DESIGN DATA SHEET
DEPARTMENT OF THE NAVY
NAVAL SHIP ENGINEERING CENTER

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DESIGN DATA SHEET - STABILITY AND BUOYANCY OF U.S. NAVAL SURFACE SHIPS

CONTENTS

079-1-a. Introduction

The purpose of this Design Data Sheet is to present the NAVSEA design practice for stability and buoyancy of U.S. Naval surface ships. It is assumed that the reader is familiar with the naval architectural calculation methods for intact and damage stability and, therefore, references to calculation methods are limited to illustrating application of the criteria.

This Data Sheet is divided into 4 parts: Part I provides a summary of the stability and buoyancy performance requirements and is intended to aid management in their evaluation of requirements; Part II deals with conventional monohull surface ship types; Part III deals with advanced marine vehicles in their waterborne displacement mode of operation and Part IV gives a description of the calculation methods.

The information herein is based on material contained in the references listed in paragraph 079-1-f, updated as appropriate, and rewritten to suit design data sheet format.

079-1-b. Part I SUMMARY OF STABILITY AND BUOYANCY PERFORMANCE REQUIREMENTS FOR ALL U.S. NAVAL SURFACE SHIPS

U.S. Naval Ships are classified into two main groups for purposes of this Design Data Sheet.

a. Ships without side protective systems.
b. Ships with side protective systems such as large aircraft carriers.

Both groups of ships may be subjected to external influences as well as underwater flooding. Sufficient initial stability and buoyancy are required to enable the ships to withstand the effects of these hazards. Details of hazards, design philosophy, design considerations, and the stability and buoyancy criteria for each ship type are discussed later. A summary of the governing stability and buoyancy criteria is presented at this point for ready reference.

079-1-b-(1) Intact Criteria (Conventional monohull types and advanced marine vehicles)

1. Beam winds combined with rolling is usually the governing case for intact stability.

Ships are required to withstand the effects of beam winds as follows:

Table 1 Wind Velocities

Service	Minimum * wind velocity for design purposes (knots)	Minimum Acceptable** wind velocity for ships after 5 years in service (knots)
1. Ocean		
(a) Ships which must be expected to weather full force of tropical cyclones. This includes all ships which will move with the amphibious and striking forces	100	90
(b) Ships which will be expected to avoid centers of tropical disturbances	80	70
2. Coastwise		
(a) Ships which will be expected to weather full force to tropical cyclones	100	90
(b) Ships which will be expected to avoid centers of tropical disturances, but to stay at sea under all other circumstances of weather	80	70
(c) Ships which will be recalled to protected anchorages if winds over Force 8 are expected	60	50
3. Harbor	60	50

* Ships built to Ship specifications dated subsequent to 1 August 1975 shall meet this wind throughout service life.

** Ships built to Ship specifications dated prior to 1 August 1975 shall meet this wind after five years of service

Criteria for Adequate Stability. The criteria for adequate stability under adverse wind and sea conditions are based on a comparison of the ship's righting arm curve and the wind heeling arm curve. Fig. 1.

Stability is considered satisfactory if:

a. The heeling arm at the intersection of the righting arm and heeling-arm curves (Point C) is not greater than six-tenths of the maximum righting arm; and

b. Area A_1 is not less than 1.40 A_2 where area A_2 extends 25 deg or θ_r (for high performance types) to windward from point C.

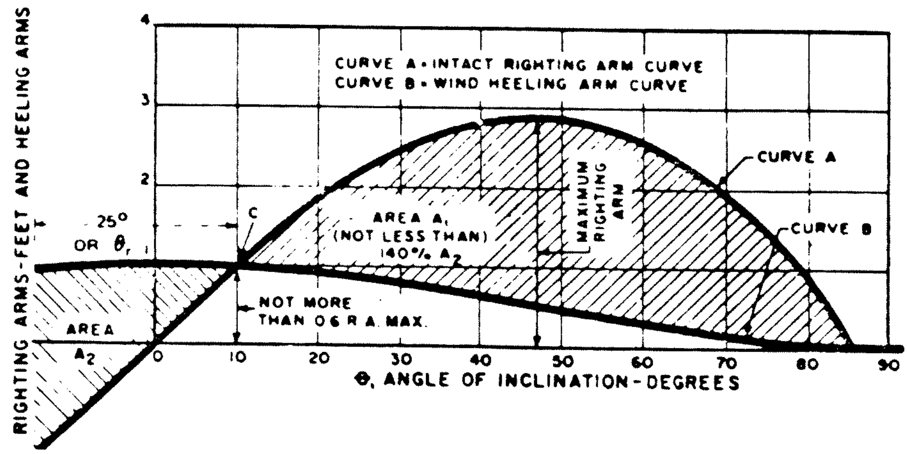


FIGURE 1

2. Lifting of Heavy Weights Over the Side will be a governing factor in required stability only on small ships which are used to lift heavy items over the side.

Criteria for adequate stability when lifting weights are based on a comparison of the righting arm and heeling arm curves, figure 2.

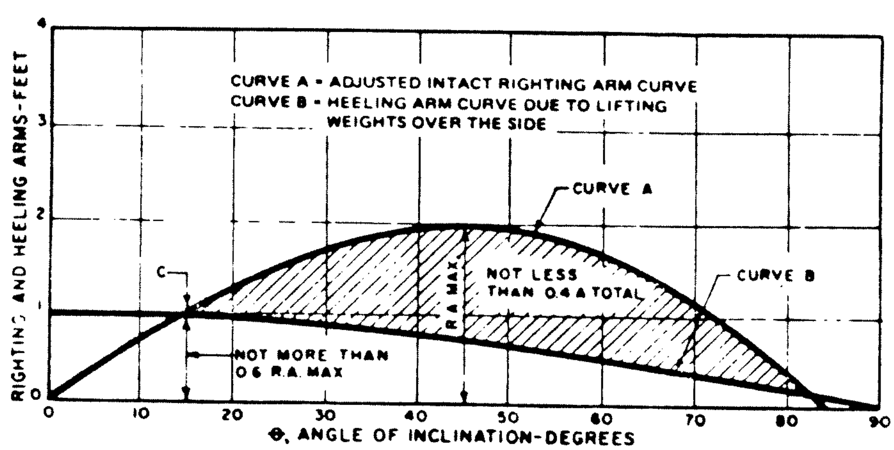


FIGURE 2

The following must be satisfied:

a. The angle of heel, as indicated by point C, does not exceed 15 deg.

b. The heeling arm at the intersection of the righting arm and heeling arm curves (point C) is not more than six tenths of the maximum righting arm, and

c. The reserve of dynamic stability (shaded area) is not less than four tenths of the total area under the curve.

3. Towline pull for tugs, which may be the result of a pull by the towed ship on the tug, can cause serious heeling forces.

Criteria for adequate stability for the tow line pull are based on a comparison of the righting arm and the tow line heeling arm curve as in figure 2, except the righting arm terminates according to a. below.

