**	**0.22**	**0.43**	**0.63**	**0.80**	**0.96**	**1.08**	**1.17**	**1.23**
GZ_{cor}	**0**	**0.48**	**0.77**	**1.17**	**1.6**	**2.14**	**2.52**	**2.53**	**2.27**

DAMAGE CONTROL DIAGRAM
0-6
CROSS CURVES OF STABILITY



(scanned 270 cross-curves with notes)

The resulting static stability curve for a 270 WMEC at a displacement of 1824.3 LT and a KG of 17.25 ft is:



Note: The cross-curve data above stops at 80 degrees of heel. This does not mean that the ship does not have righting arms beyond 80 degrees. We just do not have the data to plot the curve beyond 80 degrees. An approximation can be made by fairing in the curve in the general direction it is going at 80 degrees. This gives the 270' WMEC a range of stability of approximately 0 to 100 degrees.

Example: Draw the Static Stability Curve for a 110' WPB at a displacement of 160 tons and a KG of 9.0 ft.

Solution:

1. Using the Cross Curves of Stability for the 110' WPB shown on next page, pick off values of righting arm (GZ) at a displacement of 160 tons. These are the uncorrected GZ values.
2. the assumed center of gravity is at the baseline (KA = 0) The actual center of gravity is 9.0 ft. Therefore, the correction is

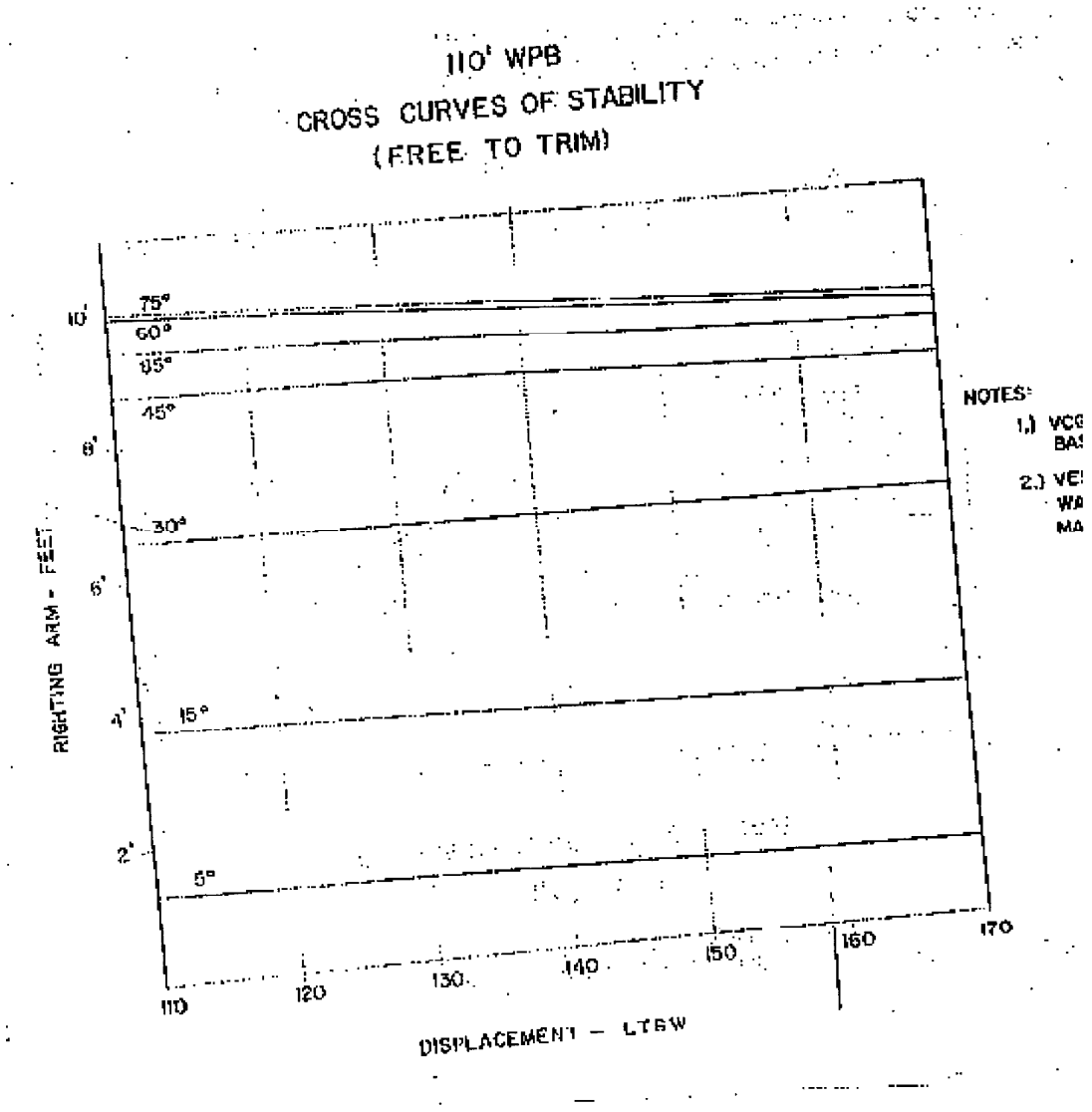
$$AG * \sin ø = 9.0 * \sin ø$$

Since G is above A, the correction is subtracted from the uncorrected GZ values to obtain the corrected GZ values.

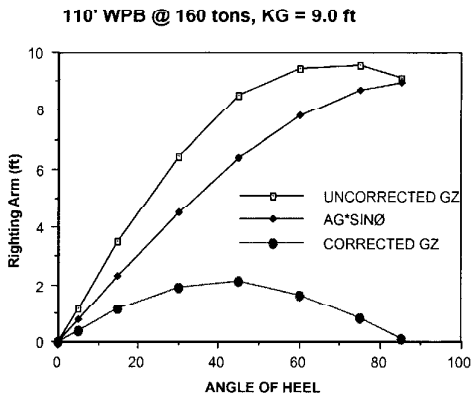
3. $GZ_{cor} = GZ_{unc} - 9.0 * \sin ø$

Heel Angle	**0°**	**5°**	**15°**	**30°**	**45°**	**60°**	**75°**	**85°**
GZ_{unc}	**0**	**1.15**	**3.5**	**6.45**	**8.5**	**9.45**	**9.55**	**9.1**
AG * sinø	**0**	**0.78**	**2.33**	**4.5**	**6.36**	**7.79**	**8.7**	**8.97**
GZ_{cor}	**0**	**0.37**	**1.17**	**1.95**	**2.14**	**1.66**	**0.85**	**0.13**

Note: Always include the values for zero degrees in your table. They will be zero in this case but it will become important in later problems. Get in the habit of automatically including them in your table now.



(scanned 110 cross-curves with notes)



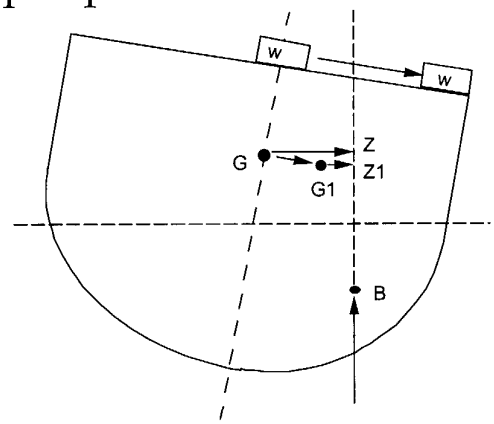
You can clearly see from the 110' WPB example the necessity of correcting the curve for your ship's actual KG.

The sine correction to the curve is to correct for a different vertical height of the center of gravity. This assumes that the center of gravity is on the centerline. What if it is not??

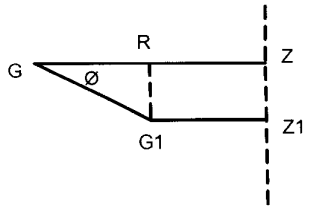
B. STABILITY WHILE LISTING

Any time a ship has a permanent angle of list its stability has been impaired. Righting arms are smaller, and range of stability to the side of the off-center weight is reduced.

As shown in the drawing below, when a weight is shifted off-center (or added/removed off-center) the center of gravity shifts off of the centerline in the direction of the weight shift. When this happens, the buoyant force and the weight force are no longer lined up and the ship will rotate until they do line up or until the ship capsizes.



If we expand the view of the righting arm area from the above drawing, we can clearly see the reduction in righting arms due to the movement of G off-center.



The reduction in righting arms at all angles is shown to be:

$$GR = GG_1 * \cos ø$$

The actual righting arm is:

$$G_1Z_1 = GZ - GR \quad \text{or} \quad \underline{\mathbf{G_1Z_1 = GZ - GG_1 * \cos ø}}$$

The cosine correction is <u>always subtracted</u> because it always causes a reduction in stability. This correction is applied in conjunction with the correction applied to correct for the vertical height of G.

Finding GG1: How far G moves off the center line is dependent upon the amount of weight in question and the distance the weight is shifted (or the distance from the centerline for a weight addition/removal).

$$GG_1 = (w * t) \div W$$

where,

w = weight added/shifted/removed (tons)
t = transverse distance shifted or distance from the centerline for weight additions/removals (feet)
W = Ship's Displacement (tons)

The following example shows how to correct a static stability curve for an off-center weight.

<u>Example</u>: A 210' WMEC with a displacement of 1110 tons and a KG of 15.11 feet adds 30 tons of equipment to the flight deck (30 ft above

baseline) 10 feet to port of the centerline. Draw the corrected static stability curve for this condition.

Solution:

1. Compute new KG using KG worksheet (new KG = 15.5 feet)
2. Compute sine correction to curve:

   $G_{assumed}$ = 14 ft,
   G_{actual} = 15.5 ft.

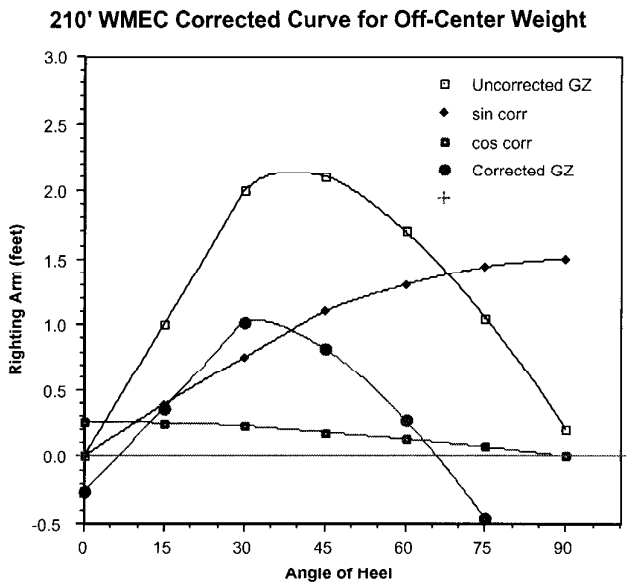
   Correction = -1.5 * sinø
3. Compute GG_1.

   GG_1 = (w * t) / W = (30 tons * 10 ft) / 1140 tons = 0.26 ft

   Correction = -0.26 * cosø
4. Get uncorrected values of GZ from cross curves diagram for W = 1140 LT
5. Set up table.

Heel Angle	**0°**	**15°**	**30°**	**45°**	**60°**	**75°**	**90°**
GZ_{unc}	**0**	**1.0**	**2.0**	**2.1**	**1.7**	**1.05**	**0.2**
-1.5 * sinø	**0**	**0.39**	**0.75**	**1.1**	**1.3**	**1.44**	**1.5**
-0.26 *cosø	**0.26**	**0.25**	**0.23**	**0.18**	**0.13**	**0.07**	**0**
GZ_{cor}	**-.26**	**0.36**	**1.02**	**0.82**	**0.27**	**-.46**	**-1.3**

6. Plot corrected static stability curve.



The righting arm curve no longer starts at zero degrees, instead it crosses the axis (zero righting arm) at approximately 8.5 degrees. This is the angle of permanent list. As the corrected curve clearly shows, the stability of the ship has been significantly reduced; it has an 8.5 degree list to port, the maximum righting arm is only about 1 foot, and the range of stability is 8.5 to 65 degrees.

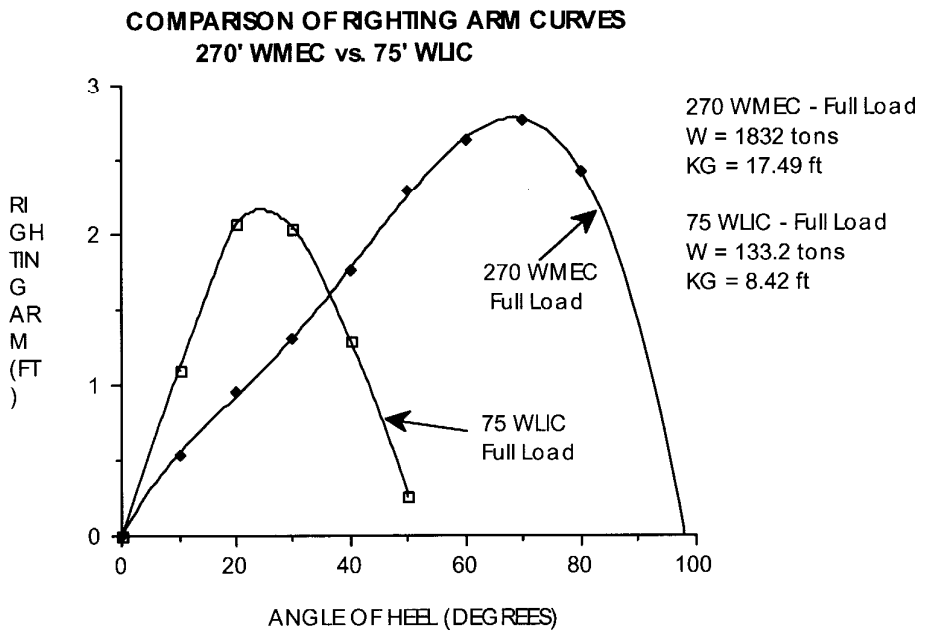
Chapter Four
Dynamic Stability

A. Overall Stability
B. Dynamic Stability
C. USN Stability Criteria
D. Dynamic Response

A. OVERALL STABILITY

In order to determine a ship's over-all stability, you have to look at the ship's initial stability as well as the ship's stability at large angles of heel. Looking at only one or the other does not give you the complete picture of a ship's stability. For example, a barge shaped hull typically has very high values of GM (initial stability), however, its static stability curve indicates a small range of stability. In comparison, a fine hull, such as a destroyer hull, has relatively low values of GM but has a large range of stability as shown in the static stability curve. So which hull form has greater overall stability? There is no simple answer to this question.

On the opposite page we can compare the stability characteristics of a 75' WLIC and a 270' WMEC. The 75' WLIC has a very barge shaped hull and correspondingly has a high value of GM (6.17 ft) but a small range of stability (0° - 51°). In comparison, the 270' WMEC has a fine hull with a smaller value of GM (2.63 ft) but a range of stability (0° - 98°) of nearly twice that of the 75' WLIC. From this we can see that the 75' WLIC has high initial stability but low stability at large angles of heel whereas the 270' WMEC has moderate initial stability but excellent stability at large angles of heel.



COMPARISON OF STABILITY PARAMETERS

	GM	RANGE OF STABILITY	GZ_{MAX}	ANGLE OF HEEL @ GZ_{MAX}
75' WLIC	6.17 ft	0° - 51°	2.2 ft	25°
270' WMEC	2.63 ft	0° - 98°	2.75 ft	70°

B. DYNAMIC STABILITY

Until this point we have analyzed ships' stability (after adding/removing/shifting weights) by plotting their corrected static stability curves and then looking at such things as range of stability, maximum GZ, GM, etc... In all of these cases we have only considered the "static" effects of applied loads on a vessel's stability (hence the term Static Stability Curve). We will now consider the effect of dynamic forces, specifically:

- wind (especially beam winds)
- high speed turns
- crowding of passengers to one side (migrants)
- heavy lift over the side (buoys, small boat ops.)

Each of these situations cause a ship to heel (they create heeling moments) beyond the angle that it would eventually list at, if the force was not removed. This is known as the dynamic response of a vessel, and it occurs because the applied load is a dynamic one, involving the sudden application of force. There is a simple method for finding the angle a ship heels to during its dynamic response, and this is covered later in the text.

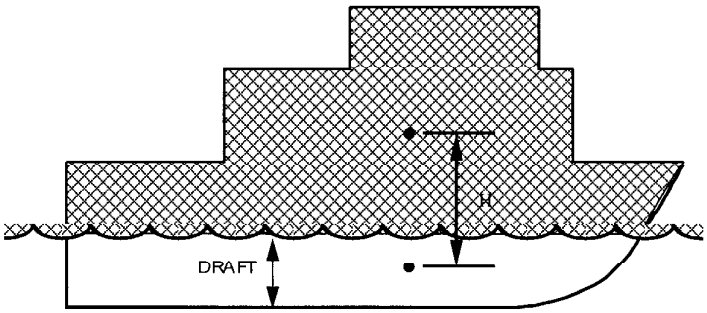
So what is dynamic stability? NSTM 079 defines it as the amount of work necessary to heel a ship over to some angle, visually displayed by the area under a

ship's static stability curve up to this angle of heel (see below). An alternative way to look at dynamic stability would be to consider the righting energy (or resistance to heel) possessed by a ship at some angle of heel. This may be a bit of a tongue twister, but just remember that dynamic stability allows us to further assess how a ship will react in situations beyond just those involving static forces. In essence, we move that much closer to answering the question, "What is this vessel's stability like?"

C.USN STABILITY CRITERIA

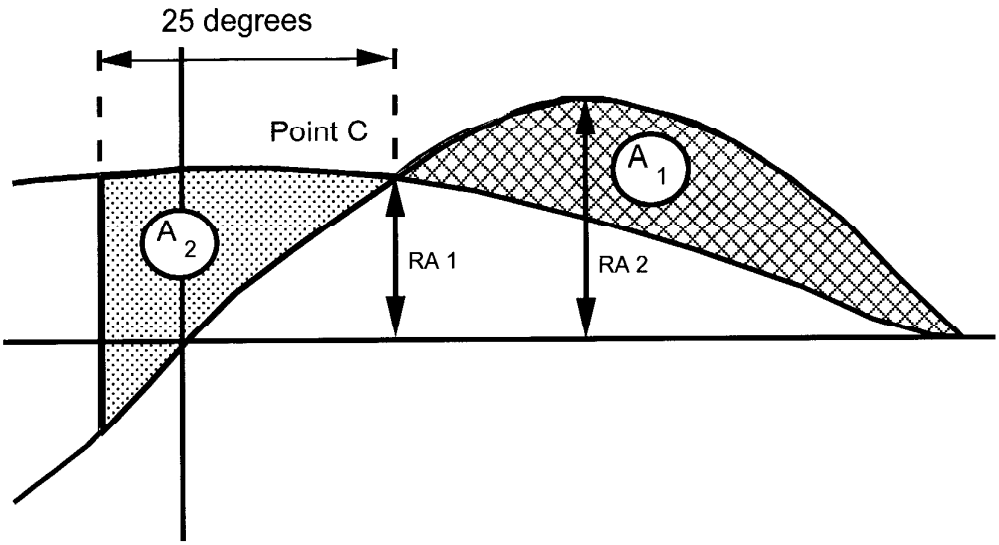
The USN stability criteria are used to insure a vessel (typically a naval combatant) possesses some minimum level of dynamic stability in each of the four situations listed below. Naval arhcitects and shipbuilders are very familiar with the criteria. These criteria are used to assess the viability of a vessel design prior to vessel construction. Each element of the criteria must be met in order for that vessel to pass the specific criteria.

1. BEAM WINDS with ROLLING STABILITY TEST



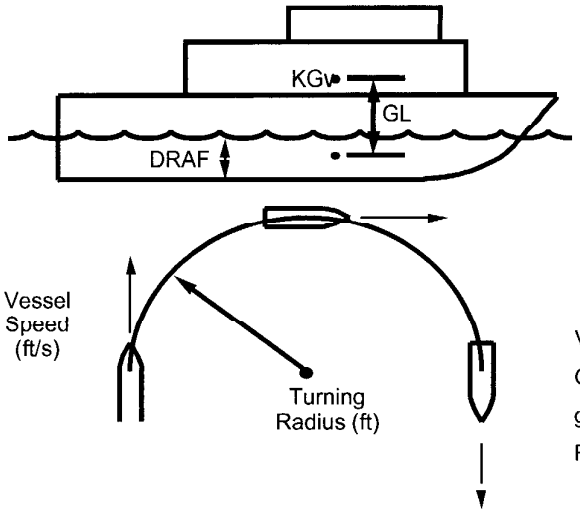
H - LEVER ARM (feet) - From Center of SAIL AREA to 1/2 DRAFT
A - SAIL AREA (square feet) [cross-hatched area]
Vw - VELOCITY of WIND in knots

$$\text{HEELING ARM Created by WIND} = \left[\frac{0.004\ V_w^2\ A\ H}{2240\ \Delta} \right] \cos^2 \phi$$



Beam Wind Criteria
Element 1: Righting Arm at Point C (RA_1) < 60% of Max Righting Arm (RA_2)
Element 2: Excess Righting Energy (A_1) > 140% of Excess Heeling Energy due to 25° roll to windward (A_2)

2. High Speed Turn



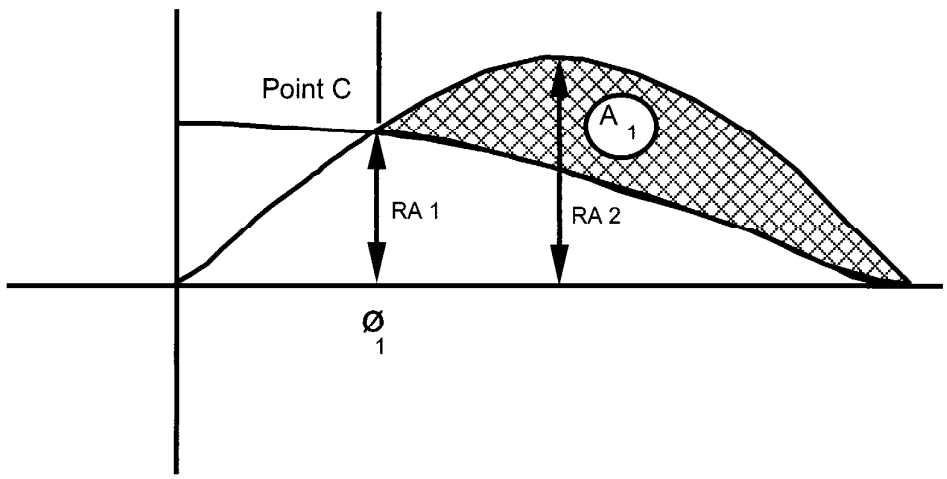
$$\text{HEELING Arm caused by TURN} = \left[\frac{V_s^2 \quad GL}{g*Radius}\right] \cos ø$$

V_s - Vessel speed in ft/sec (1 knot = 1.689 ft/sec)

GL - Distance between Vessel KG_v and Half Draft in feet

g - Acceleration due to Gravity (32.2 ft/sec squared)

Radius - Turn Radius (Half Tactical Diameter) in feet



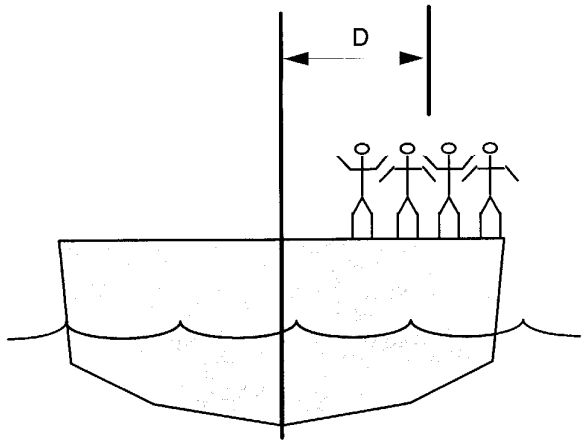
High Speed Turn Criteria

Element 1: Angle of Heel at Point C (Φ_1) < 10° for ***newly*** constructed ships
Angle of Heel at Point C (Φ_1) < 15° for ***existing*** ships

Element 2: Excess Righting Energy (A_1) $\geq$ 40% of Total Righting Energy

Element 2: Righting Arm at Point C (RA_1) $\leq$ 60% of Max Righting Arm (RA_2)

3. Passenger Crowding

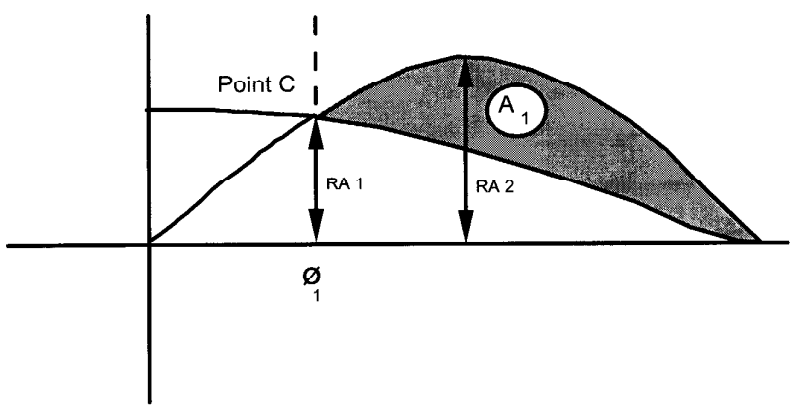


D - Distance in feet from Vsl Centerline to Center of Crowd

2 - Displacement of Vessel in L. Tons including Passengers

w - Weight of Passengers Crowding to One Side in L. Tons

$$\text{HEELING ARM caused by Crowding to One Side} = \left[\frac{w * D}{2}\right] \cos \varnothing$$



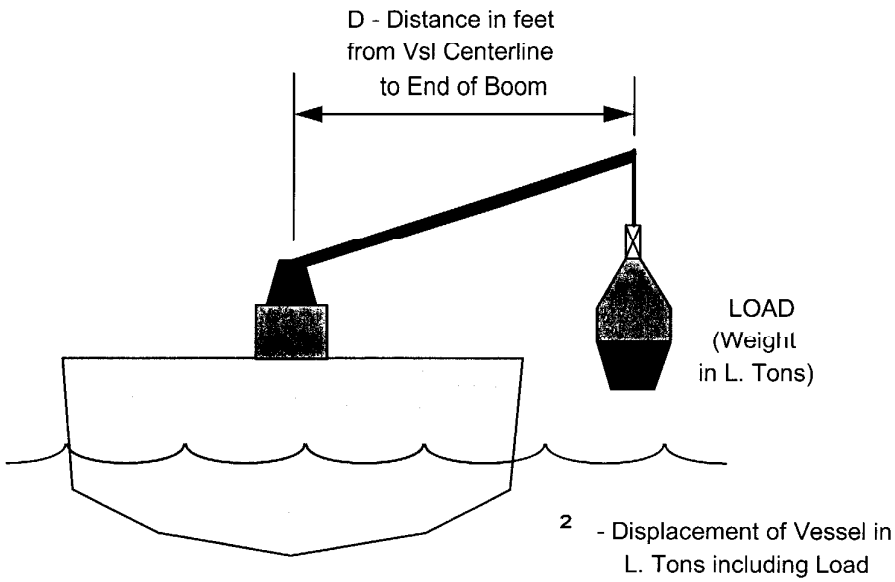
Passenger Crowding Criteria

Element 1: Angle of Heel at Point C (Φ_1) < 15°

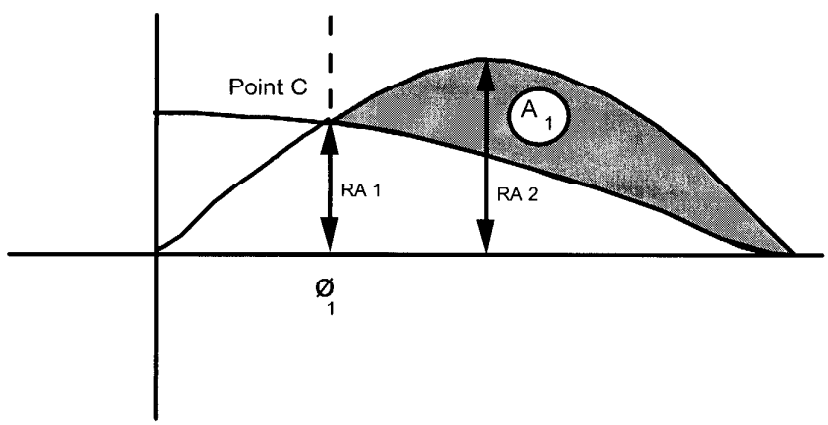
Element 2: Excess Righting Energy (A_1) $\geq$ 40% of Total Righting Energy

Element 2: Righting Arm at Point C (RA_1) $\leq$ 60% of Max Righting Arm (RA_2)

4. Heavy Weight Over the Side



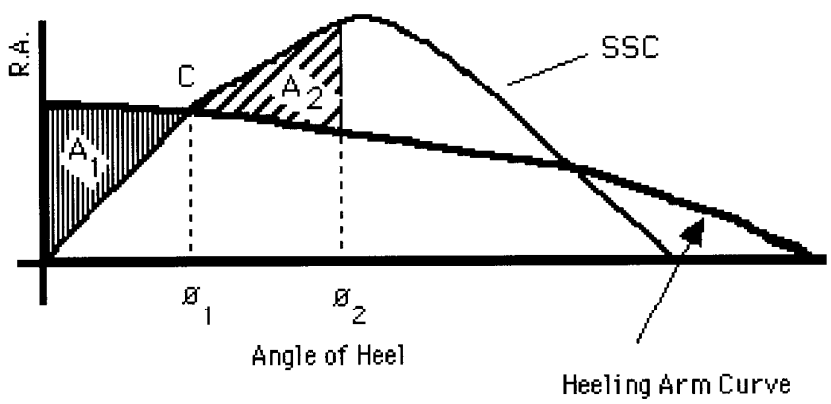
$$\text{HEELING ARM caused by LOAD over Side} = \left[\frac{\text{LOAD} * D}{2}\right] \cos \phi$$



Heavy Weight Over the Sdie Criteria
Element 1: Angle of Heel at Point C (Φ_1) < 15°
Element 2: Excess Righting Energy (A_1) $\geq$ 40% of Total Righting Energy
Element 2: Righting Arm at Point C (RA_1) $\leq$ 60% of Max Righting Arm (RA_2)

D. DYNAMIC RESPONSE

The dynamic response (a.k.a. the angle of heel – $ø_2$) that a vessel will initially reach after being exposed to a dynamic force is shown below. The dynamic response, as defined here, is not explicitly a part of the criteria for the above situations. Here A_1 is a "fixed" area (once your curves are plotted this area is "fixed") bounded by the y-axis, the SSC, and the heeling arm curve. Thus, $ø_2$ is found by moving a vertical line (shown as the dashed line above $ø_2$) to the right of point C until it bounds an area (A_2) that equals A_1. Dropping this vertical line down to the x-axis will determine $ø_2$. Note that $ø_2$ <u>does not</u> automatically twice the value of $ø_1$.



So what does this mean, in English? Remember the area under the curves represents "energy". The area under the heeling arm curve represents "heeling energy" that causes the ship to heel. The area under the righting arm curve represents "righting energy" causing the ship to return upright. If we look at the curve above, you can see that, up until $ø_1$, there is more heeling energy than righting energy. This excess energy has to be dissipated (or cancelled) by righting energy. This dissipation occurs in the range between $ø_1$ and $ø_2$ (where the righting energy exceeds the heeling energy). The sum total of energy at $ø_2$ is equal to zero and the ship stops heeling in that direction. The righting moment takes over and returns the ship in the other direction and this oscillation continues (like a spring) until the ship settles out at a permanent angle of list equal to $ø_1$.

As you can see from the previous diagrams, to apply the Navy Stability Criteria to a vessel we must plot the ship's static stability curve (righting arm curve, including any sine corrections) as well as the heeling arm curve caused by the outside force. Notice that these heeling arm curves are always cosine function derivative, which makes sense since the ship develops some temporary list (cosine correction when doing static stability). This is shown graphically by

the angle of heel directly below point C, the intersection of the SSC and heeling arm curve.

By comparing the proper areas, righting arms, and angles we can determine if a vessel passes the USN stability criteria. A vessel must satisfy <u>all</u> the elements of the criteria for a given situation in order to pass the minimum dynamic stability requirements of the situation. (i.e. to pass beam winds your vessel must satisfy both elements of the USN beam wind criteria).

Note: The simplest way to find needed areas is to make the plots on graph paper and then "count the squares" within the enclosed areas needed.

<u>EXAMPLE</u>: You are aboard a 378' WHEC with a forward draft of 14' 3" and an aft draft of 15' 10". The ship's KG = 17.6 ft. In preparation for refueling you deballast your ship of 124,000 gallons of salt water ballast. Does your ship meet the U.S. Navy 100 kt beam wind criteria for the deballasted condition?

<u>Solution</u>:
124,000 gallons SW = 473.64 tons @ Kg = 8.5 ft (from DC Book)

1. From nomograph (using draft readings): W=3275 tons

2. After deballasting: New KG = 19.14 ft (from KG worksheet),
   W = 2801.36 tons

3. From cross curves diagram: assumed KG = 17 ft

AG = 19.14 - 17 = 2.14 ft

Heel Angle	0°	10°	20°	30°	40°	50°	60°	70°	80°
AZ	0	0.7	1.4	2.06	2.6	2.66	2.28	1.84	1.1
AGsin	0	0.37	0.73	1.07	1.38	1.64	1.85	2.01	2.11
GZ	0	0.33	0.67	0.99	1.22	1.02	0.43	-.17	-1.0

4. Heeling Arm curve for 100 kt wind = 1.4 cos2ø

Heel Angle	0°	10°	20°	30°	40°	50°	60°	70°	80°
Heeling Arms	1.4	1.36	1.24	1.05	0.82	0.58	0.35	0.16	0.04

5. Plot righting arm curve and heeling arm curve.

(scanned image of 378 dynamic plot)

6. Maximum roll if suddenly subjected to 100 kt wind:

Ship would capsize because the area between the heeling arm curve and the righting arm curve from 0 to 31° (excess heeling energy) is greater than all the area between the two curves from 31 to 63° where they cross again (excess righting energy). There is not enough excess righting energy to dissipate the excess heeling energy. Note: to determine maximum roll, you take the area from 0° to point C and compare it to the area between the curves to the right of point C. The 25° to windward comes into play when calculating A_2 for the U.S. Navy criteria.

7. Apply U.S. Navy criteria for beam winds:

Element 1: Righting arm at point C < 60 % of max righting arm:

R.A. @ pt C = 1.03 ft

60% of max R.A = 0.6 *(1.22) = 0.73 ***Does not meet criteria***

Element 2: A1 > 140% of A2:

A_1 = approx. 19 squares

A_2 = approx. 31 squares

19 squares < 1.4 *(31 squares) ***Clearly does not meet criteria***

The ship clearly does not meet the criteria in the deballasted condition. (That is the major reason why ships ballast: to improve their dynamic stability as well as their static stability). The ship has to pass both elements to meet the U.S. Navy beam wind criteria.

Chapter Five
Dynamic Stability

A. Hydrostatic Pressure & Added Weight
B. Free Surface Effect
C. Free Communication Effect
D. Stability After Flooding
E. Floodable Length

A. HYDROSTATIC PRESSURE & ADDED WEIGHT

There are four effects of loose liquids on a ship:

- Hydrostatic Pressure on the structure of the ship
- Additional Weight
- Free Surface Effect
- Free Communication Effect

If the skin of the ship is ruptured and flooding follows, the hydrostatic pressures formerly exerted on the shell plating are now placed on the bulkheads of the flooded compartments.

This is one of the reasons why bulkheads require stiffeners to prevent them from bulging, and why bulkheads that are farther below the water line are thicker, require more stiffening, and are given a higher test pressure.

Flooding water will exert a considerable upward pressure against the overhead deck of a flooded compartment if the deck in question is some distance below the water line. This pressure will be just as great if there is an air bubble trapped above the flooding water.

Therefore, damage control teams must give thought to the problem of shoring weakened decks

downward as well as upward, and to the consequences of opening a hatch, scuttle, or manhole over a flooded compartment.

Hydrostatic pressures are also imposed on bulkheads and decks by the contents of intact fuel and water tanks. Those bulkheads are obviously designed to withstand the normal pressure of the liquid carried in the tank. Damage to the ship may weaken those bulkheads, however, and they may require shoring.

The amount of water (in gallons per minute) coming through a hole in a ship's hull is shown in the table below. The flooding flowrate is dependent upon the depth of the hole below the surface of the water.

Hole Dia. in inches	Head of Water in Feet			
	2′	6′	12′	18′
1″	28 gpm	49 gpm	69 gpm	84 gpm
3″	250	433	612	750
6″	1000	1732	2449	3000
12″	4000	6926	9795	11996

It should be apparent looking at the table that it does not take a very large hole to rapidly overwhelm your ability to pump out flooding water. **The importance of plugging the hole cannot be stressed enough.** Put anything in the hole to slow the flow. The proverbial square peg in a round hole will help and is certainly better than nothing.

The term flooding water refers to water that has been introduced into a ship as a result of damage. It may be the water that enters immediately after a hit or may be the deliberate sprinkling or counter-flooding of a space which is normally kept dry or void. Flooding is handled as added weight. Hence, the effect of the added weight on the vessels Center of Gravity (G) must be determined.

In most cases of flooding there will also be free surface effects, and possibly free communication effects. In any event, the added weight effect must be taken into account. If there is free surface or free communication, the effect of these factors must then be evaluated. Free Surface and free communication will be discussed later in the chpater.

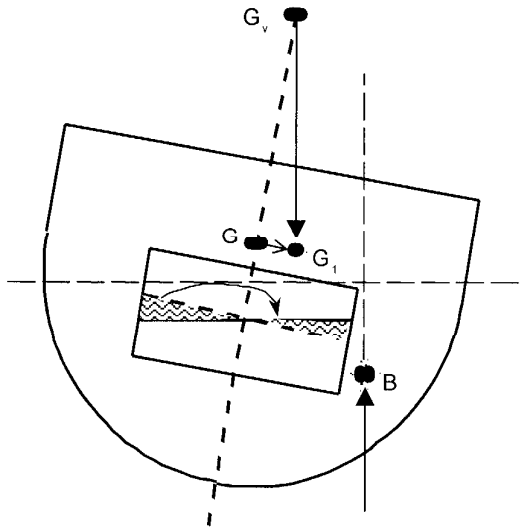
Solid flooding refers to a compartment completely filled from deck to overhead deck. The effect on the stability of the ship is that of an added weight only.

Partial flooding refers to a condition in which an intact compartment is not completely flooded. An intact compartment means that the deck on which the water rests and the bulkheads that surround it remain watertight. If the boundaries remain intact, water will neither run into nor out of the flooded compartment as the ship rolls. This type of flooding has all the effects on stability of an added weight, and in

addition, the free surface effect that will always reduce GM and over-all stability. Except where the free surface is relatively narrow (athwartship) and the flooding is low in the ship, the final result of partial flooding is likely to be a decided loss in over-all stability. Both surface permeability and pocketing tend to reduce the adverse effects of partial flooding, so that the net loss is not quite so large as it would otherwise be.

B. FREE SURFACE EFFECT

As the ship rolls, any liquids which have a "free surface" (an unpressurized air interface) slosh from side to side. Examples of liquids with free surfaces include; partially filled tanks, partially flooded compartments, slack water in the bilge. This sloshing of liquid results in a "wedge" of liquid being transferred from the high side of the ship to the low side. This is a **transverse weight shift** that causes the center of gravity to shift off of the centerline. The weight shift increases with increasing angles of heel as more and more liquid runs to the low side of the ship.



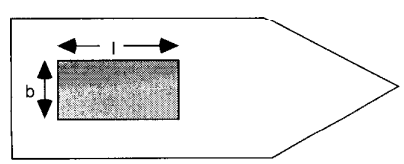
As the diagram above shows, when G moves off of the centerline the righting arms are reduced to that side and stability is reduced. The difference between

this effect and that of a solid weight is that as the ship rolls farther, G also moves farther off the centerline, which further reduces stability. As the diagram shows, this reduction in stability can be represented by a "virtual rise" in the center of gravity up to G_v. This representation gives us the same righting arms as G_1 but keeps G on the centerline. As you remember, a rise in the center of gravity results in a reduction of stability that gets worse as the angle of heel increases (sine correction to Static Stability curve). This is exactly what is occurring with the free surface effect. We cannot model this as an off-center weight (cosine correction) because as the angle of heel increases, the off-center weight increases also, and a cosine correction shows just the opposite; decreasing effect with increasing angle of heel.

How much does G "rise" (GGv) due to the free surface effect? The formula for the rise in G, for a rectangular compartment flooded with salt water, is:

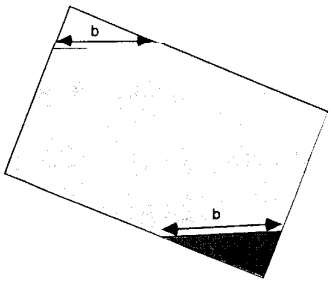
$$GG_v = \frac{(b^3 * l)}{(12*35*W)}$$

GG_v = Rise in G due to free surface (feet)
b = width of free surface (feet)
l = length of free surface (feet)
W = Displacement of ship <u>including</u> added liquid (tons)



It is clear from the formula that the free surface effect is highly dependent on the width of the compartment or tank that is flooded. Designers carefully control the width of tanks on a ship and in larger tanks swash bulkheads (baffles) are placed longitudinally to slow down the sloshing effect and therefore reduce the detrimental effect on stability. *By cutting the tank width in half, you reduce the free surface effect by a factor of four.* Nowhere in the formula is there mention of location or depth of the liquid. The free surface effect is independent of location (Don't forget though that the location does matter with regard to the added weight of the liquid). The depth of the liquid also does not matter unless the compartment or tank is nearly full or nearly empty.

This can result in **pocketing** where the surface of the liquid hits the overhead of the tank or fills the bottom corner of the tank thus reducing "b" and therefore reducing the free surface effect. The pocketing effect is not considered when calculating the free surface effect, therefore, if it does occur, your ship's stability may be slightly better than the calculations indicate.


b
b

Surface permeability is basically how much "stuff" is sticking up thru the surface of the liquid. If there are engine blocks, lockers, bunks, or other things sticking up above the surface of the liquid, they reduce the "free" surface. They act somewhat as baffles and reduce the sloshing of liquid from side to side, thus, they reduce the free surface effect. This reduction is generally not considered in the calculation of the free surface effect, therefore, if it exists, the ship's stability is slightly better than the calculations indicate.

Ways to Minimize Free Surface

- Keep bilges dry
- Minimize partially filled tanks (follow liquid loading instructions)
- Never have a partially filled ballast tank
- After Damage - Press up or pump out partially filled compartments

<u>ANY</u> FREE LIQUIDS (FUEL, WATER, FLOODING) ABOARD A SHIP HAVE A NEGATIVE EFFECT ON STABILITY

C. Free Communication Effect

Flooding in free communication with the sea occurs when a compartment *open to the sea* is not completely filled, and the sea is free to flow in and out as the ship rolls.

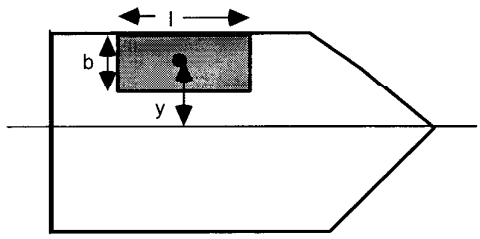
Free communication exists only when there is a condition of partial flooding and the water level in the compartment remains at sea level regardless of the movements of the ship. This condition usually occurs when a large hole in the side extends above and below the water line and the partially *flooded compartment is vented* as the ship rolls. The results of partial flooding in free communication with the sea are the same as those for partial flooding with boundaries intact, except that the free communication effect is added to the free surface effect. The free communication effect further decreases the stability of the ship.

Even though the compartment is open to the sea, the water in the compartment space is still *regarded as an added weight*. The displacement of the ship will be increased and the position of G will shift as for any added weight.

The free communication effect is also modeled as a "virtual rise" in the center of gravity.

$$GG_v = \frac{(b * l\, y^2)}{(35*W)}$$

GG_v = Rise in G due to free surface (feet)
b = width of free surface (feet)
l = length of free surface (feet)
y = transverse distance from centerline to center of compartment (feet)
W = Displacement of ship <u>including</u> added liquid (tons)



The reduction in stability caused by free communication is <u>superimposed</u> on the effect of the added weight and the effect of free surface. The free communication factor accounts for the weight of water that moves in and out of the compartment as the ship either rolls or lists away from the upright condition.

Note: To have free communication, you must have two things;

- *A compartment or tank open to the sea*
- *An off-center compartment (if on centerline, y=0)*
-

If you have free communication, you also have free surface effect, and must consider the effects of <u>both</u> on your stability.

How do you eliminate free communication?
PLUG THE HOLE!!

D. STABILITY AFTER FLOODING

To analyze flooding problems, it is necessary to follow the following steps:

1. Consider the effect of the *added weight* of the flooding water:

- Loss/Gain of stability? KG Calculation Worksheet
- Is there enough reserve buoyancy to support weight of flooding water?
- Typically flooding is low weight – lowering G, increasing stability (looking at it only from an added weight view)
- Is it an off-center weight? Compute angle of list.

2. Consider the *free surface effect*:

- Determine loss of stability due to free surface if it exists

$$GG_v = \frac{(b^3 * l)}{(12*35*W)}$$

GG_v = Rise in G due to free surface (feet)
b = width of free surface (feet)
l = length of free surface (feet)
W = Displacement of ship <u>including</u> added liquid (tons)

- How to eliminate? - Press up or Pump out

3. Consider *free communication effects*:

- Determine loss of stability due to free communication if it exists

$$GGv = \frac{(b * l y2)}{(35*W)}$$

GG_v = Rise in G due to free surface (feet)
b = width of free surface (feet)
l = length of free surface (feet)
y = transverse distance from centerline to center of compartment (feet)
W – Displacement of ship <u>including</u> added liquid (tons)

- How to eliminate? - Plug the hole

4. Put all effects together:

KG_v = KG(due to added weight) + GG_v(FSE) + $_{GGv}$(FCE)

It is usual to combine the added weight effect, free surface effect, and free communication effect steps which affect the vertical position of G and deduct one sine curve from the new stability curve (taken from the cross-curves). Then the cosine curve of heeling arms for the off-center position of G (due to the off-center weight of the liquid) is applied.

Let's look at an example of analyzing a flooding problem:

Example: On November 25, 1972, CGC JARVIS grounded in Iliuliuk Bay, Alaska (Dutch Harbor). The grounding punctured a 4" by 6" hole in the starboard side of the engineroom on the bottom (It also sheared off the sonar dome). After plugging the hole in the engineroom, JARVIS got underway enroute Honolulu for permanent repair. Shortly after getting underway the ship encountered 30 foot seas and 70 knot winds and the patch on the hole in the engineroom failed. The engineroom flooded to the 15 foot level, disabling all main propulsion machinery. JARVIS maintained some control over drift by using the bow prop until help arrived. It was towed to Dutch Harbor for more permanent repairs before transiting back to Honolulu.

Solution:
Let's perform an analysis of the JARVIS's stability with the engineroom flooded to the 15 foot level. We must consider the effects of the added weight of the flooding water and also the free surface of the flooding water. Free communication does not have to be considered since the engineroom is a centerline (y=0 ft) compartment.

Loading condition prior to grounding:

W	KGv	KM	GM
3020 tons	17.43 ft	20.5 ft	3.07 ft

After flooding occurs, we estimate the weight of the flooding water to be approximately 816 tons and its center of gravity is 9 ft above the keel.

A. Considering added weight only:

W	KG_v	KM	GM
3836 tons (3020+816)	17.43 ft (From KG worksheet)	20.5 ft (From nomograph with W=3836)	3.07 ft (KM-KG)

Looking at added weight only our stability has improved greatly (Now if we could only freeze that water in place!)