The following must be satisfied:

a. The righting arm curve shall terminate at the angle at which unrestricted down flooding may occur, or 40 degrees whichever is less.

b. The angle of heel, as indicated by point C, does not exceed 15 deg.

c. The heeling arm at the intersection of the righting arm and heeling arm curves (point C) is not more than six tenths of the maximum righting arm, and

d. The reserve of dynamic stability (shaded area) is not less than four tenths of the total area under the curve.

4. Crowding of personnel to one side will have an important effect only on smaller ships which carry a large number of personnel.

Criteria for Adequate Stability are based on a comparison of the righting arm and off-center personnel heeling arm curves, figure 3. The criteria are the same as for lifting weights over the side.

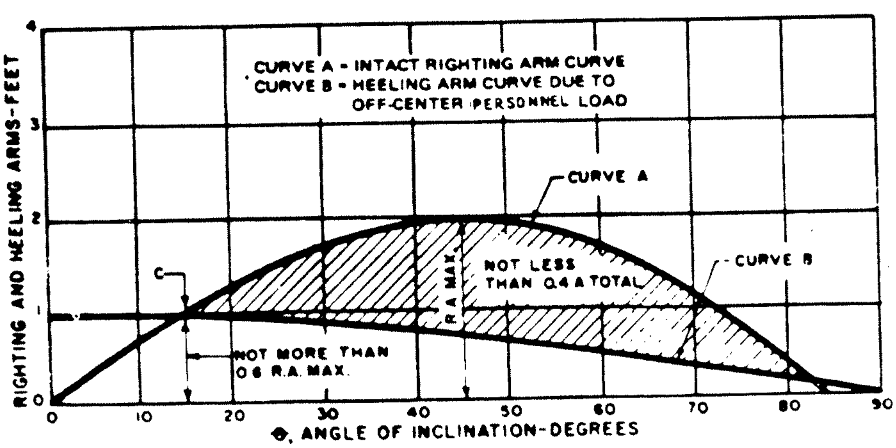


FIGURE 3

5. High Speed Turning may represent a stability problem on high speed ships with small turning circles.

Criteria for adequate stability are based on a comparison of the righting arm and high speed heeling arm curves, figure 4. The following must be satisfied:

a. The angle of steady heel, point C, does not exceed 15 deg.

b. The heeling arm at the intersection of the righting arm and heeling arm curves (point C) is not more than six tenths of the maximum righting arm.

c. The reserve of dynamic stability (shaded area) is not less than four tenths of the total area under the righting arm curve.

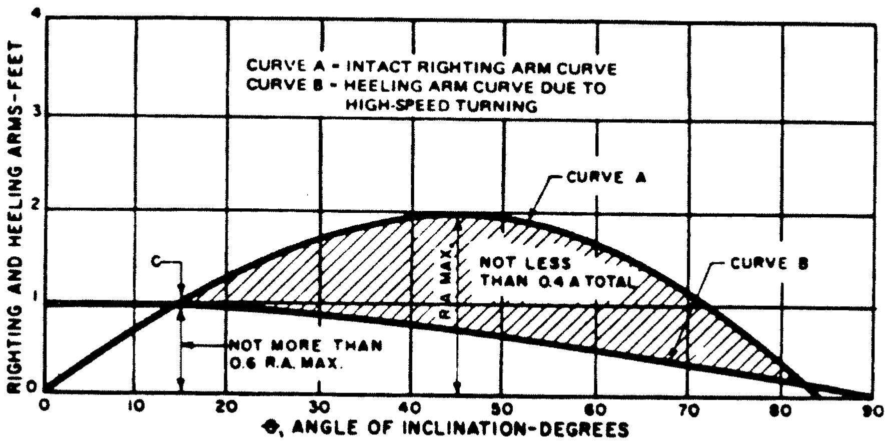


FIGURE 4

6. Topside icing is treated on a case basis. For ships required to operate in ice areas, stability effects are considered at the beginning of a design for assumed amounts of ice accumulation. Stability curves are developed for cases with ice accumulations and analyzed with respect to expected wind-heel in the specified operating areas. For ships not required by characteristics to operate in ice areas, the effects of topside icing are examined towards the end of the design and the design would be considered satisfactory if the ship could withstand a reasonable wind when loaded with ice.

079-1-b(2) Damage (Underwater flooding) Criteria

Monohull

1. Ships without side protective systems

a. Seagoing craft under 100 feet in length

Criterion: Withstand flooding of any single main compartment.

b. Ships between 100 and 300 feet in length

Criterion: Withstand the flooding of any two adjacent main compartments.

c. Ships over 300 feet in length

Category I includes combatant types and personnel carriers such as hospital ships and troop transports.

Criterion: Withstand flooding from a shell opening equal to 15 percent of the ship's length at any point fore and aft along the length of the ship.

Category II includes all ships not in category I.

Criterion: Withstand the flooding from a shell opening equal to 12.5 percent of the ship's length at any point fore and aft.

The following must be met to satisfy the above listed stability and buoyancy for damage of monohulls without side protective systems:

(1) The static trimmed-heeled waterline after damage does not submerge the margin line at side.

(2) From figure 5, point C, the static heel angle without wind effects, does not exceed 15 deg.

(3) There shall exist adequate dynamic stability availability to absorb the energy imparted to the ship by moderately rough seas in combination with beam winds. The shaded area, fig. 5, is a measure of the dynamic stability and is compared with required specified areas.

(4) The damage righting arm curve is terminated at 45 deg or at the angle where unrestricted flooding may occur, whichever is less.

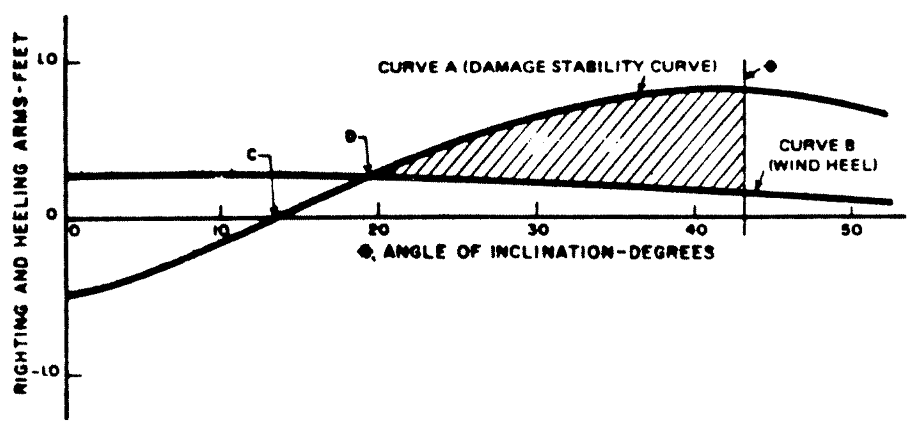


FIGURE 5

2. Ships with Side Protective Systems

Flooding damage for these ships is measured in terms of multiple torpedo or other non-nuclear weapon attacks, the number and kind being classified. Stability and buoyancy criteria are expressed in angles of heel resulting from multiple hits on one side for the case where the holding bulkhead is not pierced, and for the case where the holding bulkhead is assumed to be ruptured.