B. We must now look at the effect of free surface on the ship's stability. The outside dimensions of the enginerrom are approximately 64 ft long by 42 ft wide. With these values, we can determine the virtual rise in the center of gravity due to the free surface effect.

$$GGv = \frac{(b3 * l)}{(12*35*W)} = 2.94 \text{ ft}$$

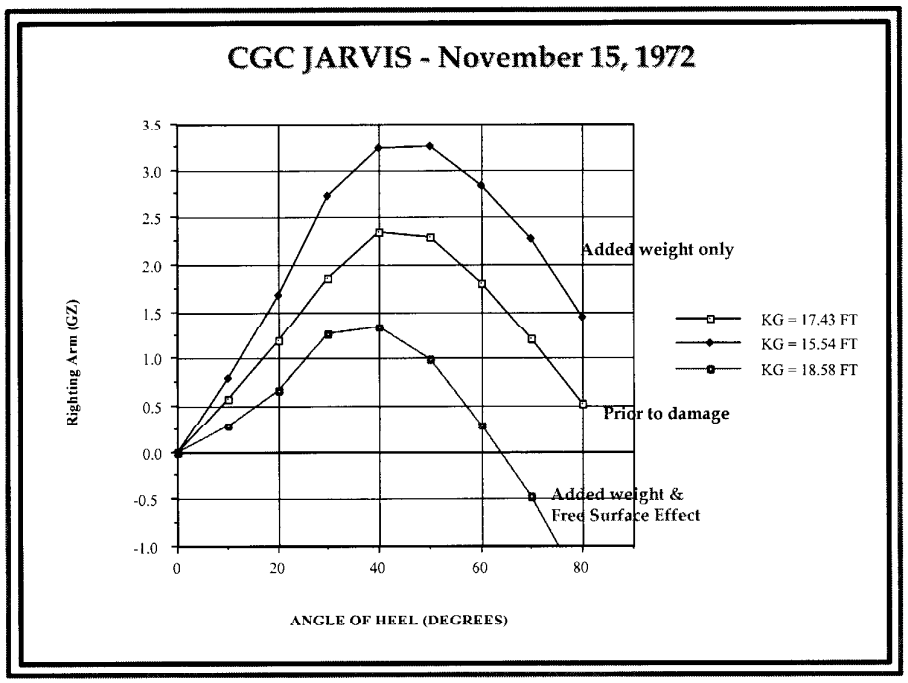
GG_v = Rise in G due to free surface (feet)
b = width of free surface (feet)
l = length of free surface (feet)
W = Displacement of ship <u>including</u> added liquid (tons)

Looking at the overall effect on stability, we take the KG due to added weight and add the virtual rise in KG due to free surface:

$$KG_v = 15.64 \text{ ft} + 2.94 \text{ ft} = 18.58 \text{ ft}$$

$$GM_{new} = 19.9 - 18.58 = 1.32 \text{ ft}$$

The effect of this flooding on the ship's righting arm curve is dramatic as shown by the plot on the next page. In the flooded condition, while waiting for assistance, the JARVIS experienced 60° rolls. How close to capsizing did they come, according to our stability analysis? Remember, our analysis did not consider the effects of surface permeability. Had the compartment not been on the centerline, we would have also had to consider the effects of free communication.

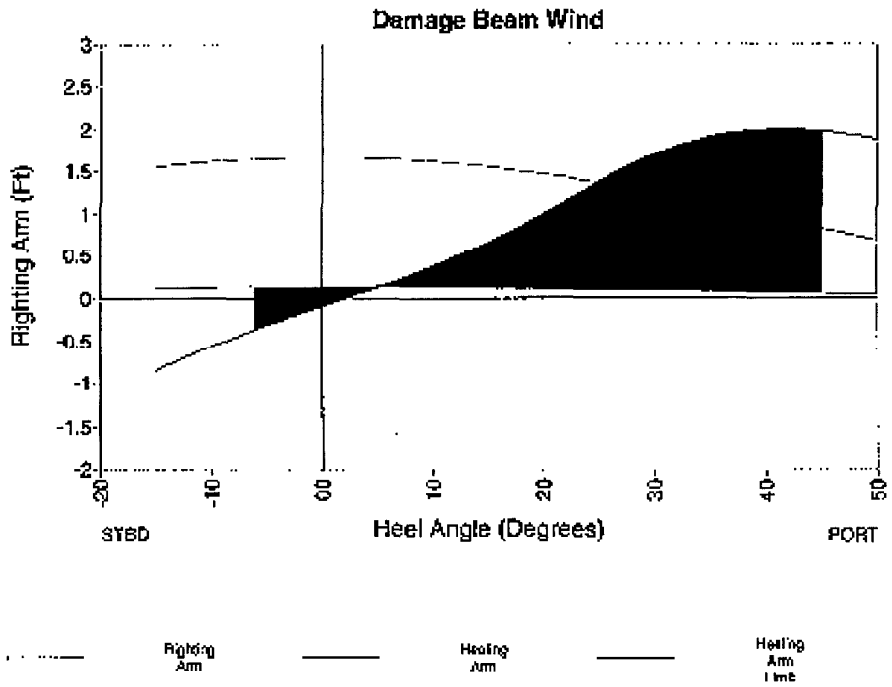


(scanned image of Jarvis plot)

Damage Beam Wind

Required Beam Wind Speed: 31.0 Knots
Maximum Acceptable Beam Wind Speed: 108.3 Knots

Criteria	Status	Sub-Criteria Value	Green/Yellow	Yellow/Red
Required A1/A2	SAFE	16.108	1.600	1.400
Required GZ/GH	SAFE	14.899	1.429	1.667
Allowable Heel Angle	SAFE	2.270	10.000	15.000
Required GZ-GH	SAFE	1.880	0.350	0.250

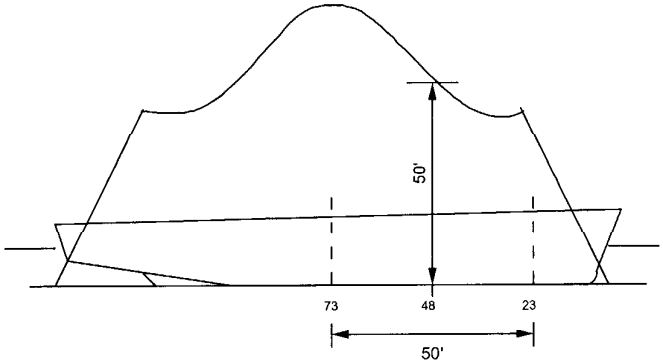


(scanned image of FCCS plot)

Prior to damage the max beam winds was 120 kts. Note list of 25 degrees due to wind.

E. FLOODABLE LENGTH

Floodable length is the maximum length of the ship that can be symmetrically flooded without the margin line being submerged. The *margin line* is a line parallel to and 3″ below the uppermost watertight deck (also known as the damage control deck or bulkhead deck). For most ships this is the main deck. The height of the floodable length curve above the baseline at any point indicates that when the length of the ship equal to the height of the floodable length curve, centered at that point, is flooded, the margin line will be at the water's surface. In the figure below, the floodable length at frame 48 is 50 feet, indicated by the vertical distance between the baseline and the floodable length curve. This means that if 50 feet of the ship were flooded, centered on frame 48 (between frame 23 and frame 73), then the margin line at the bow would be at the water's edge. Flooding any more than 50 feet centered at frame 48, would submerge the margin line.

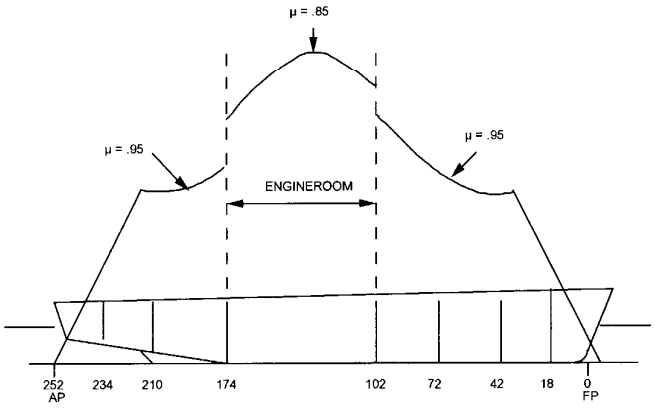


The floodable length curve has the characteristic J-shape in the bow and stern areas. This is because flooding centered at or near amidships results in *parallel sinkage* with little or no trim, and a great volume of flooding water is needed to bodily sink the ship. The curve is low near the ship's quarter lengths because flooding here produces trimming as well as bodily sinkage, and it does not take a great deal of flooding to bring the margin line at the bow or stern down to the sea surface. At the ends of the ship, the floodable length increases because the fineness of the hull at the ends, particularly the bow, reduces the volume of the flooded spaces. Therefore, a greater length of the ship must be flooded in order to bring the ends down to the water's surface.

The floodable length curves are developed for certain values of volume permeability (This differs from surface permeability mentioned with the free surface effect). Permeability is the percentage of the volume within the space that can be flooded with water. Spaces with large amounts of solid objects

such as enginerooms and full cargo holds would have lower values of permeability that an empty space which would have a permeability of 100% (1.0).

A permeability of 95% (0.95) is usually assumed in all spaces outside the main machinery space (engineroom) while a 0.85 permeability value is typically used within the engineroom. (Note figure)



Use of the Floodable Length Curve:

One use of the floodable length curve is to checked to see whether flooding of individual compartments or combinations of adjacent compartments exceeds the floodable length (at the appropriate permeability), indicating submergence of the margin line. Using the floodable length curve, submergence of the margin line can be determined by comparing the longitudinal distance bounding the spaces flooded with the vertical distance to the curve,

measured from the baseline at the midpoint of the spaces in question. If this longitudinal distance exceeds the vertical distance to the curve, then the margin line will be submerged, and the ship's safety endangered.

The floodable length curve is only an indicator of the severity of a damaged condition and should not be used alone to determine whether or not a vessel will survive a particular casualty.

When using the floodable length curves you always have to keep in mind the curves limitations. They include:

- Floodable length does not take into account transverse stability (GM/righting arms). The ship may capsize well before the margin line is submerged.
- Floodable length always assumes symmetric flooding (creating no list). Therefore it does not consider list resulting from asymmetric flooding.
- The floodable length curve defines a compartment as all of the volume bounded by watertight transverse bulkheads, not considering any watertight decks or watertight longitudinal bulkheads.
- Considers flooding of adjacent compartments only. You cannot look at the individual effects of non-adjacent compartment flooding and combine them to determine their final result.
- The floodable length curve is generated at one loading condition, usually full load (minimum reserve buoyancy). Therefore, if you are in a loading condition other than full load (before damage), then the floodable length curve will generally give you a more pessimistic view of your condition after damage.
- The floodable length curve only considers the added weight of the flooding water. It does not consider free surface or free communication effects on the ship's stability.

The previous figure shows a floodable length curve for a particular ship. With the information contained in this figure, it is possible to determine at a glance whether the flooding of a compartment or a combination of compartments will cause the margin line to be submerged.

Step by step procedures for using the floodable length curve:

- Locate the watertight bulkheads that bound the forward and after extent of the flooding.
- Where these bulkheads intersect the baseline, draw diagonal lines toward the center of the flooded region at 63.4° to the baseline. These two diagonal lines should intersect directly above the center of the flooded region of the ship.
- Where these diagonal lines intersect relative to the floodable length curve determines the severity of the flooded condition. If the intersection falls below the floodable length curve, then the margin line will not be submerged. If the intersection falls above the floodable length curve, then the margin line will be submerged. Also the relative distance from the floodable length curve, above or below, will indicate the relative severity of the flooding condition (bad, really bad, not so bad).

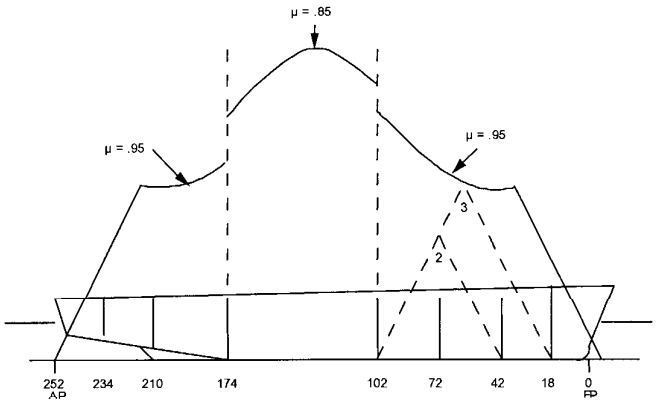
If the margin line is slightly submerged, it may still be possible to save the ship provided that the deck openings, vents, hatches, doors, etc. are watertight and will prevent downflooding. Likewise, if the margin line is close to but not yet submerged, the ship may still be in danger. This is because doors, hatches, vents, etc. and other openings on the main deck are brought close to the sea surface and may be

awash due to waves, rolling of the ship, wind heel, etc.

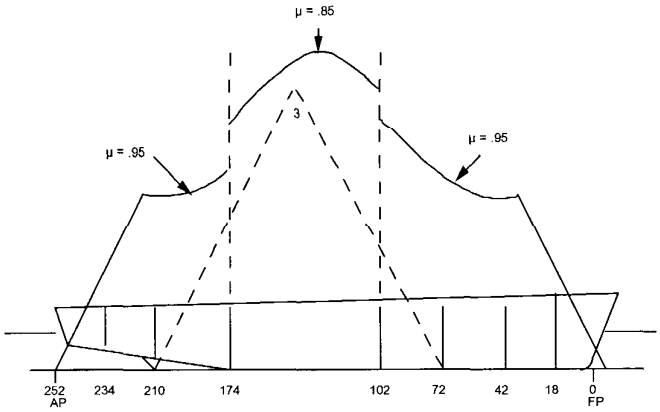
Examples:

1. The ship experiences flooding between frame 42 and frame 102. Will the margin line be submerged? (No, far from being submerged.)

With the above flooding condition, you receive a report that bulkhead 42 has given way and bulkhead 18 is now the primary flooding boundary. Is the margin line submerged? (The margin line at the bow should be right at the water's edge.)

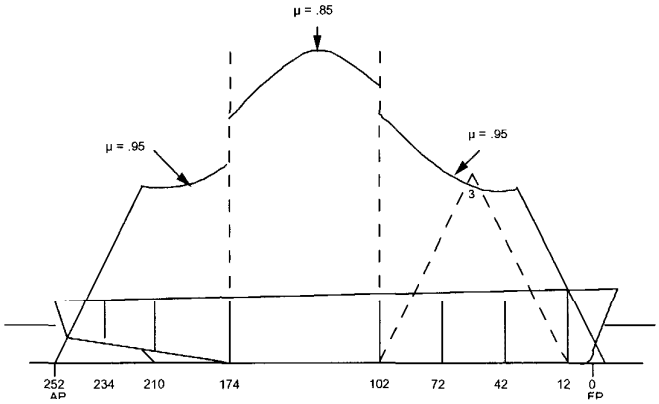


2. Your ship detonates a mine and you experience uncontrollable flooding between frame 72 and frame 210. Is your margin line submerged? (No) If not, where is it closest to the water's surface? (This flooding condition creates nearly parallel sinkage, therefore the margin line is nearly parallel with the water's surface, perhaps a little closer at the stern.)



3. Your ship strikes a pinnacle and you find yourself floating freely (not grounded). Reports indicate that the ship has flooded all compartments between frame 12 and frame 102. Is the margin line submerged? (Yes) Can you survive this flooding condition? Yes, if you can maintain watertight integrity on the main deck and prevent any additional flooding.)

How important is the bulkhead at frame 102? (Extremely important. I think it would be safe to say that the loss of bulkhead 102 would cause the ship to be lost due to a lack of reserve buoyancy.)



Chapter Six
List, Lolling & Inclining Experiments

A. List & Lolling
B. Inclining Experiment

A. LIST

There are two basic conditions that may cause the ship to take on a permanent list:

Condition One – Off-center weight (with or without positive GM).
Condition Two – Negative GM (lolling).

Condition One

1. An off-center weight may occur with:
   - Flooding in compartments that are off the centerline.
   - Flooding in compartments which are not symmetrical about the centerline.
   - Flooding in centerline compartments that have off-center volume permeability.
   - Pumping liquids across the ship.
   - Pumping overboard the contents of wing tanks.
   - Jettisoning topside (or below-decks) weight from one side.
   - Shifting of ammunition, cargo or personnel, from one side of the ship to the other.

The angle of list produced will depend on two factors;

- the inclining moment of the weight
- the righting moment of the ship.

The size of the angle of list can be calculated using the following formula:

$$\tan \varnothing = \frac{(w * d)}{(\Delta * GM)}$$

$\varnothing$ = angle of list in degrees
w = size of off-center weight (tons)
d = distance from centerline or distance shifted transversely (f
Δ = ship's displacement, including added weight (tons)
GM = ship's new GM taking into account the weight (ft)

This formula is *only accurate for angles of list less than 10°.* Beyond 10° the metacenter is no longer stationary and GM has no meaning.

A ship which is listed due to off-center weights may feel stiff and roll with a snap, or it may feel tender and have a slow, logy roll. Two identical ships may list at a given angle, one with unimpaired GM and a large off-center weight, the other with impaired GM and a small off-center weight. The first ship is likely to be fairly stiff and stable, whereas the second is likely to be tender and sluggish in returning from a roll, even though the angle of list is the same in both cases.

The feel of the upright ship depends on the size of the righting moment that is developed. Likewise, the stiffness of the listed ship depends on the size of the righting moment developed as it heels away from the angle of list. In general, if the list is due solely to an off-center weight, the roll characteristics of the ship will not dramatically change. The ship will roll with about the same period, it will just roll about the angle of list.

In warships the most usual cause of negative metacentric height is damage involving large amount of loose water. It is rare that a damaged ship has no off-center weights whatsoever. Consequently, a combination of negative GM and off-center weights is more likely than negative GM alone.

It can occur in smaller ships that take aboard large amounts of loose water on high deck levels. This is especially true if such ships fail to ballast their fuel tanks properly (for those that have the capability) or extremely low on fuel and incapable of ballasting. It can also occur in small ships which have several engineering spaces flooded with off-center volume permeability.

A list due to a combination of off-center weights and negative initial stability cannot necessarily be identified by flopping in a seaway, since the ship will probably list to one side only.

You may suspect this condition if one or more of the following exist:

- Large areas of broad free surface, accompanied by some unsymmetrical flooding or other off-center weights.
- Considerable amounts of topside weight or high flooding, accompanied by unsymmetrical flooding or other off-center weights.
- A large list (>10°) out of all proportion to what the known amount of off-center weight should produce.
- The ship listing to one side only, but very logy and sluggish in its response to wave action or other disturbance.

Condition Two

Negative GM may occur when G is on the centerline but has risen above M. When the center of gravity is above the metacenter, upsetting arms instead of righting arms develop for the first few degrees of heel. The ship cannot remain upright, and must either capsize or list to some angle where positive righting arms again develop. The list developed must be greater than approximately 10°. The metacenter must move to prevent the ship from capsizing; this only occurs beyond 10°. This is termed **lolling**.

Thus, it is possible for a damaged ship to list even though all solid weights in it are symmetrically disposed and all flooding is symmetrical with respect to the centerline.

When negative GM creates upsetting arms, positive righting arms can again develop at some angle of heel due to one or both of two causes:

- Form and weight characteristics of ship.
- Pocketing of loose water.

One possible cause of negative GM may be a large amount of *loose water* that produces a virtual rise in G. If the loose water is pocketed as the ship heels over, the effect of the pocketing is to diminish the sine correction curve of the free surface effect.

Note that in both cases the residual dynamic stability is relatively small. A ship with negative GM may have seriously impaired over-all stability,

although this is not necessarily the case of all types of ships. For example, a cargo ship may have negative GM when empty, and yet have satisfactory over-all stability for its normal loading conditions.

A Coast Guard cutter with negative GM has seriously impaired overall stability and very little residual dynamic stability.

The following factors are involved in causes of list due to negative GM:

- Added high weights, raising G.
- Removed low weights, raising G.
- Considerable loss of freeboard, lowering M.
- Extremely light draft, lowering M.
- Loose water, causing a virtual rise in G due to free surface and free communication effects.

The last item above, *loose water*, is the major contributing cause of negative GM in warships. For the typical Coast Guard cutter, changes of loading in excess of design limits are rare. However, severe damage frequently introduces large areas of loose water, which renders GM negative and would cause the ship to capsize if it were not for the beneficial effect of pocketing. Most destroyer hull-shapes do not redevelop positive righting arms due to form and weight characteristics. If G is raised above M in this

type as the result of solid weight changes, the ship will capsize. Such a hull can list due to negative GM, provided the negative GM is caused by loose water which pockets at larger angles of heel. For the typical Coast Guard cutter to loll, it would take either the last item alone, or a combination of two or more of above. Generally if only one of the first four items above is present, it alone is not enough to cause the ship to have negative GM.

A ship with negative GM and no off-center weights will list with equal facility to either port or starboard, and, in a seaway, or after a hard turn, may flop over to the other side. The angle of list will be large (>10°). The ship's roll will be very slow and sluggish. A damaged ship with negative GM is in jeopardy. A damaged ship with very low GM (i.e., almost negative) can also be in a very critical condition because of its reduced dynamic stability.

The following conditions should lead damage control personnel to suspect negative metacentric height:

- Listing with no off-center weights and no external inclining moments such as wind, rudder, or other such items.
- A list to either side, or flopping from side to side.
- Large areas of broad free surface, particularly if near the water line.
- Large amounts of unusual topside weight (i.e.; icing, large numbers of passengers).
- Large amounts of removed low weight (i.e.; low on fuel & failure to ballast).

<u>DO NOT</u> attempt to remove the list by transferring weights or liquid load transversely. This will cause your ship to, at best, flop to the other side at a greater angle of list, or, more likely, to capsize.

<u>DO</u> take steps to lower your center of gravity; jettison topside weight, reduce free surface, eliminate free communication, lower weights down in the ship, etc.

The irregular motion in seaway of a ship that has very low or negative GM is referred to as lolling. In a lolling condition, the ship is sluggish in its response to inclination, and is apt to hang at the extreme angle of a roll before coming back.

In conclusion, the recognition of the cause of a list involves identifying conditions that could render GM negative, and at the same time, identifying conditions which could introduce off-center weights.

<u>Before</u> any corrective action is taken to remove list, you <u>must</u> determine if it is due to off center weight, negative GM or both.

In correcting a list due to off center weight, it is advisable to compensate only for the known amount of off-center weight. It is advisable to under compensate slightly, and subsequently make up the difference as required.

If an attempt is made to correct immediately both the list due to negative GM and the list due to off-center weights, by any measure which creates a transverse moment (such as pumping fuel oil across the ship), one of two things will happen:

A. The ship may flop over (list to an even greater angle on the other side).
B. The ship may capsize.

If you suspect you have negative GM, whether with, or without, off-center weight, your first course of action is to take steps to lower your center of gravity.

B. INCLINING EXPERIMENT

Previously it has been indicated that the vertical location of the center of gravity must be known to determine the over-all stability characteristics of a ship. This information about G is needed both in the design phase and after the ship is completed. The designer must predict the position of the center of gravity in order to provide the ship with adequate stability.

Although the position of the center of gravity as estimated by calculation is sufficient for design purposes, an accurate determination is required to establish the over-all stability of the ship when it is operating. This is accomplished by performing an *inclining experiment* to accurately obtain the vertical height of the center of gravity above the keel, KG, when the ship is completed. The inclining experiment measures GM accurately. Since the ship's draft is known, KM can be found from the curves of form.

$$KG = KM - GM$$

An inclining experiment consists of moving one or more large weights across the ship and measuring the angle of list produced. This angle of list usually does not exceed 2°.

The metacentric height is calculated from the formula:

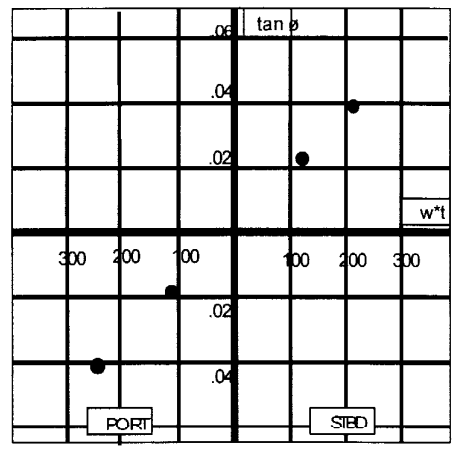
$$GM = \frac{(w * d)}{(\Delta * \tan ø)}$$

ø = angle of list in degrees
w = size of off-center weight (tons)
d = distance from centerline or distance shifted transversely (ft)
Δ = ship's displacement, including added weight (tons)
GM = ship's new GM taking into account the weight (ft)

The formula above is just a rearrangement of the formula previously given for calculating angles of list. In the case of an inclining experiment the angle of list is known but GM is not known.

DATA

w*t (ft-tons)	Tan ø
STBD	
120	.022
212	.039
PORT	
113	.018
245	.042



If an excessive trim exists and is not removed from the ship for the inclining, a correction for this trim must be made before computing KG. Also, the effect of any free surface existing in ship's tanks must be taken into account. For the experiment to be accurate, the ship must be floating freely (not constrained from moving by mooring lines, camels, etc.), there should be no wind or waves affecting the ship, and, as stated above, the free surface of liquids should be minimized and accounted for. As a result of the experiment, data is obtained which is then plotted on a graph:

The data plotted should fall in a straight line. If it does not than either the data was not taken accurately or there is some external influence on the ship (ie; wind, waves, etc). The slope of the line plotted is equal to tan ø ÷ (w*t).

GM = 1÷ (W * slope)

The KG obtained from the inclining experiment is that for the ship in the condition of loading in which the ship was inclined. This is known as the "as-inclined condition." The ship may have been in any condition of loading at the time of inclining not necessarily an operating condition. Therefore, in order to convert the data thus obtained to practical use, KG must be found for operating conditions. These conditions include an extreme light ship, a fully loaded ship, and one or two intermediate conditions.

The results of the experiment are furnished to each ship as a Booklet of Inclining Experiment Data. This booklet contains data on displacement, KG, and over-all stability for the operating conditions of load.

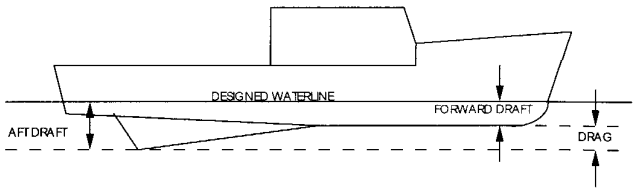
Chapter Seven
Trim and Longitudinal Stability

A. Trim
B. Trim & Draft Analysis - Weight Addition/Removal
C. Trim & Draft Analysis - Weight Shift
D. Trim Tables
E. Example Trim Problems

A. TRIM

Until now we have only discussed transverse stability. The reason for that is that your ship is much more stable longitudinally than it is transversely. Longitudinal stability is not something you generally have be concerned with; your ship is much more likely to roll over (capsize) then it is to pitch end over end.

Trim is the difference in the fore & aft drafts, minus the vessel's drag (if it has any). In equation form:



DRAG - A designed-in difference between fore & aft drafts (i.e. "designed in trim")

$$\text{Trim} = T_{aft} - T_{fwd} - \text{drag}$$

Positive Trim = Trim by the stern
Negative Trim = Trim by the bow

The mean draft is the average of the fore and aft drafts. In equation form:

$$T_{mean} = \tfrac{1}{2}\,(T_{fwd} + T_{aft})$$

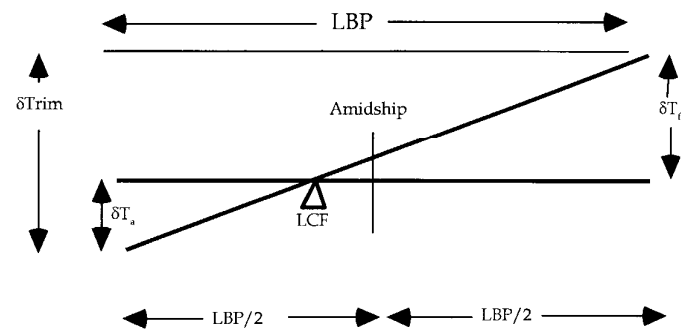
We are concerned with our ship's drafts and trim not so much from a stability standpoint but for some of the reasons listed below:

- **Seakeeping**: Trim by the bow results in wetter decks as the bow more easily buries itself.
- **Fuel Economy**: Trim by the bow creates a larger bow wave, increasing the resistance of the ship, requiring more power to go the same speed. It also puts the propellers closer to the surface where they are less efficient and more likely to cavitate (i.e. produce air pockets which can speed metallic erosion of the propeller).
- **Shallow Water Effects**: When operating in shallow water where maximum draft is a consideration, the trim should be kept to a minimum.

Trim is not considered "excessive" unless it either exceeds 1% of the length (1 foot of trim per 100 feet of length) or if it exceeds the parameters of the "Limiting Trim Diagram" contained in some of the Stability and Loading Data Booklets. For a 378′ WHEC, this would be in excess of three feet of trim. However, it is usually desirable to limit the amount of trim to much less than the "excessive" amounts the ship could have for the reasons mentioned above. Limiting the amount of trim is usually not a big problem if the ship is following its normal loading conditions.

B. TRIM & DRAFT ANALYSIS – WEIGHT ADDITION/REMOVAL

In analyzing a particular loading condition to determine a vessel's trim and final drafts, the procedure specified below should be followed. In a scenario in which weight is either added or removed, solve for the final, or "new" draft values by:



$$T_{a\text{-}new} = T_{a\text{-}old} + \delta T_m + \delta T_a$$
$$T_{f\text{-}new} = T_{f\text{-}old} + \delta T_m + \delta T_f$$

Where $\delta \mathbf{T_m}$ is the change in mean draft; and $\delta \mathbf{T_f}$ or $\delta \mathbf{T_a}$ is the change in the fore or aft draft due to trim. If the net change in the vessel's mean draft is positive (due to weight additions), a "parallel rise" is said to occur. If weight is removed (i.e. negative $\delta \mathbf{T_m}$), a "parallel sinkage" occurs.

The change in mean draft ($\delta \mathbf{T_m}$) is calculated by dividing the sum of the weights added & removed by the Tons-Per-Inch Immersion:

$$\delta T_m = \frac{\Sigma(\text{weights added and/or removed})}{\text{TPI}}$$

Note: units of the answer will be in inches!!

The next step is to determine the total change in trim by dividing the sum of the longitudinal moments (weight times the distance to the LCF) by the Moment-to-Trim 1″.

$$\delta\text{Trim} = \frac{\Sigma[(\text{weight added/removed})*(\text{distance to LCF})]}{\text{MT1}''}$$

Note: units of the answer will be in inches!!

After determining the total change in trim (δTrim), it is necessary to apportion this trim fore and aft using the relationships below:

$$\delta T_a = \frac{[(\text{LBP}/2) - (\text{distance between LCF and amidships})]}{\text{LBP}} * (\delta\text{Trim})$$

$$\delta T_f = \frac{[(\text{LBP}/2) + (\text{distance between LCF and amidships})]}{\text{LBP}} * (\delta\text{Trim})$$

Note: units of the answer will be in inches!!

The final or new draft values are then determined using the relationship introduced above:

$$T_{a\text{-new}} = T_{a\text{-old}} + \delta T_m + \delta T_a$$

$$T_{f\text{-new}} = T_{f\text{-old}} + \delta T_m + \delta T_f$$

In solving trim problems, it is important to keep the following points in mind:

- Weights removed or added must have a location from longitudinal point of reference (amidships or LCF).
- Of primary importance is the location of the LCF (since this is the "rotation point" of the ship in the longitudinal direction).
- The nomograph is used to determine the distance the LCF is from amidships, as well as the TPI and MT1".
- It is vital a consistent sign convention be employed and maintained. Typically, distances measured aft of the LCF are positive, and weights added are positive. Likewise, distances measured forward of LCF and weights removed are negative.
- Ensure correct units are used, particularly when determining the final or new drafts.

C. TRIM & DRAFT ANALYSIS – WEIGHT SHIFT

In a scenario in which weight is shifted, there is no parallel rise or sinkage. The final or "new" draft values are determined by the below relationships:

$$T_{a\text{-new}} = T_{a\text{-old}} + \delta T_a$$

$$T_{f\text{-new}} = T_{f\text{-old}} + \delta T_f$$

Where $\delta \mathbf{T_f}$ or $\delta \mathbf{Ta}$ is the change in the fore or aft draft due to trim.

Determine the total change in trim by dividing the sum of the longitudinal moments (weight times the distance to the LCF) by the Moment-to-Trim 1".

$$\delta \text{Trim} = \frac{\Sigma[(\text{weight added/removed})*(\text{distance to LCF})]}{\text{MT1}''}$$

Note: units of the answer will be in inches!!

After determining the total change in trim (δTrim), it is necessary to apportion this trim fore and aft using the relationships below:

$$\delta T_a = \frac{[(\text{LBP}/2) - (\text{distance between LCF and amidships})]}{\text{LBP}} * (\delta \text{Trim})$$

$$\delta T_f = \frac{[(\text{LBP}/2) + (\text{distance between LCF and amidships})]}{\text{LBP}} * (\delta \text{Trim})$$

Note: units of the answer will be in inches!!

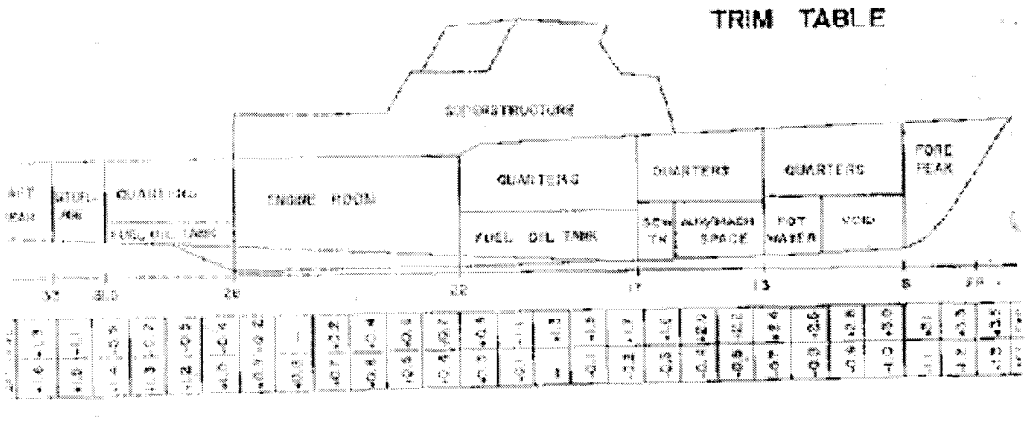
The final or new draft values are then determined using the relationship introduced above:

$$T_{a\text{-}new} = T_{a\text{-}old} + \delta T_a$$

$$T_{f\text{-}new} = T_{f\text{-}old} + \delta T_f$$

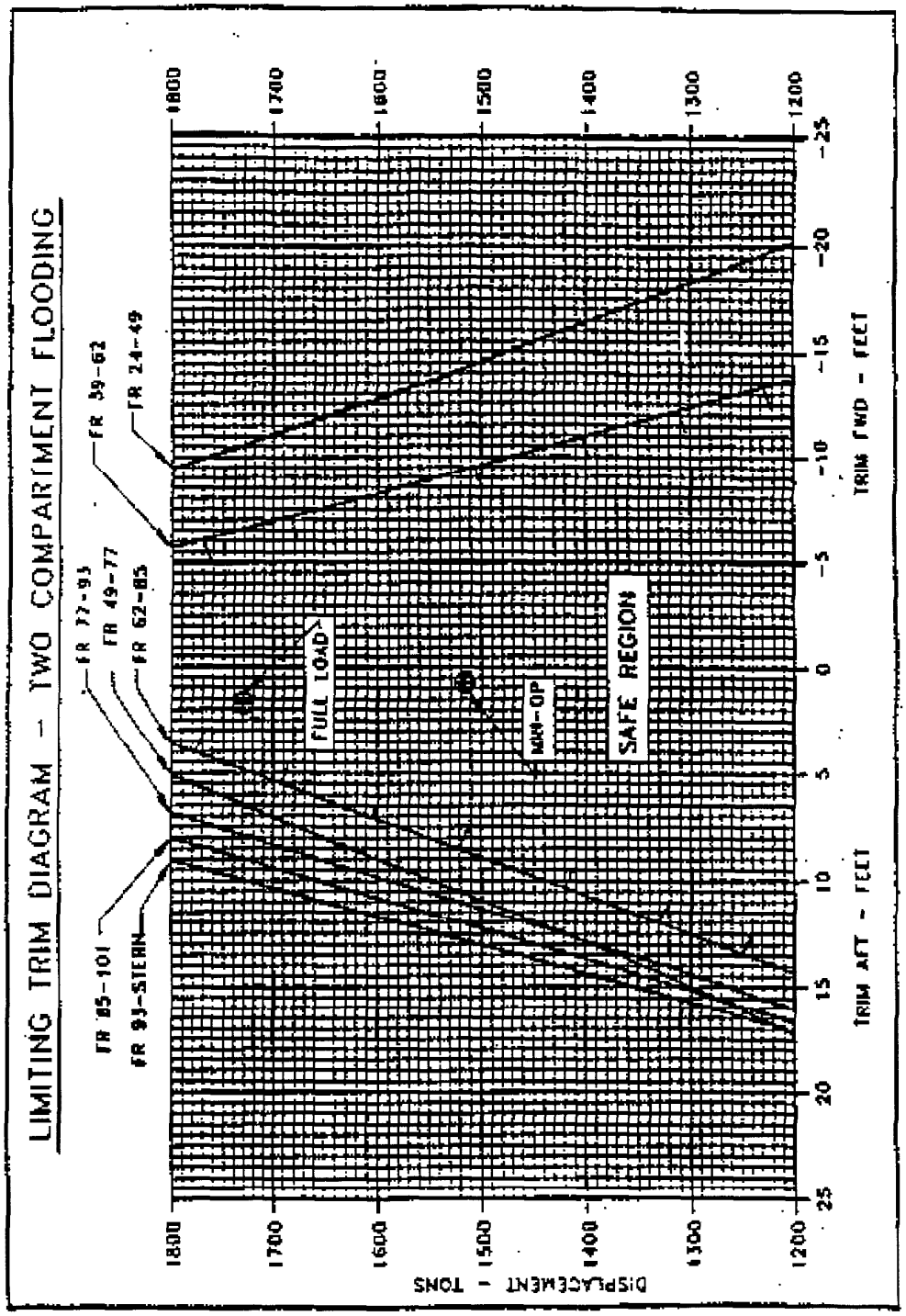
D. TRIM TABLES

In many cutter Stability and Loading Data Booklets a simplified way of calculating the changes in fore and aft drafts due to weight additions, removals or shifts is presented. The *Change in Trim Diagram* computes the change in fore and aft draft directly, taking into account both the change in trim and the change in mean draft. The diagram is set up for changes due to a specific size weight (it varies with cutter class) but if you add or remove a different size weight, the changes are proportional. For example if the diagram is set up for 2 tons of weight and you add 4 tons, just multiply the changes by 2. For weight shifts, just remove the weight from one location and add it to its final location and take the cumulative effect of both changes.



(scanned 110′ Trim Table)

Some Stability and Loading Data Booklets have a *Limiting Trim Diagram*. This diagram is similar, but usually less important, to the *Limiting KG Diagram* discussed in Chapter One. This diagram shows the limiting trim value that is permissible based on your loading condition. Generally speaking it is usually difficult to load your ship in such a way that exceeds your limiting trim, but the diagram may be of use in extreme trim scenarios, such as flooding due to damage. The diagram is useful though, in that it points out which cases of damage have the worst effect on your trim and survivability.



(Scanned Limiting Trim diagram)

E. EXAMPLE TRIM PROBLEMS

Example: (using formulas) A 270' WMEC loads 500 immigrants on the flight deck. Prior to the onload, the forward draft is 12' and the aft draft is 13' 6". A 270' WMEC has 0" drag. The length between perpendiculars (LBP) for a 270' is 255 feet. The immigrants are spread out on the flight deck so we will assume the center of the mass is about the center of the flight deck (59 ft aft of amidships – obtained from DC Book for location of helicopter). Find the new trim and new drafts after onloading the immigrants.

Solution:

Existing trim = 13' 6" - 12' - 0" = 1' 6" by the stern

Weight added=[500 * 150 lbs/each] ÷ 2240 lbs/ton
= 33.5 tons

From nomograph using prior to onload drafts:

Δ= 1600 tons
TPI = 17.52 tons/inch
MT1" = 253 ft•tons/inch
LCF = 14 ft aft of amidships

Compute the change in mean draft (parallel sinkage):

δT_m = [Σ(weights added and/or removed)] ÷ TPI
= 33.5 ÷ 17.52 = 1.9 **inches**

Note: units of the answer will be in inches!!

Compute the total change in trim:

δTrim = [Σ(weights added and/or removed)]÷ MT1"
= [(33.5) * (59 - 14)] ÷ 253 = 6 **inches** by the stern

Note: units of the answer will be in inches!!

Apportion the trim fore & aft:

Forward:

$$\delta T_f = \frac{[(LBP/2) + (\text{distance between LCF and amidships})]}{LBP} * (\delta Trim)$$

$$= ([255/2 + 14] \div 255) * (6)$$

$$= 3.3''$$

Note: units of the answer will be in

Aft:

$$\delta T_a = \frac{[(LBP/2) - (\text{distance between LCF and amidships})]}{LBP} * (\delta Trim)$$

$$= ([255/2 - 14] \div 255) * (6)$$

$$= 2.7''$$

Note: units of the answer will be in

Compute the final (new) drafts and trim:

$$T_{f\text{-}new} = T_{f\text{-}old} + \delta T_m + \delta T_f$$
$$= 12' + 1.9'' - 3.3''$$
$$= 11'\ 10.6''$$

$$T_{a\text{-}new} = T_{a\text{-}old} + \delta T_m + \delta T_a$$
$$= 13'\ 6'' + 1.9'' + 2.7''$$
$$= 13'\ 10.6''$$

New Trim: 13' 10.6" - 11' 10.6" - 0" = 2' by the stern

Or

= existing trim + change in trim

= 1' 6" by the stern + 6" by the stern = 2' by the stern

Note: When the change in trim gets divided up between the fore and aft drafts, the two parts (3.3" and 2.7") need to add up to the total (6").

Example: (using trim table) A 180' WLB in minimum operating condition loads an additional 25 tons of cargo on to the buoy deck, placing it approximately in the center of the deck (longitudinally and transversely). Determine the new fore and aft drafts.

Solution:

From Stability and Loading Data Booklet for Min Ops:

T_f = 10.91 feet (10' 11")
T_a = 12.93 feet (12' 11")

From Trim Table (next page):

δT_f = + 1.4 inches
δT_a = - 0.4 inches

Note: This is for a 5 ton added weight; we added 25 tons

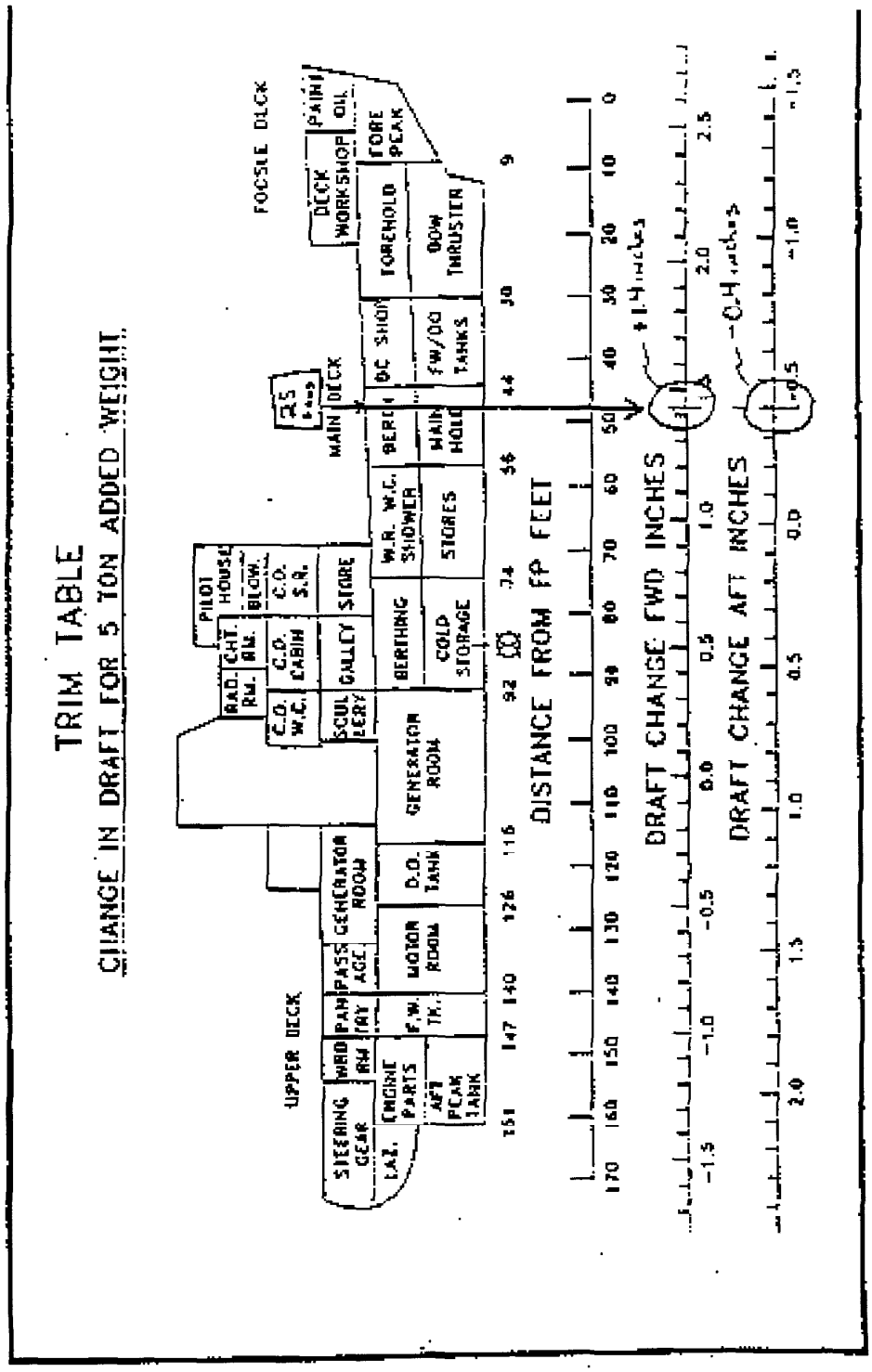
Ratio = 25/5 = 5

Actual Change in Drafts:

δT_f = +1.4" * 5 = + 7 inches
δT_a = - 0.4" * 5 = - 2 inches

New Drafts:

$T_{f\text{-new}}$ = 10' 11" + 7" = 11' 6"
$T_{a\text{-new}}$ = 12' 11" - 2" = 12' 9"

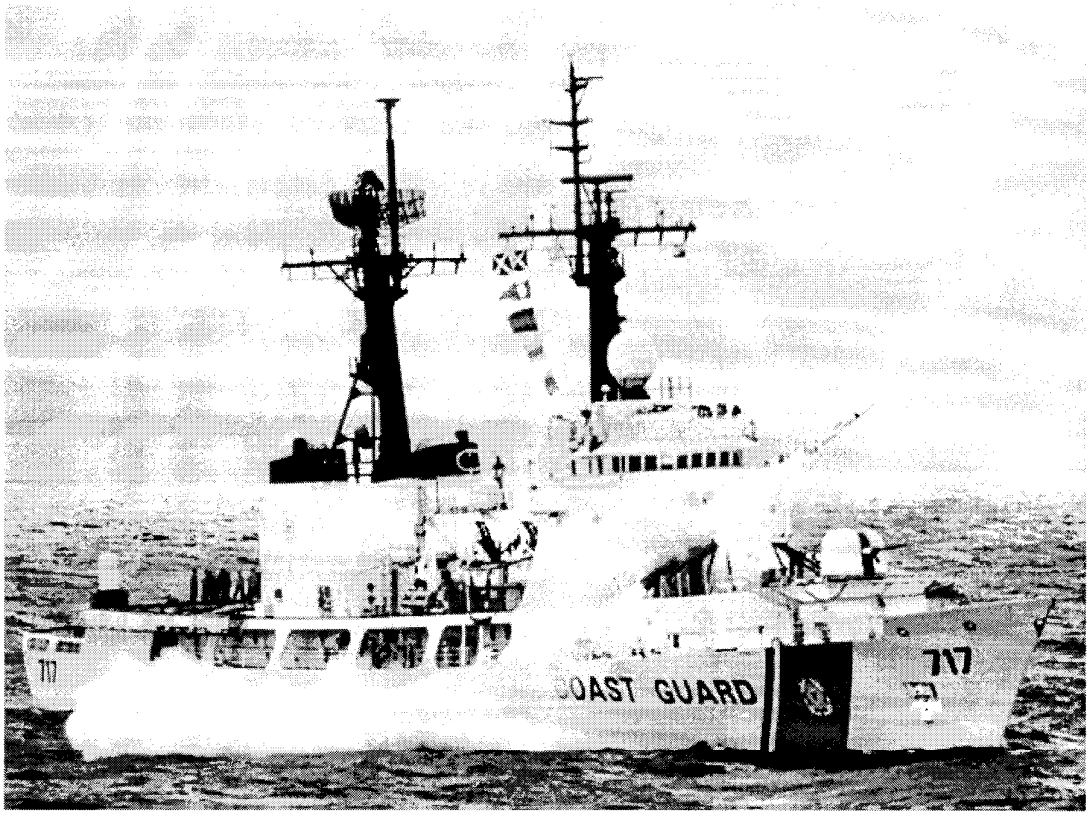


(scanned 180′ Trim Table w/ example)

Chapter 8

Damage Control Prior to Damage

A. Causes of Damage
B. Preparedness for Damage
C. Damage Control Books
D. Shipboard Training and Damage Control Programs



A.) CAUSES OF DAMAGE

Damage Control is 90 % preparation before an actual casualty and 10 % action after a casualty. It is important for the Captain to know the extent of damage which the ship can sustain. The survivability of the ship depends, in large part, on the ability of the ship's DC Organization to efficiently and effectively combat damage.