Criteria: apply to both cases:

a. Initial heel due to multiple hits on one side shall not exceed 20 degrees.

b. Arrangements exist for rapidly reducing the initial heel to less than 5 degrees.

c. The requirements for ships without side-protective systems with regard to dynamic area under the damage stability curve, and the final trimmed-heeled water-line with respect to the margin line, apply to ships with side protection systems.

3. Advanced Marine Vehicles (in waterborne displacement mode)

For the specified flooding listed below, stability and buoyancy after damage to vehicles of this category shall be considered satisfactory if:

The static trimmed-heeled waterline after flooding does not submerge the margin line at side, and

The required limit on initial heel (point C), and the required area A, of figure 6, are met.

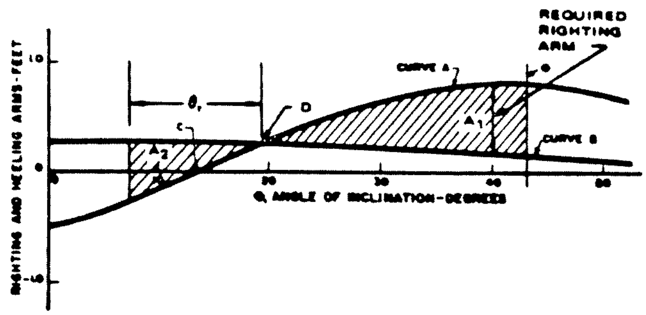


FIGURE 6

a. Hydrofoils

Criterion: Withstand same extent of flooding as conventional monohull of same size for the worst case of foils up or down.

(1) θ_r = 15 deg or angle from model test.

(2) Initial heel angle (point C) $\leqslant$ 15 deg.

(3) $A_1/A_2 \geqq 1.4$

(4) Minimum acceptable righting arm above heeling arm = 0.3 feet.

b. Small Air Cushion (ACV) or Surface Effects (SES) Types (less than 100 feet in length)

Criteria: The craft shall withstand the flooding of the worst of the following cases of damage:

(1) Longitudinal shell opening of 10 percent of the flotation box length or eight feet, whichever is greater, with transverse damage up to the centerline.

(2) Longitudinal shell opening of 15 percent of the flotation box length or eight feet, whichever is greater, with transverse damage extending up to, but not including bulkheads located more than 20 percent of the beam inboard of the shell.

Referring to fig. 6, the following must be satisfied for the above flooding cases:

(a) θ_r = 15 deg. or the angle from model tests

(b) Initial heel angle (point C) $\leq$ 15 deg.

(c) $A_1/A_2 \geq 1.0$

(d) Minimum righting arm above heeling arm = 0.3 feet.

c. Large Air Cushion Types (over 100 ft in length, ACV or SES)

Criteria: The ship shall withstand the flooding of the worst of the following cases of damage:

(1) Longitudinal shell opening equal to 15 percent of the design waterline length (including seals) or a length of hit required for an equivalent monohull design, whichever is greater. Transverse damage shall extend to the centerline.

(2) Longitudinal shell opening equal to 50 percent of the design waterline length (including seals) with a transverse extent to the first longitudinal bulkhead inboard of the shell.

Referring to fig. 6, the following must be satisfied for the above flooding cases:

(a) θ_r = 15 deg. or angle from model tests.

(b) Initial heel angle (point C) $\leq$ 15 deg.

(c) $A_1/A_2 \geq 1.0$

(d) Minimum righting arm above heeling arm = 0.3 feet.

d. Small Waterplane Area Twin Hull Type (SWATH)

Criterion: Withstand flooding from a shell opening approximately equal to that required for an equivalent monohull counterpart.

Referring to fig. 6, the following must be satisfied:

(1) θ_r = 15 deg. or angle from model tests.

(2) Initial static angle of heel (point C) $\leqq$ 20 deg.

(3) Counterflooding capability to reduce static heel angle to $\leqq$ 5 deg for an aircraft carrier mission and $\leqq$ 15 deg for a non-aircraft carrier mission.

(4) $A_1/A_2 \geqq 1.0$

(5) Minimum righting arm above heeling arm = 0.3 ft.

c. Catamaran Types (Other than SWATH)

Criterion: Withstand flooding from a shell opening equal to that required for an equivalent monohull counterpart.

Stability and buoyancy criteria are the same as for SES.

079-1-c. Part II CONVENTIONAL MONOHULLS

079-1-c(1) Hazards

Naval ships are designed with the capability of withstanding the effects of certain hazards which may be thought of as:

1. Applying to the intact ship
2. Causing flooding of the ship as a result of underwater damage
3. Applying to the ship in the flooded condition

Examples for external influences and hazards for each of these cases are:

1. For the intact ship:

   a. Beam winds combined with rolling

   b. Lifting of heavy weights; particularly off-center weights, also, towline forces for tugs.

   c. Crowding of personnel to one side.

   d. High-speed turning.

   e. Topside icing.

2. Damage to the ship resulting in flooding:

   a. Stranding involving moderate flooding.

   b. Bow collision.

   c. Collision or stranding resulting in extensive flooding.

   d. Enemy explosive action causing extensive flooding.

3. For the flooded ship:

   a. Beam winds combined with rolling.

   b. Progressive flooding.

079-1-c(2) Design Philosophy

The design criteria outlined in paragraph c(7) are practical in that they represent standards which are reasonably attainable for new designs and conversions and can be met by many older ships in service.

It would be desirable to provide every ship with the capability of withstanding each type of hazard under the most extreme conditions which are likely to arise; however, this cannot be done due to other overriding design limitations.

The loss of a hospital ship some years ago as a result of a harbor collision is an example of extreme underwater flooding. For survival, it would have been necessary to provide a capability to withstand flooding from total shell openings equivalent to about one half to two thirds of the ship's length. Although the ship more than met stability criteria, the ship was lost because the extensive damage required a degree of stability far in excess of that which could be provided.

Generally, the stability and reserve buoyancy required to withstand the extent of underwater damage specified in the criteria for a particular ship type, will satisfy the requirements for overcoming the hazards to the intact ship even under extreme conditions.

The underlying philosophy in establishing stability standards is that as the ship becomes larger, or more important from a military standpoint, or carries large numbers of personnel, the degree of hazards to which it may be exposed is considered to increase, and adequate stability and buoyancy are provided accordingly. As mentioned previously, this approach is both logical and reasonable since the personnel carrier or militarily important ship is usually of sufficient size to permit extensive internal subdivision which enhances its ability to survive underwater damage. The detailed description of criteria, which will be presented later, will illustrate the variation of stability requirements and standards with ship size and function.

079-1-c(3). Design Considerations

For new designs, a naval architect is presented with a set of ship characteristics, many of which present conflicting demands. For naval ships the stability and buoyancy standards which are detailed later are among the prescribed characteristics. Those features which generally favor stability and reserve buoyancy such as a low center of gravity, adequate beam, optimum bulkhead arrangement and watertight integrity, absence of off-center compartments, and adequate freeboard are in conflict with the demands of other characteristics. Beam is influenced by speed requirements and seaworthiness; bulkhead spacing is affected by size of machinery plant and other arrangement requirements; the armament and electronic installations are high weights; below decks fore-and-aft access and ventilation system penetrations are in competition with watertight integrity requirements; liquid tank arrangement and the need to protect vital spaces present problems of potential off-center flooding. Consumption of liquid load generally results in a rise in the center of gravity. In the case of oil, compensation by seawater ballasting is possible if the corrosion and pollution problems associated with such ballasting and deballasting can be overcome. Otherwise designs must be based on the premise that there will be no sea-water ballasting of empty oil tanks for normal operations.