The causes for losing a ship can be grouped into three categories:

1.) FLOODING: (approximately 75 % of losses)

BODILY SINKAGE: Ship sinks on an even keel (lack of reserve buoyancy)

PLUNGING: Loss of longitudinal stability causes ship to sink bow first or stern first.

CAPSIZING: (most common) Loss of transverse stability causes ship to capsize

2.) UNCONTROLLABLE FIRES: (approx. 25% of losses): Inability to control fires necessitates abandoning ship.

3.) FAILURE OF THE SHIP'S GIRDER: Ship's structure fails due to damage or improper loading.

In most cases, the loss of a ship is a combination of one or more of the above causes. Ships, particularly military vessels, are designed with damage-resistance features to improve their survivability in hostile situations. Some of the damage resistance features designed into ships are listed below.

1.) ADEQUATE STRUCTURAL STRENGTH: Ships are built strong enough to withstand considerable structural damage without breaking in two.

2.) WATERTIGHT SUBDIVISION: Watertight subdivision is provided to limit the ingress and spread of flooding water after damage. It also limits the spread of fire and smoke.

3.) ADEQUATE RESERVE BUOYANCY: Ships are designed to have sufficient reserve buoyancy to withstand considerable flooding. Reserve buoyancy is measured by the ship's freeboard.

4.) ADEQUATE STABILITY CHARACTERISTICS: Ships are designed with adequate stability characteristics to keep it from capsizing after absorbing some damage (commensurate with ship type)

Knowing why ships are typically lost and the damage resistance features "built in" to your ship is a good start in assessing your vessel's overall survivability. As with any effective "team," knowing your people, and the procedures which they use in combating damage, are the key ingredients for success.

B.) PREPAREDNESS MEASURES TO RESIST VESSEL DAMAGE

1. DAMAGE CONTROL BILLS:

- established and tailored to ship policies
- effective, well planned documents
- crew well trained in their use
- reflect your actual procedures
- DC Book/DC drawings up to date and used

2. SHIP'S COMPANY INDOCTRINATION - TRAINING

- all hands should know the proper steps to take to save the ship (Drills/PQS)

- all hands should be familiar with the ship and its systems (Indoc)

- Often overlooked - training/drilling of CO, XO, EO, DCA, OOD in damaged stability and familiarity with damage control bills/DC Book

3. MATERIAL PREPARATIONS

- maintenance of ship's watertight integrity (bulkheads, fittings, closures)

- proper setting of material conditions of readiness/closure

- all damage control equipment aboard and well maintained

- maintaining proper DC closure log. Do your OODs take it seriously and understand the significance of not knowing the ship's closure condition?

4. WEIGHT CONTROL

- ship's grow heavier with age (authorized/unauthorized alterations, spare parts/equipment above allowance, etc)
- AVOID OVERLOADING
    - reserve stability is reduced
    - reserve buoyancy is reduced
    - reduces speed
    - reduces range (raises fuel consumption)
    - may invalidate stability info in DC Book/SLDB if location/amount unknown

- Ship's are designed to be able to withstand a certain amount of damage. If overloaded, the ship may not be able to withstand the damage it was designed to.

- Check by comparing your actual drafts/actual displacement at full load with the full load drafts specified in your Damage Control Book. Make sure you do not exceed the limiting draft/limiting displacement values specified in the DC Book.

5. Preventative Damage Control Actions

- Poor maintenance of watertight boundaries/fittings

- Failure to set proper condition of readiness/closure. Know what rounds are being made and what spaces are getting checked. Are some getting double-checked while others go unchecked?? Organize your BMOW and oiler/security rounds to ensure all critical spaces are checked.

- Improper/insufficient damage control classifications (as a guideline: Question any door or hatch below main deck with Zebra classification)

6. ADDITIONAL TOPSIDE WEIGHT

- Additional topside weight will increase KG/decrease GM to a point that the ship can no longer survive the damage it was designed to.
    - Passengers/survivors
    - Icing
    - A to N equipment

- Use the Limiting/Allowable KG diagram or the Minimum GM diagram to determine if you have sacrificed any ability to survive damage.

7. KNOW YOUR LOADING CONDITION AT ALL TIMES

- Daily, DCA's on larger ships should estimate values of displacement, KG_V, drafts and trim, determine if they are in a "safe" loading condition (using Allowable KG and Limiting Trim Diagrams) and post these numbers in DC Central and the Repair Lockers. FCCS is a great tool for documenting this information.

- Smaller ship CO's should know their approximate loading condition at all times.

C.) DAMAGE CONTROL BOOKS

Important information contained in the text of the Damage Control Books. This book is the primary source of ship-specific DC and Stability information.

1. Principal Characteristics - Simply a listing of the dimensions of the ship, basic power plant information, etc.

2. Summaries of Typical Loading Conditions (Full Load & Minimum Operating Load)

    a. Loading Summaries for each loading condition, identifying weights and locations of all items aboard the ship in a tabular format

    b. Trim, Draft and Stability Information for each loading condition, including values of KG, GM, displacement, drafts, etc.

3. Liquid Loading Instructions - Gives specific sequence of consuming fuel load and compensating with ballast. The liquid loading sequence takes into account minimizing free surface, minimizing list, maintaining acceptable trim, maintaining acceptable longitudinal stress on the hull and maintaining acceptable damaged stability.

4. Limiting Drafts/Limiting Displacement - Maximum draft or maximum displacement is specified considering reserve buoyancy, transverse stability, longitudinal strength and power requirements. Not given in all books.

5. Flooding Limits/Stability after Extensive Damage - Identifies the limits of flooding that the ship was designed to withstand while maintaining adequate stability characteristics. Survival of the vessel under these damage conditions is dependent on:

    a. Adhering to the liquid loading instructions.
    b. Maintaining proper drafts (not exceeding limiting drafts).
    c. Maintaining watertight integrity.
    d. Not exceeding the allowable KG_V values (according to limiting/allowable KG_V curve) or not falling below minimum GM values (according to the minimum GM curves).

Diagrams typically contained in the Damage Control Books:

1. Draft diagram and Functions of Form (nomograph)

2. Intact Static Stability Curves - For Typical loading Conditions
    a. Full Load
    b. Minimum Operating Condition

3. Heeling Arm Curves Usually combined with intact static stability curves.

4. Cross Curves of Stability - Used to generate Static Stability Curves.

5. Allowable/Limiting KG_V Curve - This diagram indicates the maximum allowable KG_V (in an intact condition) that will satisfy damaged stability criteria, hull strength requirements

and weather criteria (e.g. 90 knot beam wind and waves). The KG_V of any intact condition should be below all of the curves shown to ensure adequate damaged stability. 378' WHEC book does not have diagram but specifies a limiting KG_V in the text.

6. Limiting Trim Diagram - Not always provided. If not provided in a diagram, then some limiting draft/limiting displacement is typically specified in the text.

7. Floodable Length curve - Not always provided. Can be misleading and in general is not much use to you, the operator. More of a design tool than a useful diagram for the user.

Cutters over 200 feet only

8. Liquid Loading Diagram - This diagram indicates the distribution of the liquid load normally carried aboard. Specified in the diagram is the normal contents of each tank (potable water, fuel, salt water ballast, etc.), the weight of the liquid in the tank when full and also the list and trim created when filling the tank from empty.

9. Flooding Effect Diagram - This diagram indicates visually the effects on stability of the flooding of compartments below the main deck A PINK colored space indicates that flooding this compartment always has a negative effect on stability. GREEN colored spaces indicate an improvement in stability even though a free surface exists and YELLOW colored spaces indicate an improvement in stability only if a free surface does not exist. Uncolored spaces, whether dry or flooded have a negligible effect on stability. Also specified in the diagram is the capacity (in tons of salt water) as well as the transverse moment resulting (in foot-tons), computed assuming the compt is flooded solid.

Cutters under 200 feet only:

10. Change in KG Diagram/Change in GM Diagram (sometimes in tabular format) This diagram/table quickly shows you the effect of adding weights on the ship and its effect on KG or GM. It gives you the change of KG or GM due to the addition of a standard weight (e.g. 1 ton or 2 tons). Results can be scaled up or down according to the actual weight added. The effect of weight removals can also be determined by reversing the sign of the result.

11. Trim Table - This table allows you to determine the change in forward and aft drafts due to a weight addition. Similar to the Change in KG Diagram above, the Trim Table gives you changes in draft (fwd and aft) due to the addition of a standard weight (e.g. 1 or 2 long tons) which can be scaled up or down accordingly. Weight removals can be analyzed by reversing the sign of the result. Weight shifts can be analyzed by removing the weight from its old position and adding it to its new position, being careful with signs.

12. Tank Capacity Curves/Tables - These curves/tables correlate tank soundings to tank volume (in gallons of fuel or water).

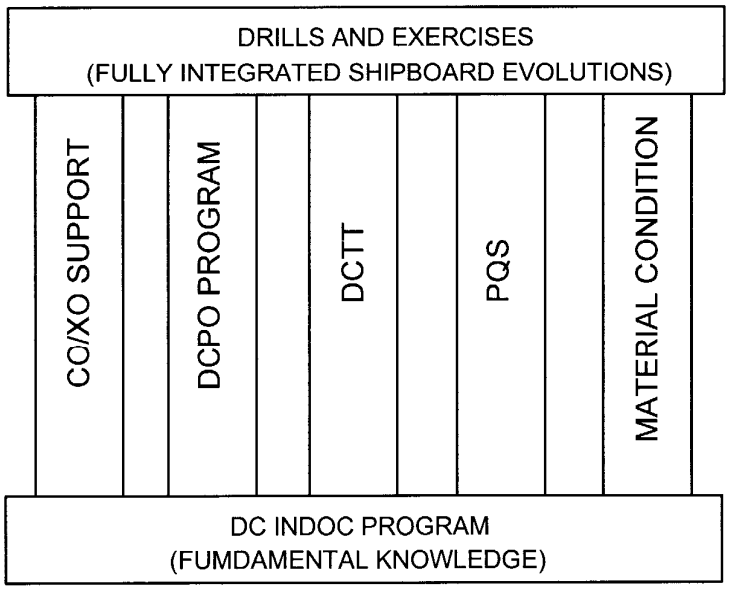
13. Minimum GM Curve - This diagram is similar to the Allowable/Limiting KG curve described above in that it helps you to determine if the ship is in a safe or unsafe loading condition. You want to always have a value of GM greater than the minimum GM obtained from this curve. You plot your position on this diagram using your ship's values of GM and mean draft and you always want your plotted position to lie above and to the right of the curves on the diagram.

Other Damage Control References

(a) NSTM Chapter 079 Vol. 2
(b) NWP 62-1 (series); Surface Ship Damage Control
(c) NSTM Chapter 555
(d) COMDTINST 3541.4; Anti Flash Clothing
(e) COMDTINST 9555.1; Machinery Space Fire Fighting Doctrine for Class Bravo Fires
(f) COMDTINST 9664.1 Cutter Standard Repair Locker Inventory
(g) COMDTINST 3502.4; Cutter Training and Qualification Manual

D.) SHIPBOARD TRAINING AND DAMAGE CONTROL PROGRAMS

Shipboard training and damage control programs are the cornerstones to a ship successfully combating damage. It is imperative that all of the below pillars are fully integrated into the ship's philosophy so that when a casualty occurs the ship will respond as trained.



1.) SHIPBOARD DCPO PROGRAM

THE DCA MUST BE ACTIVELY AND CONSPICUOUSLY SUPPORTED BY THE CO, XO AND DEPARTMENT HEADS IN ORDER TO SPEARHEAD AN EFFECTIVE DCPO PROGRAM.

DEPARTMENTAL DCPOS ARE THE RESPONSIBILITY OF THE DEPARTMENT HEAD. THIS INCLUDES SPACES IN WHICH THEY WORK AND FUNCTIONS THAT THEY PERFORM.

DCPO TRAINING IS IN THE HANDS OF THE DCA.

2.) DAMAGE CONTROL PETTY OFFICER

a. RESPONSIBLE FOR ENSURING ALL MAINTENANCE REQUIREMENTS ARE COMPLETED IN ACCORDANCE WITH PROPER PMS PROCEDURES. (Your DCPO does not have to personally do all the work. He/She can train others in the proper procedures and then supervise and ensure that the work is completed. Spread the work out, it makes it easier on everyone and also makes more people aware of and familiar with DC equipment)

b. RESPONSIBLE, HIGHLY MOTIVATED PETTY OFFICER OR NONRATE IF P.O. NOT AVAILABLE.

-SERVE FOR A MINIMUM OF SIX MONTHS

-COMPLETE DCPO PQS

-ASSIGNED IN WRITING

-WILL NOT BE RELIEVED WITHOUT XO APPROVAL

-MAINTAIN SUFFICIENT NUMBER OF TRAINED ALTERNATES

c. SUGGESTED DCPO PROGRAM PROCEDURES

-DCA MAINTAINS QUARTERLY SCHEDULE FOR EACH DCPO

-DCA TRANSFERS MAINTENANCE FROM QUARTERLY SCHEDULE TO WEEKLY CARDS

OR LOG BOOKS. (DISTRIBUTED THROUGH DEPARTMENT HEAD)

- LAMINATE THE MPC CARDS FOR THE DCPO ITEMS AND DISTRIBUTE TO EACH DCPO. THE DCPO CAN THEN TAKE THE CARD WITH THEM WHEN THEY CONDUCT THE PMS. THIS ENSURES THE ITEM IS COMPLETED PROPERLY AND ALLOWS THE DCPO TO WRITE DOWN ANY DISCREPANCIES FOUND WHILE DOING THE PMS RIGHT ON THE CARD IN GREASE PENCIL FOR LATER TRANSFER TO THE DCA FOR CORRECTION/ADDITION TO THE WORKLIST.

-DCPO ACCOMPLISHES PMS THROUGHOUT THE WEEK AND ANNOTATES CARDS/SCHEDULE. SUBMITS ACCOMPLISHMENTS TO DEPARTMENT HEAD, NOTATIONS ARE MADE, AND ALL CARDS ARE REVIEWED WEEKLY BY THE XO.

-XO RETURNS WEEKLY CARDS TO DCA VIA DEPT. HEADS AND NEW SCHEDULES ARE FORMULATED FOR THE NEXT WEEK.

-WEEKLY CO'S MATERIAL INSPECTIONS SPOT CHECK DCPO ITEMS

-IF NUMBER OF DISCREPANCIES CONTINUES TO GROW, CONDUCT "DCPO DAYS" UNTIL BROUGHT UNDER CONTROL.

- IF DCPO DAYS ARE SCHEDULED, DCA MUST ENSURE THAT THE DC'S ARE OUT AND ABOUT ASSISTING AND TRAINING THE DCPOs IN COMPLETING THEIR WORK.

-DC DISCREPANCIES MAINTAIN HIGH PRIORITY IN SHIP'S BUDGET

3.) DC TRAINING

a. Assign the XO as the head of DCTT - It shows the command emphasis on damage control and that damage control/firefighting is a shipwide evolution not just the responsibility of the engineers.

b. On larger ships, use your junior deck watch officers as members of DCTT - If you are running a damage control drill, the JO's on weapons, CIC, etc are usually not fully utilized or occupied. Rather than strip your repair parties to provide DCTT members, use the JO's. By having to train people in damage control/firefighting, it will make them a better inport (and underway) OOD. Sure, they need training in their GQ billet as well; if you get enough trained DCTT members you can rotate who runs the drills. It will take some training to get them up to speed and qualified to run drills so you will still need some of your experienced (former) repair party members to be in DCTT.

c. Having some of your experienced members in DCTT helps bring up the level of training of everyone in the repair party. The repair party cannot rely on those experienced members to "carry them" through the drills. It forces them to learn the necessary information and procedures and not just "follow the leader".

d. When you run a Main Space fire drill, practice rotating people in and out of the space. In a real fire scenario the people fighting the fire will not be able to remain in the space for very long. Your ace, highly trained, nozzlemen, hosemen, and NFTI man will get relieved fairly quickly because of the heat. Are your backups as highly trained?

e. How do you train your upper management (CO, XO, EO, OPS, DCA)?????

f. General Emergency Bill vs. GQ: Pros and Cons to each

g. Run as realistic drills as safely possible. Use the smoke generator, secure the power, use charged hoses (in non-machinery/electronics spaces). Minimize the intervention or interaction of the DCTT

h. Ensure that crews debrief is held after every drill. This allows the DCTT to critique the drill, point out the good and the bad, and offer feedback to the crew. It also allows the crew to critique the procedures used and provide feedback to the DCTT.

i. When running fire drills ensure that part of your procedure is to set vertical fire boundaries as well as horizontal boundaries. We always stress "primary forward", "primary aft" boundaries. Heat rises... so also stress setting and maintaining a boundary <u>above</u> the fire as well as the fore and aft boundaries.

j. Protective Clothing: You can't fight a fire in shorts or short sleeves. Consider buying the red flight deck turtlenecks for wear by your repair parties. They protect the arms and neck; they're sturdy and can withstand many washings. It also immediately identifies someone as being in the repair party. You may also want to put a few pairs of coveralls in the locker to protect those that may come to the locker in something less than a full set of clothes.

k. Fire Fighting Ensembles: Only required for Main Space Fires. Can be worn at other fires at the discretion of the On Scene Leader but not required. (NSTM 555 pg 109 para 5.2.1)

l. Cross training is essential , especially in minimally manned ships, in order to maintain the flexibility to handle any contingency. <u>All hands</u> must be proficient in

damage control and fire fighting skills as any one at any time may be called upon to save a ship during an emergency.

4.) SHIPBOARD DC INDOC/PQS

a. Upon Administrative Check-in to the unit, all crewmembers shall receive a complete tour of the vessel and receive training in emergency egress (from berthing area and workspace) and EEBDs. This should happen the first day they are aboard.

b. The new crew member then needs to get familiar with the location of all damage control equipment including; all fire stations, repair lockers, installed CO2/Halon flooding systems, etc.

c. All officers and enlisted personnel shall complete General DC PQS within six months of reporting. Personnel who have completed this PQS during a previous afloat assignment, and within the past six years, may not require as comprehensive an indoctrination program.

d. All personnel assigned to repair parties, inport or underway, shall complete DC Emergency Party PQS, up to the watch station they will fill, as soon as possible.

e. All personnel assigned as Repair Party Leader shall complete Repair Party Leader PQS as soon as possible.

f. Make the PQS answers available to the crew. Don't make it a "treasure hunt". You want them to know the answers. On the other hand, don't accept written or oral answers as proof that they know the material, require them to demonstrate that they know it. Have them put on an OBA and show how it is used rather than just

explaining the procedure. This should apply to everyone; officers, CPOs, as well as enlisted.

5.) TYPICAL DAMAGE CONTROL PROBLEM AREAS

a. MATERIAL CONDITION:

WATERTIGHT INTEGRITY
DC MARKINGS/ STENCILING
DC PMS ACCOMPLISHMENT
REMOTE OPERATIONS
CCOL'S NOT UP TO DATE

b. EQUIPMENT:

REPAIR LOCKER INVENTORY NOT COMPLETE
FIRE STATIONS NOT MAINTAINED
PORTABLE PUMPS INOP
CASUALTY POWER
PORTABLE EXTINGUISHERS NOT CHECKED

c. TRAINING:

PQS DOCUMENTATION INCOMPLETE OR NONEXISTENT

MAIN SPACE FIRE FIGHTING

RESCUE AND ASSISTANCE TEAM TRAINING/CROSS TRAINING

6.) TEN MOST COMMON CART DISCREPANCIES

a. INADEQUATE NUMBER OF PEOPLE IN REPAIR ORGANIZATION

b. REPAIR PARTY NOT STAFFED WITH SUFFICIENT EXPERIENCED PERSONNEL

c. DCPO MAINTENANCE INEFFECTIVE DUE TO LACK OF FORMAL TRAINING

d. DC CLASSIFICATION PLATES INCORRECT OR MISSING

e. ORGANIZATIONAL BILLS INCOMPLETE OR NOT SPECIFIC ENOUGH FOR ACTUAL USE

f. LIQUID LOADING CHARTS NOT UPDATED DAILY

g. REPAIR PARTY MANUAL NOT TAILORED TO SHIP

h. P-250S NOT OPERATIONAL

i. COUNTERMEASURE WASH DOWN SYSTEM DAMAGED OR INADEQUATE

j. CCOLS NOT MAINTAINED PROPERLY

"WE ARE DETERMINED TO SAVE OUR SHIP, PERIOD! THAT IS OUR INTENTION. WE CAN SAVE OUR SHIP. I INTEND TO STAY HERE TO DO JUST THAT."

CDR PAUL X. RINN, USN
COMMANDING OFFICER
USS SAMUEL B. ROBERTS, APRIL 14TH, 1987
after striking an M-08 mine in the Persian Gulf

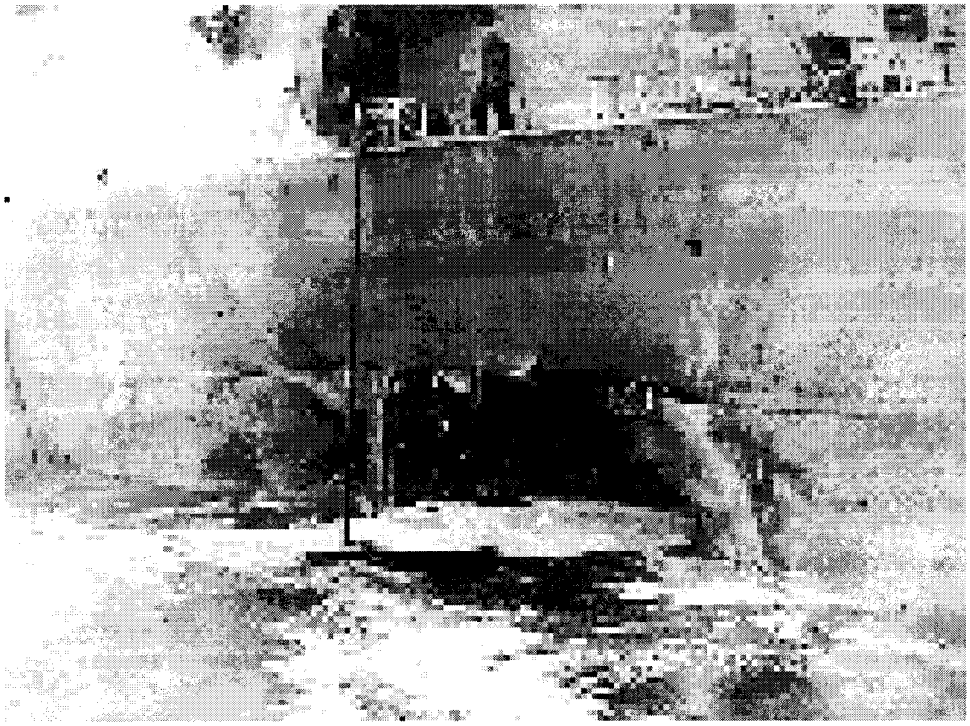
"NO DRILL COULD FULLY PREPARE THE STARK'S CREW MEMBERS FOR 3500° FIRES, CHOKING SMOKE, A 16° LIST, DEHYDRATION, FATIGUE AND HEAVY CASUALTIES. BUT THEIR INTENSE, ALL-HANDS DAMAGE CONTROL TRAINING SAVED THE SHIP"

"THE STARK WAS READY," CDR JOHN JACKSON,
U. S. NAVY SUPPLY CORPS
DECEMBER 1988

Chapter 9

Damage Control After Damage

A. After Damage
B. Condition Assessment
C. Survivability
D. Corrective Measures



AFTER DAMAGE

In the event of damage onboard your ship, immediate action of the crew should be a conditioned response for which the ship trains regularly. Training for damage control occurs on multiple levels from basic skills for the junior personnel through the more global considerations made by the CO/XO and Damage Control Officer. These decisions throughout much of the damage control efforts are typically a matter of tactics and strategies to most effectively limit the extent of damage and impact on the ship's capabilities. However, in extreme conditions the Commanding Officer must consider the following question...