079-1-c(4). Watertight Subdivision, Watertight Integrity, and Compartment Arrangement

There are numerous considerations involved in determining the optimum watertight subdivision of a naval ship. The principal factors are:

1. Ability to survive underwater damage.
2. Protection of vital spaces against flooding.
3. Interference of subdivision with arrangements.
4. Interference of subdivision with access and systems.
5. Provisions for carrying liquids.

6. Stranding.

7. Bow collision damage.

It has been noted already that design features which favor stability are often in competition with other phases of the design. Similarly, in the case of watertight subdivision, there may be certain conflicts among the various factors listed. Where such conflicts occur, the relative importance of the conflicting factors are evaluated in determining the best arrangement.

1. Ability to Survive Underwater Damage

Naval ships may be classified as having a side protective subdivision system or not having such a system. Both types usually have an inner bottom which in addition to serving as tankage for liquids may provide some protection against under bottom near-miss explosions. Aircraft carriers are examples of ships with a side-protective system. Such a system consists of outboard layers of longitudinal bulkheads forming compartments which contain liquids or are voids which can be flooded readily. Numerous transverse bulkheads form the fore-and-aft boundaries of these compartments. The system extends about two thirds of the ship length and is intended to minimize flooding of vital spaces inboard of the system which otherwise might result from enemy torpedo action. Generally, a side-protective system is not feasible on smaller ship types so that most naval ships are in the category of not having a side protective system.

For ships without a side-protective system, transverse watertight bulkheads are the most effective form of internal subdivision from the standpoint of developing the ship's overall resistance to flooding. Longitudinal bulkheads generally have an unfavorable effect on damage stability unless the off-center spaces formed by these bulkheads are cross-connected to ensure rapid cross-flooding or unless these spaces are kept full of liquids. Each transverse bulkhead is extended watertight to a height which is above the expected flooding water level on this bulkhead when the bulkhead acts as an intact flooding boundary. Bulkheads are normally carried watertight to a deck referred to as the bulkhead deck. The bulkhead deck on most designs coincides with the weather deck and may be a continuous main deck as in the case of cargo types or a stepped deck as in the case of some destroyer types.

Decks and platforms, other than the weather deck, may have either a favorable or unfavorable effect. If damage occurs below a watertight deck and the space below the deck floods completely, the effect is definitely favorable because high flooding water is eliminated. On the other hand, if damage occurs above a watertight deck and flooding of spaces below is prevented, the effect of the watertight deck is unfavorable since low flooding will not be obtained. Because of the uncertainty as to the location of the damage relative to the deck, and the probability that all or most decks will be ruptured in way of damage except on the largest ships, no reliance can be placed on watertight decks and platforms below the weather deck in evaluating a ship's resistance to underwater damage. A watertight weather deck throughout the ship's length is desirable to prevent flooding into undamaged spaces when the weather deck is permanently or temporarily submerged. Considerations other than reserve buoyancy or stability after damage determine whether other decks or platforms are made watertight.

2. Protection of Vital Spaces Against Flooding

Vital spaces are defined as those spaces which are manned at "general quarters" (ready for action) and those unmanned spaces that contain equipment essential to the primary mission of the ship. It is obviously desirable to surround each of these spaces within the hull by a completely watertight or airtight envelope, as appropriate since such protection might prevent flooding or contamination by smoke of the space from nearby damage, thus preserving the function of the space. The damage control deck, on which damage-control equipment and stations are located, is also considered to be a vital space boundary and is made watertight on as many ship types as feasible. The damage-control deck is located high in the ship and is usually the covered deck having fore-and-aft access through watertight openings in the main transverse bulkheads.

The subdivision fitted as protection for vital spaces involves decks and longitudinal bulkheads and may reduce the overall resistance of the ship to underwater damage. It is, therefore, necessary in the overall design to provide sufficient stability to overcome this adverse effect. The disadvantage is minimized, insofar as possible, by so locating vital spaces as to avoid unsymmetrical flooding.

3. Interference of Subdivision with Arrangements

The spacing of transverse watertight bulkheads which is necessary to develop resistance to underwater attack will often interfere with obtaining the most favorable arrangement of ship compartments. Since all of the main transverse bulkheads should, if possible, extend continuously from the keel up, without steps, all compartments on the various levels between two main transverse bulkheads are restricted to the same length, whereas the optimum arrangement might require compartments of different lengths. The most favorable location of bulkheads from the standpoint of resistance to underwater damage may make it difficult to obtain the desired length of main compartments from the arrangement standpoint. Generally, the desired locations and lengths of the machinery spaces and magazines establish the approximate location of the adjacent transverse bulkheads and influence the number and spacing of the remaining bulkheads. As mentioned before, necessary minor longitudinal subdivision is arranged to minimize the possibility of unsymmetrical flooding.

4. Interference of Subdivision With Access and Systems

Penetration of watertight subdivision by piping, electric cable, ventilation ducts, and access openings involves some weight, effort, and expense since watertight fittings and valves and piping systems must be provided. However, the associated costs are small when compared to the protection provided. Additional disadvantages are that - piping system valves, access and ventilation closures must be set, throughout the life of the ship, in accordance with the various damage-control material conditions, and rapid access is hindered by the necessity for opening and securing doors in the process of passing through. Therefore, there is a definite advantage to be gained if bulkheads which contain a considerable number of such penetrations can be made non-tight.

The bulkheads which have the greatest number of penetrations, and through which rapid access is most often required, are those between the weather deck and the deck below in the midship region. On most ships this corresponds to the main and second decks with the second deck serving as the previously-defined damage-control deck. If some of these bulkheads are nonwatertight below the weather deck, they cannot serve to confine flooding water above the openings in the bulkhead and flooding would continue fore and aft until watertight bulkheads are reached. On some ships having a relatively high freeboard and large intact stability, investigation may show that damage stability and reserve buoyancy will be adequate with some of the main transverse bulkheads considered non-tight above the second deck (or the first deck below the weather deck). In such a case it is essential to make the second deck watertight in way of the non-tight bulkheads, at least in the outboard areas which may be submerged after damage, to avoid progressive flooding below.

On most ships, however, it is necessary to take advantage of the buoyant volume below the weather deck in order to meet the criteria for resistance to underwater damage. Even in these cases, there are inboard areas in the upper levels of some bulkheads which will be above the final level of flooding water, taking roll and wave action into account. Penetrations through these bulkhead areas may be nonwatertight without introducing appreciable danger of progressive flooding into intact spaces if other considerations were not governing such as smoke contaminant and compartment air testing. As a practical matter, to permit periodic air testing of watertight compartments, ventilation ducts without permanent closures are the only nonwatertight penetrations permitted through the bulkheads. The periphery of the vent duct at the penetration is watertight, and temporary closures are installed in the duct for compartment testing. Since ventilation ducts which penetrate bulkheads below the permissible nontight areas would require permanent watertight closures, ventduct bulkhead penetrations are generally limited to levels between the weather deck and the deck below. This practice is based on the recognition that some vent-duct watertight closures which are required to be closed may be left open. By limiting bulkhead penetrations to an area between the weather deck and the deck below, it is reasonable to predict that the amount of progressive flooding through vent ducts will be small.

Penetrations through watertight decks are controlled in a manner similar to that for transverse bulkheads for the purpose of preventing progressive flooding into otherwise undamaged spaces. Of particular interest are the weather deck and the bulkhead deck if different from the weather deck. These serve as part of the ship's watertight envelope for reserve buoyancy considerations. Ventilation ducts which terminate in the weather are carried watertight to a level above the calculated external waterline for the damaged ship, allowing for ship rolling and wave action. If not feasible to extend ducts to this level, watertight closures are fitted. Vent ducts serving vital spaces below decks are fitted with watertight closures at the boundary of the vital space to prevent flooding through the ducts if these spaces are otherwise undamaged. The watertightness of the damage-control deck (usually the second deck) is protected against vent-duct flooding from below. This is done by extending the ducts vertically to about 6 ft above the damage-control deck. The foregoing are examples of the attention that must be given to accesses and systems which could jeopardize the watertight integrity of the main subdivision of the ship. There are many other controls of this nature which are covered in the "General Specifications for Ships of the United States Navy" and are included in the detail specifications for each ship design.

5. Provision for Carrying Liquids

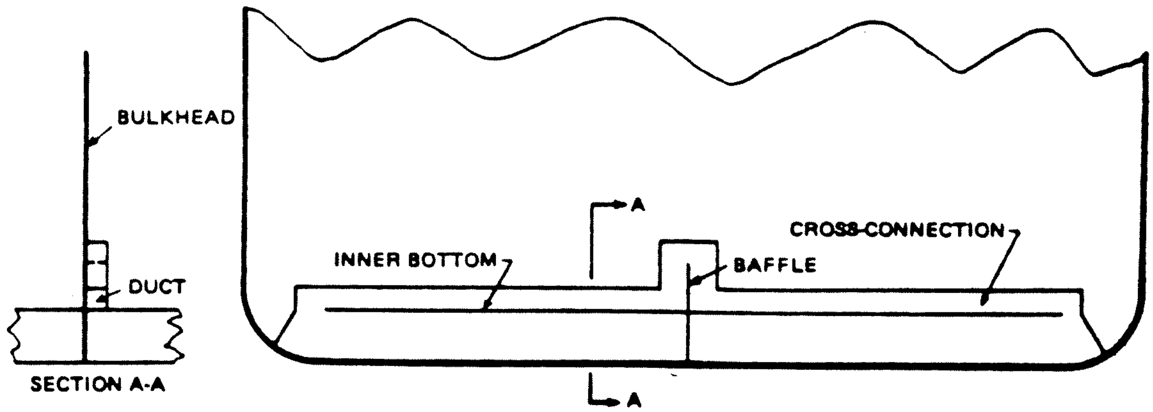
Subdivision of tankage, by its very nature is of watertight or oil-tight construction. The vertical location, size and shape, arrangement, and usage of tanks significantly affect the ship's stability in both intact and damaged conditions. The vertical location affects the height of the ship's center of gravity; the size and shape determine the free-surface effect; empty off-center tanks are a potential source of unsymmetrical flooding in the event of underwater damage; tank usage determines whether empty tanks can be ballasted with sea water. From a stability standpoint, an example of a favorable tankage system would be one in which:

a. There were clean ballast tanks, low in the ship, which could be filled as oil and fresh water were consumed.

b. There were no off-center oil and fresh water tanks.

c. The athwartships dimensions of the oil and fresh-water tanks were small to reduce free surface.

Such a tank arrangement is not feasible on most ships because of limited space. The more common tank arrangement locates oil tanks low in the ship and on past designs, equips them with ballasting facilities. Standard liquid loading instructions in the past have required ballasting of empty oil tanks. A discussion of the practical aspects of seawater ballast follows later. Cross-connections are employed in off-center double-bottom oil tanks where necessary to reduce potential unsymmetrical flooding. An example of a cross-connecting duct is shown in Fig. 7.



Cross connection for double-bottom tanks

FIGURE 7

The baffle is carried sufficently high to prevent transference of oil during normal rolling of the ship. Appropriate venting is provided. If these tanks were empty at the time one tank was bilged, automatic rapid counterflooding would occur. Recently where other than Navy Special Fuel Oil was the fuel, a sea-water displacement system was employed. This has the advantage of maintaining a constant low weight and reducing potential unsymmetrical flooding. With the advent of pollution controls, new designs must provide adequate stability without relying on sea-water ballasting of empty oil tanks during normal operations.

On several recent destroyer designs, the damage-stability criteria could not be met for certain groups of compartments owing to unsymmetrical flooding in off-center deep oil tanks. A solution to this problem was to redesign the offending wing tanks to U-shaped tanks thus eliminating the possibility of unsymmetrical flooding in the critical group of compartments. It was necessary to establish that the resulting free surface of the intact U-tanks did not cause some other group of compartments to become critical in damage stability. The large added free-surface effect was also evaluated in the intact stability cases of beam winds and high-speed turning before a final decision was made.

6. <u>Stranding</u>

The most effective subdivision for protection against the hazard of stranding consists of a complete inner bottom over areas which are subject to damage through grounding. Where no inner bottom is fitted, the lowest platform in that area is made watertight. It should be noted, that where damage from stranding is sufficiently extensive to rupture the inner bottom, subdivision considerations described under "Ability to Survive Underwater Damage" apply. For damage other than stranding an unfavorable situation can arise in the case where the double bottom consists of voids or empty tanks. This would occur from extensive flooding resulting from a shell opening above the inner bottom, with the inner bottom remaining intact.

7. Collision Damage

The case of collision damage involving considerable sideshell opening is covered under "Ability to Survive Underwater Damage." For the case where only bow damage is involved, survival is not in question and considerations of minimizing flooding govern. With this in mind, one of the forward main transverse bulkheads serves as a collision bulkhead for purposes of limiting flooding to the bow compartment. A collision bulkhead is carried watertight to the weather deck and no access is provided through the bulkhead. It is located at least 5 percent abaft of the forward perpendicular.