Should I stay aboard and continue to combat damage or should I prepare to abandon ship?

Your decision to stay aboard or abandon ship is highly dependent upon your ability to stay afloat and upright. This is influenced by several factors including:

1. Your condition prior to damage - as discussed in the previous chapter

2. Nature and magnitude of the damage incurred

3. Ability to control the spread of damage
   a. Ability to control flooding
   b. Ability to control and extinguish fires
   c. Ability to reach a haven (protected waters) based on :

      - sea and weather conditions
      - does ship still have propulsion/maneuverability
      - outside assistance (towing, equipment, etc.)

IMMEDIATE LOCAL MEASURES

Regardless of the timely strategic decision making to be accomplished by the command when damage occurs, repair parties should be conditioned to immediately:

1. Establish fire, flooding, and SMOKE boundaries
2. Control and extinguish fires
3. Establish/man secondary boundaries
4. Advance the flooding boundaries (reclaim spaces by plugging/patching/ shoring/dewatering)

Rapid and effective initial action is the greatest defense against the spread of damage. Continuous shipboard training with innovative approaches to improve initial response time should be emphasized.

CONDITION ASSESSMENT:

-Are you sinking??

The Engineer Officer/DCA must quickly decide if the ship is about to sink bodily, plunge, or capsize. War experience has shown that none of these is about to happen unless the weather deck at the low side has become more or less continuously awash. Keep this in mind along with the rate at which the ship is listing, trimming, and settling in the water.

-Establish effective lines of communication

Effective communications are an essential component in achieving an accurate picture of the state of the ship. Clearly, in the intensity of battling severe damage, achieving and maintaining effective communications become more difficult if the crew is not routinely trained for such discipline. Always do what is necessary to maintain lines of communication and ensure you are receiving accurate information; this does not preclude seeing the damage for yourself.

-If bulkheads are intact after damage, they will likely remain intact

Watertight bulkheads on ships are designed to withstand the hydrostatic pressure of sea water in a flooding condition. If the Bulkheads have not collapsed under the in-rush of water, they are not likely to collapse under hydrostatic pressure once the flow of water in has settled.

SURVIVABILITY:

As discussed in chapter 8, the factors that influence survival before the damage occurs include:

a. Maintenance of watertight integrity
b. Proper classification of closures
c. Proper setting of material conditions of closure
d. The extent to which these material conditions are violated
e. Whether the ship was overloaded
f. Whether limiting deck loads were exceeded
g. Amount and distribution of liquid load (ballast if required)
h. Readiness and distribution of tools and materials for combating flooding.

As quickly as the Engineer Officer/DCA can decide that the ship will last long enough for repair personnel to attack fire and flooding, the Engineer Officer/DCA must decide which measure will improve the situation, and which will make it worse and must be avoided. Immediate local measures to halt the sea by establishing flooding boundaries, and to control and extinguish fires, rig casualty power, restore impaired piping systems, and other such functions, are undertaken by repair parties at once and need no decision making. They are always in order. However, measures to control list, trim, stability, buoyancy, and hull strength involve selections that can spell survival or loss to the ship.

Ability to Stay Afloat and Upright:

-Stop serious flooding to remain stable and afloat

If the ship's stability is impaired from damage through flooding and fire fighting water, changes in the ship's list, trim and displacement can occur. If however, these effects slow or stop shortly after damage and initial damage control efforts, the chances of survival are greatly increased. The most important factor that determines ability to survive is the ability to halt progressive flooding by making emergency repairs, e.g., plugging, patching, and shoring. Once this is affected, the portable and fixed

drainage facilities of the ship should be able to handle the small remaining leakage. Repair parties should be trained to establish boundaries automatically around the flooding water and begin the removal of free surface. No case is on record of a ship, which sank suddenly, after it has stopped listing, trimming, and settling. The vessel may, however, stay afloat for several hours after damage before sinking where the cause of sinking is typically traceable to progressive flooding. Hence, maintaining effective flooding boundaries is a crucial aspect of the ship's survival.

-Flooding Casualty Control Software - FCCS

Most cutters now have FCCS software, which provides rapid, accurate information regarding the stability of the ship in most any condition of damage. This software has a graphical interface which overlays damage on a drawing of the ship. The DCA/EPO who is conversant with this software can provide valuable information regarding the stability of the ship and actions necessary to improve conditions.

-Free Surface Effect

The effect of a free surface can be a very serious detriment to the stability of the ship. If stability becomes questionable, your DCA/DCO should give consideration to pressing up tanks with free surface and/or concentrating Damage control efforts to eliminate the free surface. The Flooding Effects Diagram (DC Plate) from the Damage Control Book provide "quick glance" information regarding the effect of flooding on stability.

DANGER OF CAPSIZING WITH ZERO LIST

A ship that has lost most of its over-all stability may be in danger of capsizing even though it remains upright without taking on a permanent list. This is the case where high weight, free surface, or a marked loss of freeboard cuts down the total dynamic stability but leaves a small positive GM. The principal indicator to such a condition is the feel of the ship. It will be logy and sluggish in its response to wave action.

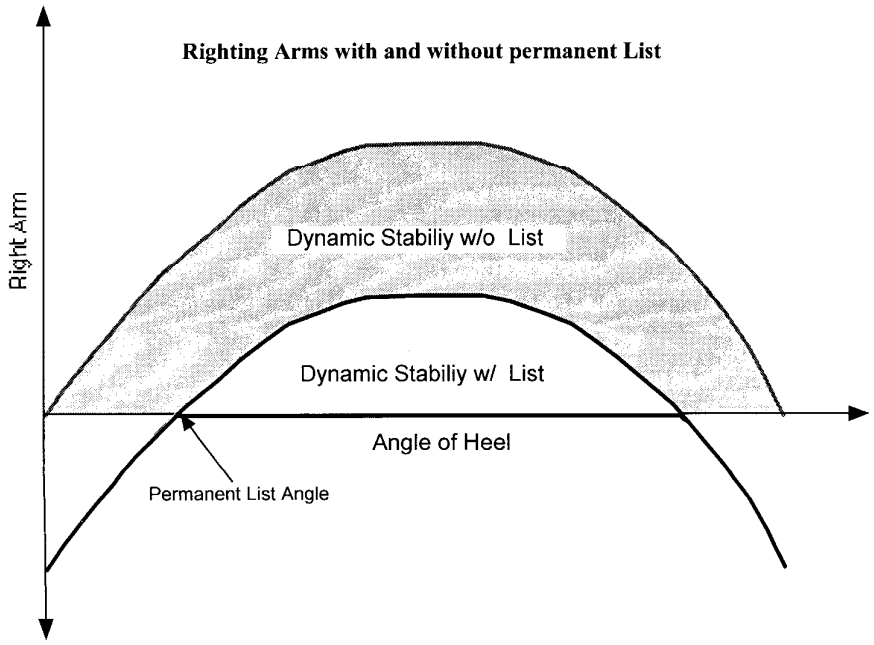
A small heeling moment will produce a large inclination and it will hang at the end of the roll before slowly coming back.

A suddenly applied heeling moment of the type produced in hard maneuvering (or the wake of a passing high speed ship) may be sufficient to capsize the ship that remains upright but has little dynamic stability Such a ship is described by such words as tender, cranky, or logy, which are the opposite of steady, and stiff.

Other evidence of this condition besides the feel of the ship are large areas of broad free surface, failure to ballast properly, and a seriously reduced freeboard (overloading).

DANGER OF CAPSIZING WITH A LIST

A permanent list may be due to negative GM, outboard center of gravity, or a combination of the two. Further, the reduction of stability (GM) or increase in amount of off-center weight cuts down over-all stability as the angle of list increases. As the angle of list approaches the angle of maximum righting arm on the curve of stability, the remaining dynamic stability decreases significantly and may capsize if subjected to a small heeling moment. The diagram below illustrates the reduction in overall stability with a significant list imposed on a typical righting arm curve.



Under adverse circumstances the Engineer Officer/DCA need some means of judging whether the ship has listed so far as to be in danger of rolling over. Familiarity with the principles of ship stability and the FCCS program offer a means of assessing this issue.

Under average conditions it is probable that most ships can list to at least one-half the angle of maximum righting arm on the intact stability curve. This is called the **"danger angle".**

In determining the maximum degree of list a ship can safely assume after damage, the Engineer Officer/DCA must consider the following factors:

a. Whether the main deck edge is rolling under or not.
b. Has the flooding been halted, or is the angle of list increasing?
c. Extent to which freeboard is impaired (either by flooding or by riddling of the topside).
d. Condition of the wind and sea (and the weather forecast).
e. The feel of the ship, is it stiff, or logy?
f. Condition of stability before damage.

The most important of the above factors are items a. and b., deck edge immersion and the rate at which the list is increasing. The other factors contribute to these first two and must be considered.

CORRECTIVE MEASURES FOR SHIP SURVIVAL

OVER-ALL SHIP SURVIVAL MEASURES

Objectives (in priority order):

1. To improve GM and over-all stability
2. To correct for off-center weight
3. To restore reserve buoyancy
4. To correct/improve trim
5. To relieve stress on a damaged hull girder

Improving GM and Over-all stability:

a. suppressing free surface (pressing up or pumping out flooded spaces)
b. Jettisoning topside weight (do not lift heavy weights with the boom if GM is marginal)
c. Ballasting (empty fuel, water and/or ballast tanks)
d. Lowering liquid or solid weights
e. Restoration of boundaries (plugging/patching holes)

Measures to correct for Off-Center Weights (after ensuring a lolling condition does not exist):

a. Pumping out non-symmetrical (off-center) flooding
b. Pumping liquids across the ship
c. Counter flooding
d. Jettisoning topside weights from low side
e. Shifting solid weights athwart ships
f. Pumping liquids overboard from low side

Measures to correct Trim (usually secondary to improvement of GM and correction of list):

a. Pumping out flooding water from low end
b. Pumping liquids fore and aft
c. Counter flooding high end
d. Jettisoning topside weights from low end
e. Shifting solid weights fore and aft
f. Pumping liquids overboard from intact tanks at low end

Measures to relieve stress in the hull girder:

hogging - remove weight from the ends, shift weight from ends to amidships

sagging - remove weight from amidships, shift weight from amidships to ends.

REPORTS FROM REPAIR PARTIES: The most dependable source of information will be the repair parties investigating at the scene of the damage. Repair personnel should be trained to make prompt, accurate reports to the damage-control station, in the following approximate order:

1. Location and nature of progressive flooding.
2. Location and nature of fires, smoke, and toxic gases.
3. Extent and over-all nature of flooding.
4. Structural damage to the hull girder.
5. Location of damage to vital piping and electrical systems.
6. Local progress made to control fire, halt flooding, and isolate damaged systems, rig jury piping, casualty power, emergency communications, and other repair party emergency operations.
7. Personnel casualties and first aid measures.
8. Compartment by compartment report on flooding, giving depth of water (or fuel and water) in each.
9. Condition of boundaries (decks, bulkheads, and closures) surrounding each flooded compartment.
10. Local progress being made to reclaim compartments by plugging, patching, shoring, and removing loose water.
11. Damage suspected which cannot be reached. As reports come into the damage control station on the flooding they can be marked up on the damage control status board, which contains a record of liquid distribution before damage. In this way, compartments, which contained liquid before damage, will not be regarded as flooded.

Basis for Choosing Corrective Measures: <u>There will be little time for calculations after damage.</u> However, with the competent use of the FCCS program, valuable insights into alternatives can be assessed. Also, knowledge gained before damage of the ship's stability and possible flooding effects will be useful. Selection of corrective measures can then be based on information received through the damage control parties and others. Five factors must be considered:

- Loss of GM (free surface, high weight)
- Off-center weight
- Freeboard
- Hull strength
- Trim

The most immediate and most important selection involves measures to correct list if GM is very low or negative. The Engineer Officer/DCA must be able to identify the condition by observing the following symptoms of critical GM:

a. Ship feels logy and sluggish in its response to inclination. (GM is very low).
b. Ship lists (beyond 10 degrees), yet you know there is no off-center weight. (GM is negative).
c. Ship changes list from one side to the other, or flops. (GM is negative).
d. List is out of all proportion to what the known amount of off-center weight should cause (GM is very low or negative).
e. Huge areas of wide free surface.
f. Huge amounts of added high weight, e.g., high flooding, icing, or excessive deck cargo.
g. Failure to ballast.
h. Extensive free communication effect.

Items e. through h. work together to reduce GM.

The ship's officers should be able to ascertain how much compartment flooding it takes, either singly or in combination, to render GM negative (after allowing for gain due to added low weight if the flooding is low in the ship). If the cause of the list is identified as one, which involves very low or negative GM, vigorous measures must be undertaken to improve GM.

If off-center weight is identified, it is vital that corrective moments be applied for the known amount of off-center weight only. In fact, it is best to <u>under compensate</u>, making up the difference as required.

If the combination of negative GM and off-center weight is identified, correct first for the most critical ailment, the reduced GM. At the same time, if facilities are available (in excess of those needed for restoring positive initial stability) some effort to shift G back to the centerline by creating a transverse moment can be safely undertaken, provided the moment created is not greater than the inclining moment of the off-center

flooding. In other words, it is safe only to correct for the known amount of off-center weight, and to use only those measures, which do not further reduce GM. The effects of the various corrective measures, which are available to Engineer Officers, are discussed in the section on corrective measures.

Information to the Captain: It is the duty of the Engineer Officer/DCA to ascertain from the Commanding Officer what information is desired with regard to extent of damage and corrective measures, how detailed it should be, what circuits it is to be supplied over, and when. The question of when involves what the Commanding Officer wants to know while the action is still in progress, and what information is to be withheld until after the action is broken off.

With such an understanding firmly in mind, the Engineer Officer/DCA must sift the information which comes to the damage control station after damage, and pass up to the bridge only what the Commanding Officer wants to hear. Key personnel at damage control and repair stations should also be indoctrinated in this respect. It requires good judgment to avoid creating a false impression on the bridge of the ship's condition and how this affects the tactical situation.

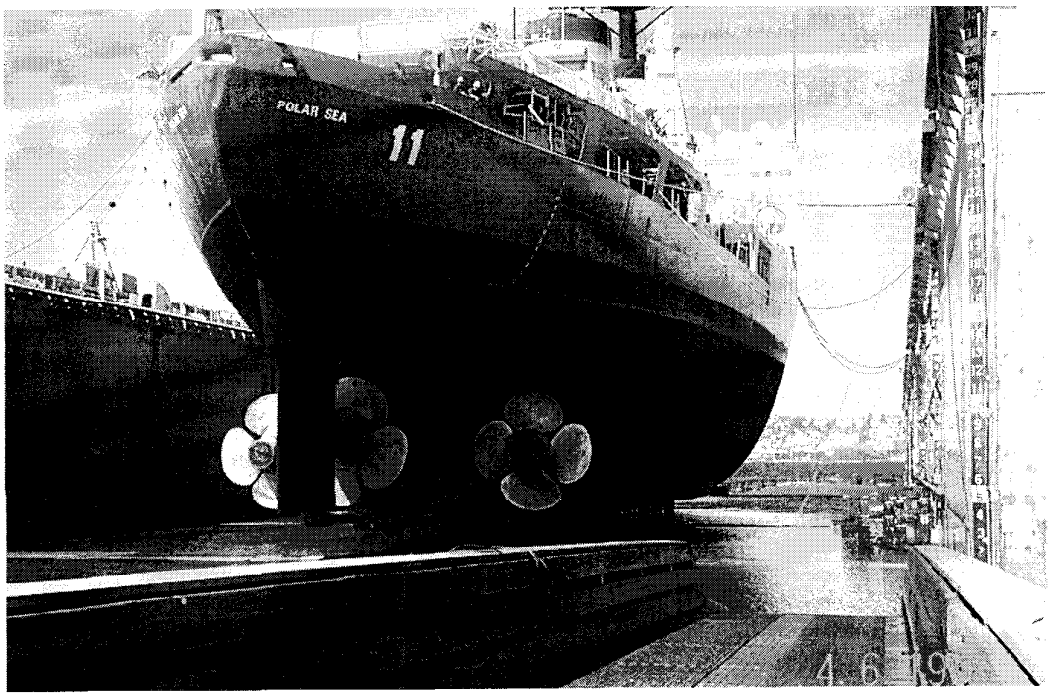
SUMMARY: In summation, in addition to the damage control action expected of the crew in an emergency, the following requirements should be considered, by their nature, as mandatory:

1. **Know the ship by studying its flooding effects before damage.**
2. **Take action ASAP to prevent the spread of damage.**
3. **Ensure effective communication to accurately assess the ship's condition on a continuous basis.**
4. **Assess the stability status of the ship and take corrective action to prevent catastrophe from an unstable ship**

Chapter 10

Drydocking

A. Preparation prior to Docking
B. Docking
C. Drydock Period
D. Undocking
E. Post Undocking
F. Critical Draft Example



WHY DO WE NEED TO DRY DOCK?? Technology has led to significant advancements in underwater repairs and maintenance. In industry, it is increasingly more cost effective and prevalent; however, with the scope and magnitude of the periodic underwater body maintenance of our cutters, dry-docking the ship is clearly the best approach.

CO/XO RESPONSIBILITIES

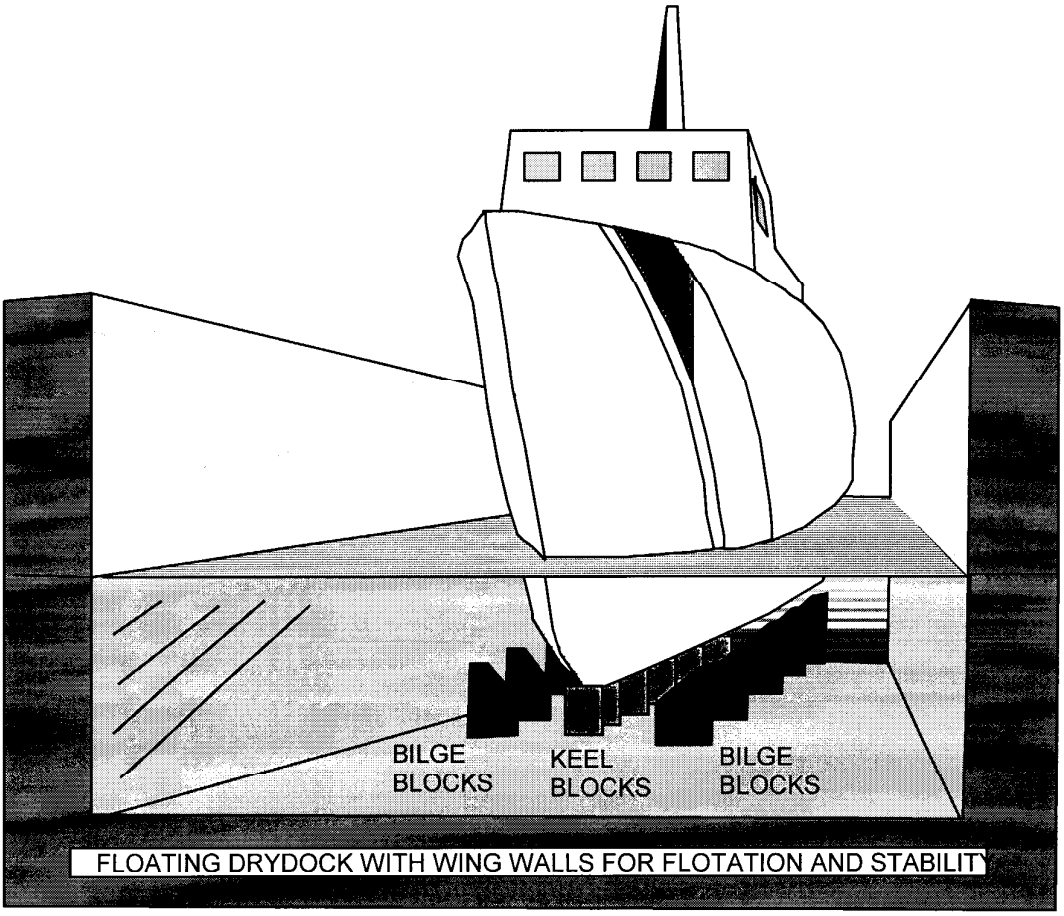
To ensure the docking process will be carried out properly, minimizing the chance of damage to the ship or injury to the crew, total attention to detail is required. The phases of a dry-dock period that will be described here are preparation prior to docking, docking, dry-dock period, undocking, and post undocking.

PREPARATION PRIOR TO DOCKING

a. Administrative and contractual preparations are scheduled to begin 240 days prior to the yard availability. This sequence of collaborative efforts between the ship, (typically represented by EO) servicing NESU, and MLC are designed to identify and include necessary dry-dock work into the shipyard availability. This includes a number of prescribed "A"-team meetings amongst these parties.

Regarding contractor efforts while in dry-dock, only dry-dock dependent work comprises the critical path of shipyard work for the ship in dry-dock. This should be demonstrated by the contractor's Ship Superintendent with appropriate planning documents. Dry-docking is expensive and its duration should be kept to the necessary minimum.

b. Communicate with the yard before commencement of the availability, BUT only after award or with the permission of the Contracting Officer, to determine the planned docking date. **Do not allow the shipyard to dock the ship immediately upon arrival if you haven't had a chance to inspect/verify the dry-dock blocking arrangement. (a.k.a. "walk the blocks").**



c. The shipyard constructs and arranges keel and bilge blocks in accordance with the ship's Docking Plan. The docking plan prescribes the precise location of the blocks such that the load of the ship's weight is safely distributed and that the ship will remain upright with the support of the bilge (or "side") blocks. Shipboard personnel (CO, EO, at a minimum) "walk the blocks" to ensure the block arrangement is in conformance with the Docking Plan. Pay particular attention to:

- height & positioning of bilge & keel blocks
- position in which the ship is to be docked
- softwood caps on all keel blocks
- blocks located near appendages
- overall contact area of keel blocks

d. Most ships have 3 docking positions that are alternated so that portions of the hull that were inaccessible (underneath keel and bilge blocks) at the last docking are exposed in subsequent dockings for maintenance and inspection.

e. Some slight differences may be acceptable as long as the overall contact area of the blocking is the same. If there are differences, the NESU representative should be consulted. Do not allow the contractor to force you to accept a docking plan that is not in accordance with your ship's docking plan. Your NESU representative should be the only one to accept a change to the docking plan. It is very important that any/all hull appendages (e.g. bilge keels, fin stabilizers, rudders, props, fathometer transducers, etc.) are considered when setting up the blocking.

f. The keel blocks are intended to support the entire weight of the ship. Soft wood "crush" blocks are on top of the keep blocks so any minor deviations from the intended line formed by these blocks are "absorbed" as the weight of the ship crushes the crush blocks. The bilge blocks support the ship outboard of the centerline and are designed only to prevent the ship from tipping over. For this reason they must be snug against the hull when the ship is dry-docked.

Once the blocking arrangement is verified, the bilge blocks are pulled away from the center to make room for the ship's approach and "grounding" on the keel blocks as the dry-dock rises. The bilge blocks are typically under control of a block and tackle arrangement which allows them to be put snug against the hull after the keel contacts all keel blocks.

g. Discuss the sequence of events of the docking evolution with the Dock master. It is recommended that your EO/EPO (in-house stability/dry-dock expert) accompany you. This will:
- help familiarize you with the entire dry-docking process.
- provide a forum in which you can address any concerns up to that point with the expert.
- help you assess the Dock master's experience and professional expertise.

h. Immediately prior to dry-docking, several important data points must be accurately determined. This includes:

- the ship's loading condition,
- displacement,
- KG, and
- critical drafts (see end of this chapter)

The Dock master uses this information as input for appropriate sequencing of dry-docking procedures. The CO/EO must verify the accuracy of this crucial information. Based on this information, verify that dry-dock/ship combination stability calculations, including all critical waterplane locations, have been completed, yielded satisfactory results, and are checked by the NESU. Regardless of the expertise each Coast Guard ship may possess, it is prudent to seek a second opinion from the NESU level if any suspect circumstances are deemed to exist.

DOCKING

a. At the commencement of dry-docking, the dry-dock is intentionally flooded to a depth which allows the ship to enter between the wing walls. Again, verify that due consideration has been given by the Dock master to any appendages that may contact the dock or any of the blocks while the ship is being positioned.

b. Set the "Docking Bill"

- assign personnel to all spaces below the waterline, each with communications with a central location (DC Central, bridge, etc.), to report any flooding, damage, cracks, etc.
- ensure communication between the ship and the Dock master
- assign crew members to continually report drafts
- Videotape the dry-docking.

c. Article 4-2-13-C of the U. S. Coast Guard Regulations states that, "If power is secured during the dry-docking or haul-out operation, the person in charge of the docking shall assume responsibility for the movement of the vessel when the vessel is no longer operating under its own power." The same applies for undocking. This is as close as you will come, during your tenure in command, to NOT being inescapably responsible.

d. The ship enters the dock in a dead ship condition with no operating machinery. It must also have no list to match the blocking arrangement. Using mooring lines, the ship remains carefully centered to avoid hitting side blocks and is slowly led forward to the precise longitudinal position for setting on the blocks as the dry-dock rises.

e. When properly positioned and held in place with mooring lines, etc., the dock is pumped out until the keel grounds on the keel blocks. The Dock master must stop pumping/lifting the ship before the ship reaches its critical drafts (that have been previously determined). At this point it is common for the shipyard to send a diver down to verify contact on the keel blocks and to ensure that all appendages are clear of the dock/blocking and not being damaged.

f. After proper contact of the keel on the keel blocks is verified, the bilge blocks are "cranked" in until they contact the hull. This should also be verified with a diver.

g. Once all the bilge blocks are in place, the remainder of the dock can be pumped out until the floor of the dock is dry.

DRY-DOCK PERIOD

a. The ship must convene the Hull Board and perform an inspection of the hull immediately after the docking procedure is complete and prior to any work being accomplished (water washing, sand blasting, etc.). The Hull Board is typically comprised of the CO,

EO, NESU/Group rep, 1st LT, recorder, etc., and is usually prescribed by MLC or NESU message.

- Using the appropriate forms as guides, obtain information for the Dry-docking and Underwater Body Inspection Worksheet (CG-2926) and the Underwater Body Paint Report (CG-4815)

- Consider using pictures and videotape to document areas of interest (remember to put some reference marks on the hull or verbally describe your location during the inspection if videotaping)

b. While in dry-dock, the ship cannot perform anything but minor weight shifts or changes (additions or removals) without the permission of the Dock master. When such changes are accomplished they must be carefully noted and tracked for dry-dock strength and stability considerations

UNDOCKING

a. Personally make a check of the underwater body to ensure all plugs are removed from seachests and overboard valves, seachest grates are installed, prop fairwaters are installed, etc.

b. Set the Docking Bill as before. Assignment of personnel to each space below the waterline is especially important during undocking due to all the work performed below the waterline.

c. After all through-hull fittings are submerged but before the ship floats free, stop the refloating process and inspect all fittings for leakage. If leaks cannot be stopped, the vessel must be re-dry-docked to repair the problem. Sufficient watertight testing of all "skin" fittings is typically performed as part of the contract to avoid this malady.

POST UNDOCKING

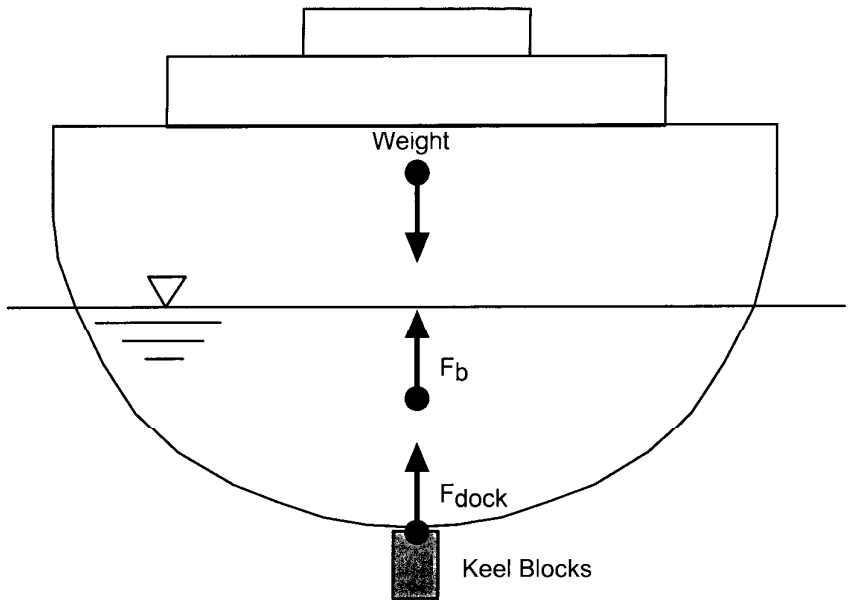
a. Prepare Reports
   - Underwater Body Paint Report (2 pages)
   - Dry-docking and Underwater Body inspection Worksheet (4 pages)
   - Optional Post Dry-dock Availability Report, this is a letter to MLC describing the successes and failures of the availability and availability process. The final A-team meeting with NESU/MLC addresses these issues.

This is not an all inclusive list of the CO's and XO's responsibilities during the docking process. Refer to the appropriate Area or MLC Instruction(s) for more detailed guidance.

CRITICAL DRAFT DETERMINATION

When a ship is being docked, there is a point after the keel has grounded and the ship starts to come out of the water, that the ship becomes unstable and must be externally supported to keep it from rolling over. The draft at which the ship becomes unstable, is called the ship's critical draft. **THE SHIP MUST BE SUPPORTED BY THE BILGE BLOCKS PRIOR TO REACHING THE SHIP'S CRITICAL DRAFT**. If not, the ship may roll over in the dock/railway, causing extensive structural damage to the ship and potentially injuring anyone aboard.

After the ship grounds and starts to be lifted out of the water, there is a force created (F_{dock}) acting on the ship at the point of contact of the keel blocks. Archimedes principle states that the buoyant force is equal to the weight of the water displaced. As the ship is lifted out of the water, it displaces less water and the force of buoyancy (F_b) gets smaller because the underwater volume of the ship is decreasing.. Since F_{dock} and F_b must combine to equal the ship's weight (W), F_{dock} must increase as F_b decreases.



We model the force on the ship from the keel block as a weight removal. Recall that a low (below G) weight removal causes G to rise which, therefore, increases KG. As more force is exerted on the bottom of the ship from the keel block, the center of gravity then also rises more. Recall the measure of initial stability is the metacentric height (GM = KM - KG). If GM is negative, then stability is negative. We are interested in finding the point where GM is neutral in its transition to becoming negative since KG continues to rise as the ship emerges. We also know that as the ship emerges, KM varies since it is dependent strictly on the underwater hull form. We find that with both KG and KM changing as the ship emerges, there is always a certain draft at which the stability becomes neutral; where KM = KG. This indicates any further rise out of the water will cause an unstable condition.

If we plot KM and KG vs. mean draft, we can see that KG increases dramatically with decreasing draft (displacement) and KM typically increases to a lesser degree with decreasing draft. Where the plots of KM and KG intersect identifies the draft where GM goes to zero (GM = KM - KG) indicating neutral stability. The drafts where KG and KM are equal are the ship's critical drafts.

NOTE: This procedure is accurate as long as "excessive trim" is not present on the vessel. Excessive trim is defined as one foot (12 inches) of trim for every 100 feet of ship. (Trim = aft draft - fwd draft - drag)

CRITICAL DRAFT EXAMPLE

Determine the critical drafts for a 110' WPB in a minimum operating condition.

SOLUTION

From the loading summary for minimum operating condition

W = 132 tons
KG = 9.3 ft
drafts fwd = 4' 11"
aft = 6' 8"

Assume the ship comes out of the water nearly parallel (drafts decrease at an equal rate fore and aft).

Determine W , KM and KG at each 3" reduction in draft.

W and KM are found by using the functions of form nomograph

KG is found using:

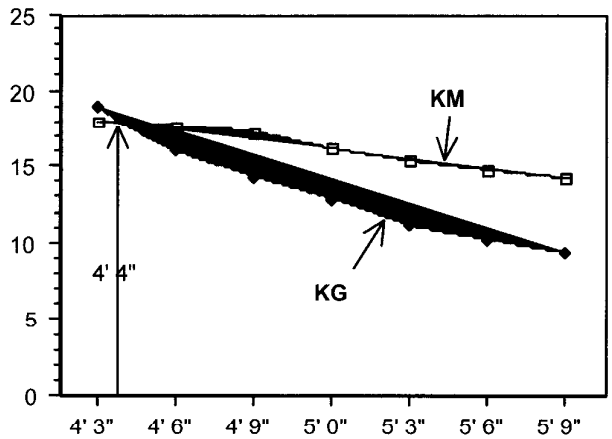
$$KG1 = (Wo)(KGo)/(W1)$$

where KGo = ship's floating KG
Wo = ship's floating displacement
W1 = ship's reduced displacement

The ship's critical draft is where KM and KG are equal (where their plots intersect). In this case, the ship's critical mean draft is approximately 4' 4".(draft fwd 3' 6", aft 5' 3").

KG1 = (9.3) * (132) ÷ 121 KG1 = 10.2
KG2 = (9.3) * (132) ÷ 111 KG2 = 11.1, etc....

FWD DRAFT	AFT DRAFT	MEAN DRAFT	KM (ft)	KG (ft)	W (tons)
4' 11"	6' 8"	5' 9.5"	14.2	KG = 9.3	W = 132
4' 8"	6' 5"	5' 6.5"	14.7	10.1	121
4' 5"	6' 2"	5' 3.5"	15.3	11.1	111
4' 2"	5' 11"	5' 0.5"	16.1	12.8	96
3' 11"	5' 8"	4' 9.5"	17.2	14.3	86
3' 8"	5' 5"	4' 6.5"	17.7	15.9	77
3' 5"	5' 2"	4' 3.5"	18.0	18.9	65



Chapter 11

Grounding

A. Rules of Thumb
B. Lightening Ship
C. Structural Strength
D. Ship Stability
E. Summary

Once a grounding has occurred that fact can't be changed, but - the situation can almost always get worse.

Following a grounding your primary goal should be to keep the situation from worsening.

After grounding occurs, you have three main concerns:

1. Getting the ship free again
2. Structural Strength of the ship
3. Stability

Getting the ship free

You may or may not not be able to float free from grounding, but, the actions you take after the grounding are crucial to minimizing damage to your ship. A quote from the beginning of this book aptly describes grounding: "When the situation does not look good, remember... it can get worse. Determine how it can get worse and take steps to prevent it from happening".

Many factors must be considered by the CO before an attempt is made to get off:

Weather (getting worse?)
Winds
Current
Seas (rough?/ surf?)
Tides
Type bottom (rocky/ sand)
Incline of bottom
Availability of help
Damage to ship (will it float after getting off?)
Stability

Instinctive actions are generally the worst things to do:

"All back full":
"Lighten ship and then back down again"

Things to consider;

- Will the ship even float if it comes free?
- Will you cause more damage in the extraction process? (i.e.; hull/propeller damage from squatting)
- Can you afford any additional damage?

- Backing action may tend to pack sand/sediment under the ship making it harder aground.
- You risk clogging sea strainers, condensers, coolers and losing main propulsion and/or electrical power.
- Propellers are not only less efficient when backing, the problem is compounded by the shallow water.

General Rule of Thumb #1: If backing down doesn't move the ship aft, give up this attempt after 3 minutes of backing. Continual efforts may cause the ship to go further aground due to astern propulsion lodging sand around the bottom of the ship. Additionally, sand and grit from the bottom will be going into the sea chests from which the engines take suction. Continuous backing may cause this sand and grit to clog strainers or coolers which could result in loss of the engine(s).

Only if the ship is very lightly aground is there any chance of successfully backing off. The efficiency of the ship's propeller□ operating in the astern mode is much less than for ahead. Generally, the propeller efficiency in the astern direction is around 25%. This also does not include losses in efficiency due to operating at such a shallow draft.

To determine the extent of a ship's grounding we use a measurement called "Tons Aaground." This is the weight of the ship that is now supported byt the ground. To estimate Tons Aground first obtain the ship's drafts on both the port and starboard sides of the ship. Average the port and stbd draft marks and use those average drafts to determine the ship's grounded displacement. Subtract the grounded displacement from the floating displacement (immediately before grounding) to get Tons Aground. This value will vary with the tidal conditions.

Next we can determine the force required to pull the ship off the bottom. Determine the Ground Effect:

- Soft sand/Mud: 0.30
- Hard sand/gravel: 0.50
- Coral: 0.50 to 1.0
- Rock: 0.80 to 0.90 but can go up to 1.50

Ground Effect (effect of ground friction) relates to the towline pull needed to pull the ship free, not considering the ship's own propulsion. Take your Tons Aground and multiply by the Ground Effect to get the towline pull required to free the ship.

General Rule of Thumb #2: Assisting ships can provide approximately 1 ton of towline pull for every 100 horsepower. (Example: 140 WTGB has 2500 hp, she can provide approx. 25 tons of towline pull.)

Lightening Ship

Lightening ship combined with backing down should never be attempted unless three conditions are met;
1) the grounding condition is fully understood,
2) the ship's position is fixed from going further aground,
3) all other conditions are optimal.

Things to consider:

- You increase your chance of being driven further aground.
- You increase your chance of pounding.
- You increase your chance of broaching.

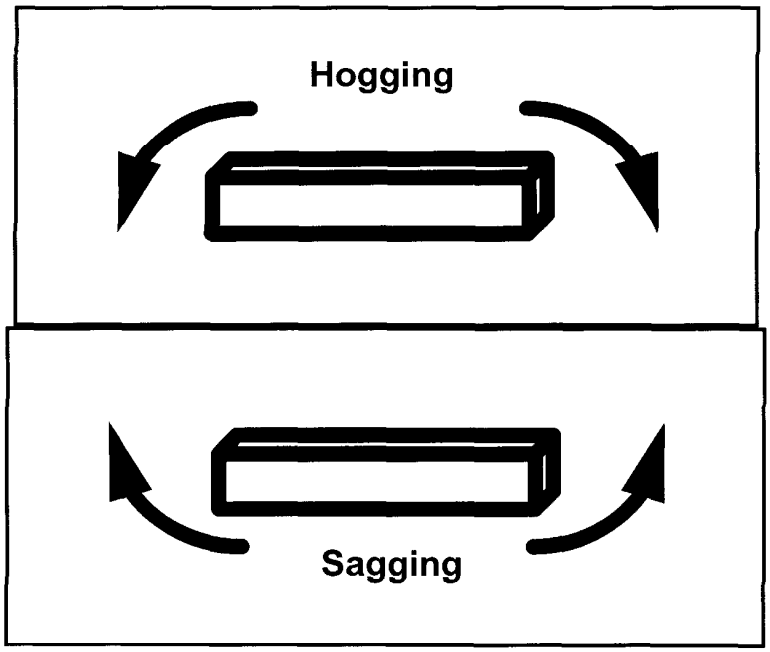
Remember, as you remove weight from your ship, it not only rises, it also trims. If you are aground aft (which you may not have even determined yet) and you remove weight forward (i.e. dumping your buoy load on a buoy tender) your bow comes up and your stern goes down making you harder aground.

Structural Strength

The ship is not designed to handle concentrated loading in a single area. If you are pounding, the forces acting on the ship may break the ship in half. If you plan to be aground for awhile (no one wants to, but it may be the best option), consider reducing those forces by moving weight towards the grounded portion of the hull. This will minimize the bending forces (moments) on the hull.

Structural strength of the ship must be considered any time the hull girder is excessively stressed due to the grounding.

Broaching can occur when a ship grounds on a beach with a quartering surf. The surf will tend to sway the ship parallel to the shore. Outgoing surf will then carry away ground at the bow and stern. The ship would then not be a supported at the ends and a hogging condition would result.



The way to remedy this problem is to transfer weight to the point of grounding, thus relieving stress from the unsupported areas of the hull.

Stability

If a significant fall of the tide is expected, the ship may reach its critical draft, becoming unstable and rolling over, causing damage to the ship and personnel injury. If you are in a region with a large range of tide, calculate your critical drafts as discussed in Chapter 10. If you expect to reach critical draft before getting free:

- Consider methods to lower G - jettisoning high weight, etc.
- Consider getting all/most of the crew off the ship.
- Consider methods of bracing the ship (jury rigged bilge blocks)

Summary

Naval Ship's Technical Manual (NSTM) states:

1) No attempt should be made to refloat under own power if wind and sea conditions indicate the possibility of the ship working harder aground, pounding or broaching.

2) Lay anchors to seaward quickly to prevent the ship from working further aground.

3) Weigh the ship down to prevent it from pounding and working harder on the beach.

DAMAGE CONTROL CHECK-OFF LIST

1. Bring engine(s) to ALL STOP.

2. Set General Quarters. Inform all stations of the situation.
   - Investigate for shipboard damage
   - Use all available means to control flooding

3. Transmit by msg/voice, report of grounding and request assistance.

4. Take and record bearings to navigational aids to determine the ship's position. This will allow you to recognize any bodily movement of the ship while grounded. Put a drift lead over the side to indicate any bodily movement of the ship.

5. Watch the ship's heading to determine if the ship is broaching. If so, an anchor to seaward is by far the best method to resist broaching. If setting an anchor to seaward cannot be accomplished quickly, perhaps a slow bell astern (or ahead if appropriate) and some rudder can be used to help prevent broaching.

6. Rig towlines and line throwing equipment for putting a line ashore or aboard another vessel.

7. Sound around the perimeter of the ship to determine the water depth and the contour of the bottom. Determine where the ship's hull is in contact with the bottom. Consider putting a boat over the side to take soundings around the ship to determine where deep water is and in which direction you want to go when freeing the ship. You may not always want to go in the direction from which you came!

8. Determine the tidal condition at the time of grounding. Determine predicted times and heights of high and low tides.

9. Obtain a weather forecast. Is the weather expected to improve or worsen? Are the seas expected to increase or subside?

10. **Develop a Salvage Plan:**

Probably the most important step is to have a plan, not a series of unrelated, unplanned, uncoordinated events.

- determine if an attempt to free the ship should be made.
  - Will ship float when backed off?
  - What additional damage will occur in backing off?
  - At what speed did the ship go aground?
  - Have the propellers/shafts incurred any damage?
  - Should I attempt to lighten ship before backing?
- determine when the best opportunity to refloat the ship will be based upon all available information (tide, weather, outside assistance, etc.)
- determine what action you will take in preparation of this best opportunity (setting and heaving around on anchors, lightening the ship, etc).

11. If the ship is going to remain aground waiting for the "best opportunity", consider ways to fix the ship firmly aground i.e. setting anchors to seaward, increasing the weight of the ship where grounded by ballasting empty tanks/voids, shifting weight to the grounded portion of the ship, etc. This will help prevent the ship from pounding, broaching and being driven further ashore while you wait.

12. In preparation of an attempt to free the ship, consider lightening the ship by discharging fuel/water/ballast, jettisoning topside gear, transferring material/liquids away from the grounded portion of the ship, etc. To make this work, you may have to jettison weight nearly equal to "tons aground". Remember, as you lighten the ship, wind and wave action will have a greater effect in moving the ship bodily. Use whatever means available to prevent the wind and wave forces from pushing the ship further aground and/or broaching the ship. Use ground tackle and/or your engines to fix your position (opposing the wind and wave forces) while lightening the ship.

13. When the "best opportunity" arrives, attempt to free the ship using the main engine(s), ground tackle and any other assistance available. While backing, if the bottom is soft, slew the stern back and forth by using the

rudders to loosen the contact/suction between the bottom and the ship. Slewing the stern back and forth on a rocky bottom will tend to open up the ship's hull like a can opener.

14. Prepare for the ship coming off the bottom with a surge. Anchors should be ready for letting go if not already dropped.

15. If the ship fails to move after a short period of time (max of 20 minutes), then stop the engines. Further backing may worsen your condition.

16. If all attempts to back the ship off have failed, drop your anchors, to seaward if possible, in an attempt to fix the ships position and prevent broaching and/or being driven further ashore. Remember, dropping large anchors will actually lighten the ship forward, which may better or worsen your situation.

17. In an effort to fix the ship firmly aground, consider increasing the weight of the ship where grounded by ballasting empty tanks/voids, shifting weight to the grounded portion of the ship, intentionally flooding spaces, etc. This will help prevent the ship from pounding, broaching and being driven further ashore.

18. Determine if the ship's transverse stability is a concern. This may be true if there is to be a large drop of the tide while grounded. If so, determine the ship's critical drafts to determine if and when the ship will become unstable.

19. Consider the longitudinal stress on the hull girder. Determine if the ship is in a hogging or sagging condition and take action to minimize the longitudinal stresses on the hull by shifting/discharging weights as appropriate.

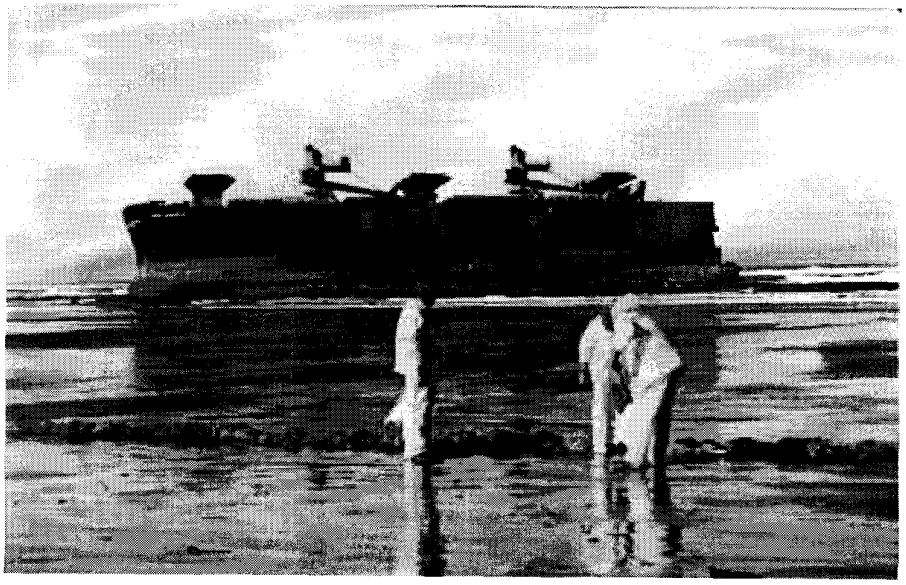
20. Ready pyrotechnics.

21. Display proper dayshapes/navigation lights for being aground.

Chapter 12

Hazardous Material
&
Environmental Compliance

A. Environmental Compliance
B. Responsibilities and Liabilities
C. Hazardous Communication Program
D. References
E. Assistance



ENVIRONMENTAL COMPLIANCE

The Coast Guard has a dual role with regard to environmental compliance

1) Regulate and enforce standards on industry
2) Ensure compliance within our organization.

Commandant's Commitment to
Environmental Excellence

The Coast Guard is committed to an aggressive internal environmental program which fully complies with environmental laws and regulations. Just as we are a leader in environmental law enforcement, so must the Coast Guard be a leader in ensuring our own vessels . . . comply with environmental laws. Only by ensuring our own house and actions are in order will we continue to receive the full support of the American public and Congress in carrying out our mission.

How this is to be accomplished:

Institutionalize environmental compliance as a command priority.

Eliminate preventable contamination from pollutants and waste from our vessels and facilities.

Procure technologies and packaging that eliminate or minimize generation of waste.

Employ innovative uses of technology to conserve resources.

Recycle

RESPONSIBILITIES & LIABILITIES

The Commanding Officer is responsible and liable for the actions (or inactions) of the ship and crew with regard to environmental compliance. Non-compliance may result in civil penalties assessed against the ship which come out of your operating funds. Criminal penalties may be assessed against the Commanding Officer including fines and/or jail time.

The most important actions you can take are to train your crew, call the experts if you have questions, document what you do (keep a file of dump receipts, 1149's, etc.) to leave a paper trail cradle to grave, and finally if something goes wrong do not try to cover it up! That is where the criminal penalties begin to apply.

Environmental Compliance issues can be broken up into 4 area:
1) Air Pollution Prevention and Reduction
2) Solid and Plastic Waste Management
3) Water Pollution Prevention and Control
4) Hazardous Material Control

1) Air Pollution Prevention and Reduction

- Volatile Organic Compounds (VOCs)
  The paint system you chose must have an acceptable VOC level.