079-1-c(5) Liquid Loading Instructions Practice

As mentioned under "Provisions for Carrying Liquids," the general arrangement requirements of naval ships have relegated oil and water tanks to low-level locations in the ship. Even with the advantage of the low center of gravity of liquids, there is usually insufficient margin to permit a significant reduction in stability, particularly in the case of damage stability. It is, therefore, necessary to compensate for the loss of low weights as fuel and water are consumed. In addition to causing a substantial rise in the ship's center of gravity, empty off-center tanks are potential sources of unsymmetrical flooding. The practice has been to issue liquid loading instructions which generally specify that oil storage tanks shall be drawn down one pair at a time and refilled with sea-water ballast before drawing from another pair. Service (settling on some merchant type ships) tanks are to be kept at the 50 percent level, or greater, if practicable. Fresh water tanks are to be maintained as full as practicable by evaporator make-up. There may be variations to the foregoing general outline. For example, in the case where unsymmetrical flooding in one large off-center tank of a port and starboard pair might result in unsatisfactory damage stability in the minimum operating condition (when the ship has been operating for an extended period), the liquid loading instructions would specify using oil from this pair first and ballasting before drawing from another pair. The ship near full load generally has better stability to withstand the unsymmetrical flooding. Special instructions govern the use of liquids in ships with side protective systems so that maximum resistance to the effects of explosion will be maintained.

Practical difficulties arise in the use of seawater ballasting. In the past deballasting of oily ballast water had to be accomplished at sea (about 100 miles from port) unless facilities were available in port to receive the oily ballast water. Dumping oily ballast water into the sea at any place will be prohibited. A ship which has deballasted at sea is in a poor condition to withstand underwater damage. An oil-water separator, capable of producing a sufficiently oil-free effluent to satisfy port regulations, and of sufficient capacity to permit deballasting in port or at sea would be an acceptable solution.

Another problem with sea water ballasting of oil tanks is the reluctance on the part of the operators to ballast oil tanks. Ballasting of fuel tanks adds to the probability of salt water contamination of the fuel and requires more rigorous fuel management practices (e.g., settling and stripping) to achieve the specified fuel quality. Failure to maintain this quality can result in serious degradation of pumping, control and burning equipment and even loss of fires in extreme cases.

In addition, a price is paid, maintenance-wise, in more rapid deterioration of fire brick or increased wear on a gas turbine as a result of sea-water ballasting of oil tanks. In the past, it was necessary to accept this disadvantage in the interest of maintaining the greatest practicable resistance of underwater damage.

In view of the above limitations to sea-water ballasting of empty oil tanks, ship designs must provide adequate stability and means of controlling trim and immersion without resorting to sea-water ballasting of empty oil tanks during normal operations.

079-1-c (6) Summary of Subdivision and Liquid Loading Practices

A summary of the subdivision and liquid loading ground rules would include the following:

1. The watertight envelope for intact stability extends to the weather deck. For damage stability the bulkhead deck, if different from the weather deck, is the upper boundary of the watertight envelope.

2. Bulkheads. Sufficient and adequately spaced main transverse watertight bulkheads provide the ability to withstand underwater damage. These bulkheads extend vertically to levels necessary to prevent flooding into undamaged compartments. Longitudinal bulkheads are avoided except in ships with side protective systems.

3. Decks. Horizontal watertight subdivision is limited to the weather deck, the bulkhead deck, the damage-control deck, that part of a deck which may connect stepped bulkheads, and the first deck or platform above the shell bottom.

4. Vital Spaces below the flooding water levels are bounded by watertight boundaries; those above the flooding water levels are bounded by airtight boundaries.

5. Tank boundaries of necessity are bounded by watertight or oiltight structure.

6. Design Heads. Watertight subdivision is designed to withstand a hydrostatic head corresponding to the level of assumed flooding water which may be loaded on such structure.

7. Protection of Watertight Integrity. Access through main watertight subdivision bulkheads is limited to levels above the damage-control deck. Watertight trunks are provided to vital spaces. Ventilation penetrations of main transverse bulkheads are limited to levels above the damage-control deck, and watertight closures are fitted where necessary to limit flooding into undamaged compartments. Vent ducts which terminate in the weather are carried watertight to a level above the expected external waterline, allowing for ship rolling and wave action. Watertight closures are fitted if it is not feasible to carry the weather openings to the required level. Vent ducts serving vital spaces are carried individually watertight to just under the bulkhead deck and are provided with closures at the boundary of the vital spaces.

8. Cross-connections are provided in off-center spaces and, if necessary, in double-bottom tanks to reduce potential unsymmetrical flooding.

9. Liquid loading instructions specify tank sequences and liquid ballasting as necessary. Clean ballast tankage may be required for stability and trim and immersion control to offset a prohibition of ballasting empty oil tanks.

10. Limiting drafts based on subdivision or strength, when applicable, are assigned to each ship as guides against overloading.

079-1-c (7) Criteria

The material which follows covers the specific criteria applicable to the ship in the intact condition and the ship after underwater damage. While a ship meeting the specified criteria will not be an unsinkable ship it will have a considerable chance of survival consistent with the practical limitations of size and arrangement. The extent of the hazards to which the ship is subjected is assumed to vary with ship size and function. This reflects the philosophy that the more important ship type, and the larger ship in a given type, should be able to withstand a greater extent of hazards affecting stability than the less important and smaller ships. The stability and buoyancy criteria are considered as attainable "floors" rather than ceilings, and where other considerations such as speed, arrangement and cost permit, the governing criteria should be exceeded.

The criteria referred to above are those applicable to conventional monohull types. Part III outlines the criteria for unusual ship types such as multi-hull and nigh performance ship and craft.

079-1-c (8) Conditions of Loading When Applying Criteria

Certain standard conditions of loading are pertinent in applying stability criteria. The operating range in which the ship is expected to meet the criteria is between full load and minimum operating condition for ships without side-protective systems, and between full load and optimum battle condition for ships with side-protective systems. Special operating conditions within this range may require investigation to insure that the stability criteria are satisfied for the worst loading condition.

1. Full Load

As the name implies, the full-load condition corresponds to a departure condition with full allowance items of a ship's variable loads and cargo. In the stability analysis, the full load is modified by assuming that service tanks are half full, one pair of storage fuel tanks is empty, potable and reserve feedwater are reduced to two thirds of full load. This reflects a condition after a few days steaming. For ships with compensating system, the same assumptions are made except that 100% sea water ballast is carried in one pair of storage hull tanks instead of assuming an empty pair of tanks.

2. Minimum Operating Condition

The minimum operating condition describes the ship after an extended period at sea and is usually the lowest stability condition consistent with following the liquid loading instructions, although some exceptions may occur as indicated later under 4, Other Operating Conditions. In view of the likely prohibition against dumping oily ballast into the seas, the normal minimum operating condition for new designs will reflect clean sea water ballast loading, where provided, as well as many empty oil tanks. For ships which were designed on the basis of ballasting of empty oil tanks, the minimum operating condition should reflect sea water ballasting of empty oil tanks in accordance with prescribed liquid loading instructions. In view of the previously noted disadvantages of sea-water ballasting of empty oil tanks, it is recognized that noncompliance with liquid ballasting instructions occurs.

Since there is better separation of oil and water in narrow deep tanks than in shallow wide tanks, ballasting of deep tanks from a practical viewpoint has more of a chance of being carried out than ballasting of bottom tanks.

a. Thus, for ships designed on the basis of requiring sea water ballasting of empty oil tanks, two combinations of fuel-ballast loading in the minimum operating condition for conventionally fueled ships are considered in order to cover both strict observance of ballasting instructions and the case where ballasting instructions are not fully observed. A typical breakdown of loads in the minimum operating condition is given in Table 2.