- Ozone Depleting Substances
  CFC Refrigerants being phased out
  R-134A going to 270s and 378s
  MKs must be EPA certified to work on AC&R equipment

- Engine Emissions
  Standards are being developed by International (IMO), Federal (EPA), State, and Local authorities.
  Engines will have to undergo radical change to meet these standards.
  Regulators using same strategy used in auto industry - establish standards to force technology.
  Reducing Visible Emissions
  - Keep engines tuned (retard timing)
  - Use the right fuel
  - Reduce warm-up times
  - Control speed changes
  - Slow speed

- Other Air Emissions (Coatings and Topside Maintenance)
    - You can be cited for allowing paint chips/dust to enter the water
    - Creativity and common sense is key
        - Vacuum tools
        - Tarps
        - Block deck drains
        - Work with the environment (wind)

2) <u>Solid Waste Management</u>

This area of legislation is covered by IMO's MARPOL Annex V.

- Waste minimization
    - Minimize packing materials at the dock
        - Waste segregation
            - Plastics
            - Food contaminated plastics
            - Metals
            - Paper/cardboard
        - Recycling

3) <u>Water Pollution Prevention and Control</u>

<u>Garbage (defined as food wastes)</u>

- No discharge within 3 miles
- OK from 3-12 miles if ground to smaller that 1"
- OK greater than 12 miles
- Foreign countries are increasingly less willing to take your garbage

<u>Plastics</u>

- No discharge anywhere
- Trash compactors

<u>Trash</u>

- No discharge within 12 miles
- Lining and packing materials (non-plastic) that float may not be discharged within 25 miles

Sewage

- No discharge within 3 miles
- No discharge anywhere in Great Lakes

Oil

- No discharge greater than 15 ppm permitted anywhere.
- "No sheen" rule applies everywhere.
- If you spill oil while refueling, transferring, etc., do not spray or sprinkle detergent on it to disperse it. That is a violation of Federal Law. Call your local MSO and inform them of spill and estimated quantity.

Medical Wastes

Dumping is prohibited unless retaining onboard would endanger safety and health of crew. If dumped, must be sterilized with steam, properly packaged, and weighted. Records must be kept of what was dumped, where, and when. Sharps (scalpel blades, needles, etc.) can never be dumped.

4) Hazardous Material Control

A Hazardous Material is any material that because of its quantity, concentration, or physical or chemical characteristics may pose a substantial hazard to human health or the environment when purposefully released or accidentally spilled. This includes aerosol containers, flammable materials, toxic materials corrosive materials, oxidizing materials and compressed gases.

Hazardous Material ControlThe best way to "control" Hazardous materials is to REDUCE their use:

- Buy only what you need
- Use safe replacements
- GSA Environmentally Preferred Products Catalog 1-800-352-2852

The Hazard Communication Program is required for all units by Federal Law and by USCG Policy. You must have a designated and trained Hazardous Materials Coordinator who is responsible for the following key elements:

A. Training
B. Inventory
C. Labeling
D. Disposal
E. Inspection

A. TRAINING

You must ensure your crew is trained in the proper use, stowage, labeling, and disposal of hazardous materials. Federal law requires training in the following cases:

- For new personnel reporting aboard
- Anytime a new hazard is introduced to the workplace
- Anytime time a person changes duties and will be exposed to new hazards
- Annually

The training requirements are detailed in COMDTINST 6260.21(series)

Training your crew is the most important thing you can do to keep yourself and your unit out of trouble.

B. INVENTORY

You must maintain an accurate inventory of all hazardous material onboard. A Material Safety Data Sheet (MSDS) must be onboard for each individual hazardous product. There should be a master inventory list and MSDS file for the entire ship listing what material is stored or used in what space. Each space that contains hazardous material or each space where it is primarily used should

have a binder containing MSDS's for that material. The binder should be kept in a easily accessible and visible location. The idea behind this is that the people working with the material have a right to, (and should), know what it is they are working with, what is dangerous about it, and how to protect themselves.

Example: You would have an inventory list and MSDS binder in the paint locker containing information on all hazmat stored there. You would also have copies of MSDS's in the scullery for all of the cleaners and detergents used there.

C. LABELING

Containers must be labeled with:

- Name of material as indicated on the MSDS
- Warning of principal hazards (health, fire, reactivity, etc.)
- Effects of overexposure on target body organs
- Name, address or location of the manufacturer, supplier, or responsible party who can provide additional information (This can be your unit hazmat coordinator).

Any container that is used by more than one person or contains material for more than one day must be labeled. (i.e.: those spray bottles of cleaner that are filled up from the drum in the Bos'n Hole must be labeled). There are several commercial firms that sell peel and stick labels with fill in the blank info areas. They may also be available through the stock system now.

D. DISPOSAL

Disposal should be done in accordance with the information contained on the MSDS. A copy of the MSDS should accompany the material being disposed of.

Typically the CG Group or host unit in your area has an EPA number and can handle disposal for you. This may vary, check who handles disposal when you get to your unit.

DO NOT MIX MATERIALS TOGETHER IN ONE "CATCH ALL" DRUM

This will cost you approximately $1000 to $2000 just to get it tested, and a whole lot more to dispose of it.

Keep a file of all 1149's, dump receipts, etc. pertaining to the disposal of hazardous material. If you are turning material over to a commercial contractor for disposal, ensure he/she is licensed by the state as an authorized hazmat handler/transporter.

There is nothing wrong or illegal about having hazardous material onboard your ship. All of it should be there because it is necessary to do your job (if not, get rid of it...properly). If the material is stored, used, and disposed of properly there will be no problems.

E. INSPECTION

Inspections by trained experts are the best way to determine the state of your Hazmat program. Regular inspections are the best way to stay on top of your Hazmat program once it has been properly implemented. MLC(kse) and the US NAVY Safety Center have inspection teams that may be able to visit your unit.

References:

(a) COMDTINST M9000.6B, Naval Engineering Manual
(b) COMDTINST 6260.21, Hazard Communication for Workplace Materials
(c) COMDTPUB 5090.1, Commanding Officer's Environmental Guide
(d) COMDTINST M16478.1, Hazardous Waste Management Manual

Where to go for Help

Internal Coast Guard resources should be utilized first before going to external agencies for help.

CG National Response Center: (800) 424-8802

Technical Questions - ELC: (410) 762-6624
or G-SEC: (202) 267-6032

MLCLANT:
Environmental Compliance Branch: (757) 628-4392
Environmental Law Branch: (757) 628-4193

MLCPAC:
Environmental Section: (510) 437-3916
Environmental Law Branch: (510) 437-3351

Your local CEU is a good source of information about local laws and regulations:

CEU PROVIDENCE: (401) 736-1700

CEU CLEVELAND: (216) 522-3934

CEU MIAMI: (305) 536-6722

CEU OAKLAND: (510) 535-7275

CEU HONOLULU: (808) 541-2077

CEU JUNEAU: (907) 463-2408

Chapter 13

ENGINEERING ADMINISTRATION

References:

(a) COMDTINST M9000.6(series), Naval Engineering Manual
(b) MLCLANT SOP, Appendix 15 to Annex D
(c) MLCPACINST M9000.6(series)
(d) MLCA E.P.O. Quick Reference Guide
(e) COMDTINST 474.0; When you enter that cargo tank
(f) COMDTINST 3502.4; Cutter Training & Qualification Manual
(g) COMDTINST 3502.11; Engineer Officer in Training PQS
(h) COMDTINST 3541.4; Anti Flash Clothing
(i) COMDTINST 5100.47; Safety & Environmental Health Manual
(j) COMDTINST 5100.51; USCG Vessel Safety Quick Reference Guide
(k) COMDTINST 6260.2; Technical Guide: Practices for Respiratory Protection
(l) COMDTINST 6260.21; Hazard Communication for Workplace Materials
(m) COMDTINST 9077.1; Equipment Tag Out Procedure
(n) COMDTINST 9555.1; Machinery Space Fire Fighting Doctrine for Class Bravo Fires
(o) COMDTINST 9664.1; Cutter Standard Repair Locker Inventory
(p) COMDTINST 10360.4; VOC Regulations Concerning Solvent Content in Paints, Coatings, Solvents, and Cleaners
(q) COMDTINST 16478.1; Hazardous Waste Management Manual

Engineer's Responsibility

Among others, the primary responsibilities of the Engineer Officer are to:

- Operate the plant safely,
- Maintain the ship in the best possible condition given the available resources,
- Follow federal, state, and local environmental and hazardous material guidance, and
- Accurately maintain the administrative records of the engineering department.

EOs' need to have a good understanding of their responsibilities as required by the Cutter Training and Qualification Manual, Naval Engineering Manual, CMP (PMS) Manuals, Casualty Control Manual, Damage Control Book, MLC Specifications, MLC Standard Operating Procedures, and the Supply Policy and Procedures Manual. EOs should review these manuals on a regular basis, ensuring that the information is relevant, and provide recommended improvements to the respective Operating and Support Program Managers.

An EO needs to maintain an effective line of communication with his/her respective NESU, MLC, Base Industrial, MAT TEAM, Navy SIMA, G-SEN POC, and other EOs. The EO should know what phase of the repair availability cycle the ship is in. The Naval Engineering Manual, MLC SOP, and CMP Manuals shall be used as guidance. Maintenance and inventory management and documentation shall be maintained using CM-PLUS.

Engineering Administration

The majority of the administrative work for the Engineering Department falls under these categories:

- Personnel Management (not discussed here),
- Watch Qualification Program,
- Cutter Maintenance Program, and
- Cutter Safety Program.

Watch Qualification Program

A sound On-the-Job Training Program is essential to the effectiveness of any Watch Section. An EO's personal oversight of and involvement in Qualification Boards, Departmental Training, EOIT Program, DCPO Program, ECCTT, DCTT and OJT for Oiler's, AEOW's, and EOW's is most important to building a quality Watch Section. This should also be a priority for the CO and XO as they share the responsibility for ensuring proper training and qualifications.

Basic Engineering Casualty Control Exercises **(BECCEs)** are a semi-annual training requirement for all cutters and are an essential part of a cutter's engineering training program. Allowing the engineers time to run these drills unrestricted demonstrates command support for the engineering watch qualification program.

CASUALTY CONTROL MANUAL

This manual details the actions the watch section should take to avert machinery casualties, minimize damage after casualties, and restore the operational capabilities of the cutter. Obviously, all engineering watch standers should be very familiar with this manual. The CO, XO, Operations Officer, and the OODs should also be familiar with the manual. Many casualties require the bridge watch to take action. At the very least, most casualties affect the operation of the cutter; hence they affect the bridge watch. One part of the manual that is particularly important is the "Restricted Maneuvering Doctrine". It is vital that both the bridge

watch section and the engineering watch section know and understand this policy. It is critical that the bridge watch keep the engine room informed of when the cutter enters, and leaves, restricted waters. Failure to do so can result in endangering the cutter or needlessly destroying machinery.

Engineering Department Standing Orders

An EO is required to prepare, revise on a regular basis, and provide his/her department with standing orders including:

- Light Off & Securing Schedule
- Watch Qualification Prerequisites
- Organization Chart
- Casualty Control Manual (Casualty Response, Required Bills, and Machinery Space Fire Doctrine)
- Maintenance & Inventory
- Night Orders and Steaming Orders
- Required Reports
- Fuel Oil and Ballast System Management
- Environmental Compliance

Cutter Maintenance Program

Ensure your EO is documenting the material condition and taking the necessary steps to improve his/her equipment and systems through CSMPs, Long Range Maintenance Planning, CASREPs, and the preparation of Maintenance Availability Packages. For an effective cutter maintenance program, each of the following must be well managed:

- Cutter Engineering Reports
- Current Ship's Maintenance Projects (CSMPs)
- Engineering Change Request Program

- Reliability Centered Maintenance (RCM) Program
- CASREP Program
- Long Range Maintenance Plan.

Cutter Engineering Report (CER)

The CER is an annual report that is submitted to MLC (guidelines are contained in the respective SOP's). It is the means by which you update MLC as to the status of your cutter from an engineering perspective. There is a block on the form that asks you to list up to five significant (high priority) problems faced by your command that require MLC or G-SEN assistance to correct. This can be just about anything you feel is a big problem. The list is compiled at MLC and a "Top Ten" list of common problems is generated for your cutter class that MLC begins to work on solving.

Current Ship's Maintenance Project (CSMP)

CSMPs are the means by which you ask for help in the form of money or contractor assistance to complete jobs beyond the capability of ship's force. Submit these as they come up, not all at once right before an availability. MLC uses your backlog of CSMPs to budget for your availabilities. If possible, try to complete one or two of these every inport. It greatly reduces the size of the availability package, increases the quality of the work (because you have tighter control over it), and it is usually easier to get the money from MLC to do the work when the work comes in small chunks rather than a big availability package.

Engineering Change Requests (ECR's)

In order to maintain similar cutter configurations, Commandant limits the type of modifications that can be made to cutters. The Naval Engineering Manual (M9000.6E) offers specific guidance on when ECRs are required, as well as the ECR process itself.

Coast Guard Headquarters must approve any modifications that change the stability, watertight integrity or equipment of the

cutter. If approved, this change is issued to all cutters of that class in the form of an Engineering Change.

All cutters must maintain an Engineering Change file that contains a section for pending and completed Engineering Change. The ECR process and tracking is managed by ELC.

Reliability Centered Maintenance (RCM)

The Coast Guard uses the RCM standard (MIL-P-24534) to develop maintenance requirements for new systems as well as optimizing existing systems. This is a condition-based maintenance philosophy that aims to determine objective evidence of maintenance need and ensure its applicability and effectiveness. All shipboard maintenance falls under one of three types: corrective, preventative or alternative. Corrective maintenance utilizes the CASREP system to restore equipment capabilities after failure. Preventative maintenance is managed through the PMS system. Alternative maintenance refers to maintenance done to improve a systems performance and is managed through Engineering Changes (EC's).

CASREPs

CASREPs are used to report to the Operational Commander that a degraded mission capability exists due to an equipment failure. They are also of benefit to the engineers in obtaining funds, parts, or contractor assistance necessary to repair the casualty. The most important measure of effectiveness regarding CASREPs is to get them corrected promptly. The MLCs can assist you effectively only if your CASREP thoroughly communicates the problem, symptoms, and troubleshooting steps taken. CASREPs must be created in CMPlus from corrective maintenance actions (CMAs).

Preventative Maintenance System (PMS)

This is a mandatory program that ensures that a minimum level of maintenance is regularly performed on critical equipment.

Performance of PMS is a proven method of reducing casualties. Percentage of PMS completion is tracked on the cutter engineering report and is an indication of how well the engineers are performing maintenance requirements. The goal is 100 %

completion, however, this is often not obtained due to operational requirements and other factors. A reasonable figure may be 75 to 95 percent. If your completion percentage falls below about 65 to 70 percent for a period of time, you will most likely notice an increase in the number of casualties. This becomes a vicious cycle; as your engineers spend more and more time fixing casualties and less time doing PMS, more and more casualties occur. Regardless of the number of casualties you have, devote some time to doing PMS on the equipment that works. If your completion rates are low due to factors beyond your control, you may be able to get MAT assistance... but only if you are reporting your actual completion percentages. If you inflate the percentages to "look good", don't expect extra help, the MAT can be better utilized elsewhere. As important as percent completion is that the deferred PMS is first to be completed during the next period. PMS manuals are being phased out and replaced by Class Maintenance Plan (CMP) manuals. Commandant mandates PMS scheduling and completion by tracked using CMPlus for applicable cutters.

Long Range Maintenance Plan (LRMP)

The LRMP will form the foundation upon which MLC(v) will base the maintenance of each OPFAC cutter. The Plan will provide continuity in the major maintenance philosophy that will transcend the routine cycles of personnel transfer in MLC(v) and aboard the cutters. The LRMP will be updated after each scheduled availability by having the servicing NESU, along with cutter personnel, conduct a Material Condition Review (MCR) during the availability. The LRMP consists of four parts:

Part I

Contains general descriptive data for the cutter. This would include date and location of construction as well as any major renovations such as FRAM/MMA/SLEP, homeport and organizational chain of command.

Part II

Contains information about previous and planned availabilities.

1. The start date of the last scheduled drydocking and all other completed dockside availabilities and unplanned drydockings since the last scheduled drydocking.
2. The cutter 5-year planned availability schedule.
3. Any official plan to decommission or change the homeport of the cutter within the next 5 years.

Part III

Identifies the major maintenance needs of the cutter and the planned action by MLC(vr).

1. The command's major maintenance concerns and their relative priority.
2. MLC(vr)'s plans for executing large projects.
3. MLC(vr)'s plans for executing major Engineering Changes and Ordalts.
4. Specific new items the cutter should document via CSMP's.

Part IV

Contains the Naval Engineering Project Listing (NEPL), which will provide a snapshot of all major AFC-45 maintenance planned for the next 5 years. The NEPL includes:

1. A list of all AFC-45 recurring items and when each is scheduled.
2. A list of all outstanding Engineering Changes and when they are scheduled to be accomplished.
3. A list of all unit CSMP's that are on file and when they are scheduled to be accomplished.

Part IV gets updated at every availability and every time you submit your Cutter Engineering Report.

Class Maintenance Plan (CMP) (formerly called CCMP)

This is a listing, by Ship Work Breakdown Structure (SWBS), of major shipboard systems and components, and the recurring maintenance that will be performed on each. For each system and

component listed, the maintenance action, maintenance activity, maintenance cycle and special support requirements are described. It is a "baseline" of routine, recurring intermediate and depot level maintenance. It defines funding and logistics support responsibilities. In other words, it defines what is AFC-45 funded work and what is AFC-30 funded work.

Cutter Safety Program

EOs may be responsible for some or all of the following Safety Related Programs:

- Hazardous Material Management Program (Chapter 13)
- Gas Free Engineering and Hot Work Safety Programs
- Electrical Safety Program (Tag Out Log)
- Heat Stress Program
- Hearing Conservation Program
- Respiratory Program
- Eye Protection Program
- Stability Program

NOTE: Safety Audits are performed by your respective MLC.

Gas Free Engineering and Hot Work Safety Programs

Every cutter (with the exception of WYTLs) must have a Gas Free Engineer program with someone designated as the Gas Free Engineer (CPO and above) or Gas Free Engineering Petty Officer (E6 or E5). EOs obtain the necessary training during DCA school, but EPOs must obtain the training from Gas Free Engineering Petty Officer School (A-495-0051). The CO must certify the Gas Free Engineer in writing annually.

The Gas Free Engineer (GFE) or Gas Free Engineering Petty Officer (GFPO) performs the following duties:

- determines whether or not confined spaces (tanks, voids, unventilated spaces, etc.) have acceptable conditions for personnel entry,
- determines whether or not a particular space or area is safe for "hot work",
- trains the crew on the safe procedures for performing hot work and concerning the hazards involved with entering spaces with toxic gases or low oxygen.

The GFE will issue Gas Free Certificates for entry or work based on tests and inspections personally conducted by the GFE on the following:

- entry into a confined or enclosed space (limited/restricted openings and a lack of natural ventilation),
- hot work in spaces or the boundaries of spaces that contain or have contained flammable liquids,
- hot work on any piping/fittings that lead to spaces described in the above hot work statement,
- hot work in any space where pressurized systems are likely to be present,
- hot work on hollow structures such as drums, skegs, pipes or bits.

When inport, gas free checks shall be made by a certified marine chemist when hot work is being conducted by an outside contractor. Under no circumstances should your shipboard gas free engineer certify a space for contractor work. However, your GFE may perform the duties of the "competent person" for hot work that is being performed by a Coast Guard civilian (for example, a civilian at the CG YARD).

Ensure your boarding parties are continually reminded of the hazards of entering untested confined spaces. Safety should not be sacrificed for expediency in our boardings. Dockside boardings are, and should be, an option when confined space entry is required.

Refer to NSTM Chapter 074 v3 for detailed guidance on GFE procedures and certification.

Electrical Safety Program (Tag Out Log)

A Tag-Out log and ship's instruction on its use are required to be maintained by all cutters to protect personnel & equipment from harm due to operation. A DANGER (red, do not operate) or CAUTION (yellow, see special instructions) tag is placed at every location from which the equipment can be operated. A standardized (and very specific) tag-out procedure for all cutters is defined in COMDTINST 9077.1(series).

The tag-out log lists the location of each numbered DANGER/CAUTION tag. When a cutter maintains ship systems and equipment not under the cognizance of the Engineering Department (i.e. electronics) the responsible department (i.e. Operations Department) must also maintain a separate tag-out log.

Heat Stress Program

A ship's instruction explaining this program is required. Personnel must be trained to use Wet Bulb Globe Temperature (WBGT) meter. Dry bulb thermometers must be installed at key locations where high temperatures are expected (engineroom, scullery, etc.). Heat conditions are monitored and personnel are given stay times or are removed from the space as necessary. Refer to COMDTINST M6260.17 & COMDTINST 6200.9 for specific guidance.

Hearing Conservation Program

Repeated exposure to excessive noise (approx. 85 db) results in irreversible hearing loss. A ship's instruction on this program is required for each cutter. The use of hearing protection devices and the posting of caution signs is required for all areas in which excessive noise might exist. All CG personnel who are exposed routinely to hazardous noise shall be given a monitoring audiometric test at least annually. Refer to COMDTINST M5100.47 for specific guidance.

Respiratory Program

A ship's instruction defining the program (purpose, background, policy, responsibilities, training, fit testing, etc.) is required. Appoint a Respirator Program Coordinator to administer the program. Ensure that adequate and proper respiratory gear is available. Respirator fit tests are required annually. Refer to MLC (k) for further information.

Eye Protection Program

Survey areas of your cutter to determine where eye-hazards exist, and then ensure that warning signs are posted and that eye protection is available and used. Ensure adequate placement and numbers of emergency eye wash stations. Train all members of your crew to use eye protection whenever the slightest hazard for flying debris exists.

Stability (Chapters 1-6)

EOs should be familiar with the liquid load status of the cutter at all times. They should be familiar with the information contained in the DC Book/ Stability & Loading Data Booklet. They should know how to use the information contained in the book. Stability Training Exercises need to be part of the Monthly Training Plan. If this is not practiced, it will be forgotten. FCCS (110's and above) is an excellent tool for stability training.

MLC DIRECTIVES - NAVAL ENGINEERING

Topic	**MLCLANT** Appendix 15 to Annex D to MLCLANT SOP Chapter-page number	**MLCPAC** MLCPACINST M9000.6D (MLCPAC SOP) Chapter-page number
MLC Organization	Chap. 002	Chap. 002
Maintenance Scheduling	042-4	042-5
Long Range Maintenance Plan (LRMP)	081-6	081-10
AFC-45 Funding	081-7&8/040-5	080-1
AFC-30 Funding	081-9/040-7	080-3
Cutter Class Maintenance Plan (CCMP)	081-5	081-5
Preventive Maintenance System (PMS)	081-6	081-6
Reports/Records/Tests	Chap. 090	Chap. 090
CSMP's	040-1/Enclosure 1	040-1/Annex 4
CASREP's	040-3	040-11
SHIPALTS's	090-5	Chap. 041
Availabilities	Chap. 042	Chap. 042/Annex 2
Docking	042-21/Chap. 997	A2-23/Chap. 997
Support Facility Resources	Chap. 087	Chap. 087/Chap. 088
Major Incident Response Team	N/A	087-6
Paint Guidance Philosophy	Chap. 631	Chap. 631
Environmental Pollution Control	Chap. 043	Chap. 043
Volatile Organic Compounds (VOC's)	043-3/631-4	043-4/631-3
Combat Systems	081-13/Chap. 700	080-9/Chap. 700

REPAIR AVAILABILITIES

	MLCLANT Appendix 15 to Annex D to MLCLANT SOP	**MLCPAC** MLCPACINST M9000.6D
	(Chapter-page number)	Chapter-page number
Availabilities	Chap. 042	Chap. 042/Annex 2
Conduct of Availabilities	042-17	042-3
Availability Timelines	042-2/042-37	Annex 2-4 (A2-4)
Acquisition Teams (A-Teams)	042-12	042-1/Annex 3
Contractor Relations	042-23	A2-25
Availability Growth/Contract Changes	042-29	A2-31
Docking	042-21/Chap. 997	A2-23/Chap. 997

KEYS TO SUCCESS/PITFALLS TO AVOID

Inspection of Work	042-19	A2-21

"Prevention of unsatisfactory work is of much more value to the Coast Guard than rejection of completed work."

Specification Interpretation "Constructive Changes"	042-24	A2-25 A2-34

"The CO/OinC of the cutter is responsible to ensure that cutter personnel do not create unauthorized commitments for the government by making constructive changes to the contract.....The only occasion for direct intercession with contractor's employees is when their actions or lack of action present a clear and present danger to humans or property"

Funding of AFC-30 Work Items	042-16 Money (Brown Sheet) must be provided prior to week 20.	A2-11 Letter/message commitment prior to contract bid opening.