   It should be noted that Case I reflects the possibility of nonballasting of bottom tanks. Case II assumes adherence to liquid loading instructions, allowing one pair of empty oil tanks which would correspond to the time just prior to ballasting the empty tanks.

   In applying the criteria, only Case II is assumed for wind criteria in intact conditions. There will be sufficient warning of impending bad weather or sea conditions to permit optimum sea water ballasting. The incentive to ballast for stability in heavy weather is stronger than for assumed damaged due to attack or collision. In other intact criteria and damage stability criteria, both Case I and Case II are considered.

b. For ships designed to operate without ballasting empty oiltanks, loading assumptions outlined in Table 3 apply. Two cases are relevant. Case III is one in which the only sea water ballast is contained in clean ballast tanks, if provided. Case IV contains clean sea water ballast, as in Case III, plus emergency sea water ballast in empty oil tanks, if necessary. Case III is used to evaluate damage stability as well as all intact stability other than beam winds. Case IV is used for beam winds which is considered as an emergency in which oil pollution of the seas is accepted as being unavoidable. Filling empty oil tanks, as in Case IV, is by sea water piping provided in the design.

3. Optimum Battle Condition

This condition applies to ships with side-protective systems and is similar to the minimum operating condition for ships without side protective systems, except for the following differences:

Ammunition	Same as full load
Provisions and General Stores	Two thirds full load
Lube oil, diesel oil, aviation fuel	Two thirds full load
Fuel oil and sea water ballast	In accordance with liquid loading instructions except that service tanks are half full, and one pair of storage oil tanks per machinery box assumed empty.

4. Other Operating Conditions

With some ships, the minimum operating condition or optimum battle condition may not be the worst condition within the operating range. For example, a ship with compensating systems may be in its worst condition with full oil instead of one third oil plus two thirds salt water. Conventional ships which ballast oil tanks may be in their worst condition after refueling, with one empty tank, instead of one third oil plus salt water ballast. The designer should keep exceptions such as these in mind and consider the worst loading condition when applying the stability criteria.

Table 2 Loads in Minimum Operating Condition for Ships Designed to Ballast Empty Oil Tanks

Crew and effects	Same as full load
Ammunition	One third of full load ammunition with maximum quantities in ready-service stowages and remainder in magazines. For guided missiles, least favorable quantity and disposition is assumed.
Provisions and general stores	One third full load
Lube oil	One third full load
Reserve feed and fresh water	Two thirds full load
Diesel Oil (other than for propulsion)	One half full load on ships below destroyer size; one third full load on larger ships
Aviation or vehicle fuel	One third of full load. Compensating sea-water ballast (or ballast water in empty tanks) is taken as remainder of the load.
Airplanes and aviation stores	Same as full load
Cargo	No cargo for ships whose normal function requires that they unload all cargo. For ships such as tenders and replenishment types which do not normally unload completely, assume one third of full load cargo

	Fuel Oil and Sea-Water Ballast Case I	Case II
(Noncompensating system)	In both cases, total fuel oil is about one third of full load	
Service (or settling tanks)	Half full	Half full
Wing storage oil tanks	Filled to approximately the external waterline with oil or sea water, except for one pair which is taken empty if it occurs within assumed underwater damage	Same as for Case I except that when a double-bottom oil tank is assumed empty in way of damage, no wing tank is assumed empty
Centerline deep tanks	Full of oil or seawater	Same as for Case I
Double-bottom tanks	A maximum of one third of bottom tanks full of oil or seawater. Other bottom tanks empty	Bottom tanks full of oil or ballast water except for one pair which is assumed empty *if the resulting intact or damage stability is worse than with an empty wing tank*

Note: "Full oil tanks" means filled to 95 percent capacity. "Full water tanks" means filled to 100 percent capacity.

Table 3 Loads in Minimum Operating Condition for Ships Designed to Operate without Ballasting of Empty Oil Tanks.

Crew and effects	Same as full load
Ammunition	One third of full-load ammunition with maximum quantities in ready-service stowages and remainder in magazines. For guided missiles, least favorable quantity and disposition is assumed.
Provisions and general stores	One third full load
Lube oil	One third full load
Reserve feed and fresh water	Two thirds full load
Diesel Oil (other than for propulsion)	One half full load on ships below destroyer size; one third full load on larger ships
Aviation or vehicle fuel	One third of full load. Compensating sea-water ballast (or ballast water in empty tanks) is taken as remainder of the load.
Airplanes and aviation stores	Same as full load
Cargo	No cargo for ships whose normal function requires that they unload all cargo. For ships such as tenders and replenishment types which do not normally unload completely, assume one third of full load cargo

Fuel Oil and Sea-Water Ballast

In both cases, total fuel oil is about one third of full load.

	Case III	Case IV
Service or settling tanks	Half full	Same as Case III
Other Oil Tanks	Most favorable distribution to bring total oil to to about one-third full load	Same as Case III
Clean Ballast Tanks	Fill to capacity if necessary	Same as Case III
Sea-water Ballast in Empty Oil Tanks	None	If oil tanks are fitted with S.W. piping, fill to extent necessary to meet criteria

079-1-c(9) Intact Stability Criteria

The stability of the ship in the operating range is expressed by the intact stability curve for full load and minimum operating conditions or optimum battle condition if applicable. If a worse condition exists within the operating range then it too should be examined. It is recognized that certain conditions will be encountered where stability is poorer than for the standard conditions. The ship deballasted in preparation for refueling, is not expected to withstand all the hazards, as in the case of unrestricted operations. If at all possible, refueling is carried out under relatively favorable wind and sea conditions in areas considered safe from enemy action.

The decrease in stability that occurs in the intact condition as a result of the previously mentioned hazards, is compared with the initial intact stability for the standard operating conditions as outlined in the following paragraphs.

1. Beam Winds Combined with Rolling

a. Effect of Beam Winds and Rolling

Beam winds and rolling are considered simultaneously since a fairly rough sea is to be expected when winds of high velocity exist. If the water were still, the ship would require only sufficient righting moment to overcome the heeling moment produced by the action of the wind on the ship's "sail area." When the probability of wave action is taken into account, an additional allowance of dynamic stability is required to absorb the energy imparted to the ship by the rolling motion.

b. Wind Velocities

The wind velocity which an intact ship is expected to withstand depends upon its service. The wind velocities used in determining whether a ship has satisfactory intact stability with respect to this hazard are given in Table 4.

c. Wind Heeling Arm

A general formula which is used to describe the unit pressure on a ship due to beam winds is as follows:

$$P = C\,p\frac{V^2}{2g}$$

where

C = dimensionless coefficient for ship type
p = air density (mass per volume)
g = gravity acceleration
V = wind velocity

There is considerable uncertainty regarding the value of C. Similarly, the variation of the wind velocity at different heights above the waterline is not exactly defined.

Table 4 Wind Velocities

Service	Minimum * wind velocity for design purposes (knots)	Minimum Acceptable** wind velocity for ships after 5 years in service (knots)
1. Ocean		
(a) Ships which must be expected to weather full force of tropical cyclones. This includes all ships which will move with the amphibious and striking forces	100	90
(b) Ships which will be expected to avoid centers of tropical disturbances	80	70
2. Coastwise		
(a) Ships which will be expected to weather full force to tropical cyclones	100	90
(b) Ships which will be expected to avoid centers of tropical disturances, but to stay at sea under all other circumstances of weather	80	70
(c) Ships which will be recalled to protected anchorages if winds over Force 8 are expected	60	50
3. Harbor	60	50

* Ships built to Ship specifications dated subsequent to 1 August 1975 shall meet this wind throughout service life.

** Ships built to Ship specifications dated prior to 1 August 1975 shall meet this wind after five years of service

The most widely used value for P, in English units, lb per sq ft, has been $P = 0.004\ V^2$ (where V is in knots). Heeling arm due to wind $= \dfrac{0.004\ V^2\ A\ L\ \cos^2\theta}{2240 \times \text{displacement}}$

where

A = projected sail area, sq ft
L = lever arm from half draft to centroid of sail area, ft
V = nominal wind velocity, knots (see Fig. 8)
Θ = angle of inclination, degrees

It is recognized that as the ship heels to large angles, the use of $AL\cos^2\theta$ is not rigorous, since the exposed area varies with heel and is not a cosine function. However other effects are also ignored and the above approach should be considered as a useful design comparative tool to obtain gross effects. Recent wind tunnel tests at the Naval Ship Research and Development Center on models representing different ship types and superstructure forms have indicated that an average coefficient of 0.0035 rather than 0.004 should be used in the foregoing formula which assumes a constant wind gradient. In order to account for actual full scale velocity gradient effects, an average coefficient value of 0.004 in conjunction with the velocity-gradient curve, Fig. 9 should be used. This curve is a composite of various values described in the literature. The nominal velocity is assumed to occur at about 33 ft. above the waterline. Use of Fig 9 for determining V in the formula for heeling arm due to wind, properly favors the smaller ships which normally would be affected by the velocity gradient and would also be

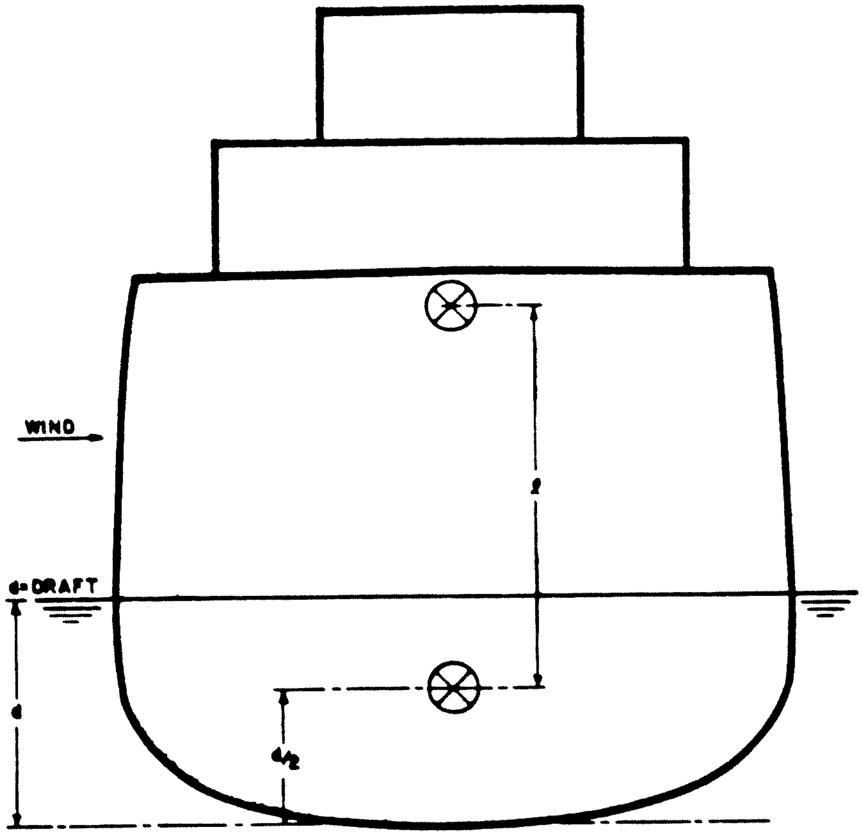
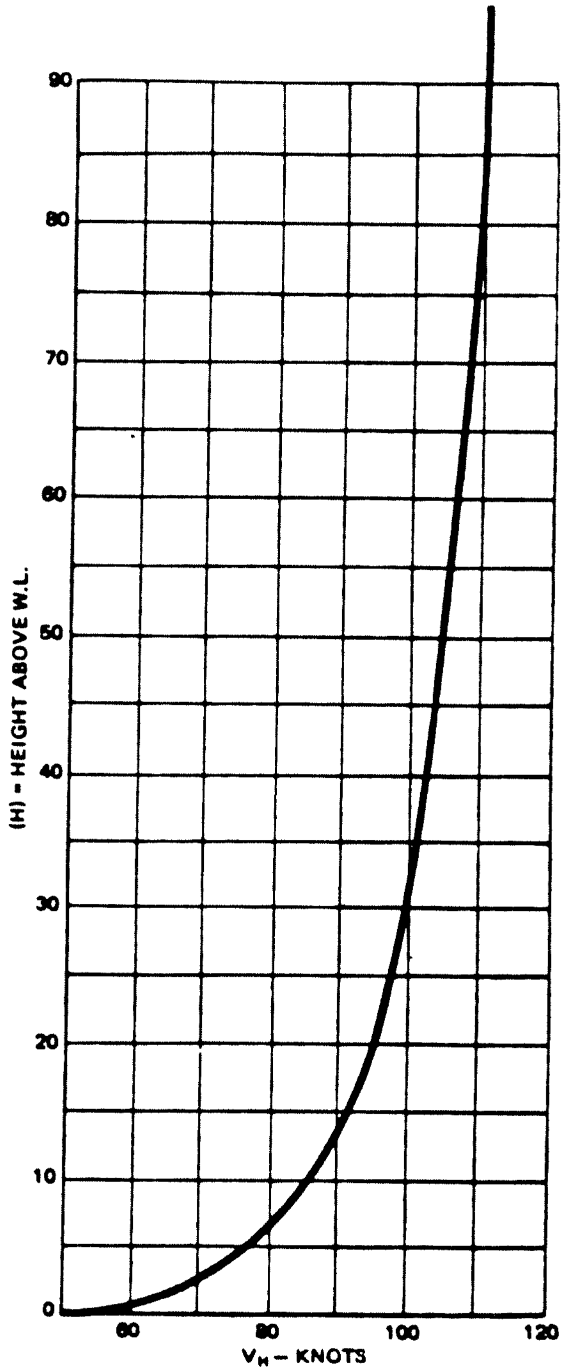


FIGURE 8

somewhat sheltered from the wind by the accompanying waves. Table 5 has been prepared for a nominal 100-knot wind as an aid in determining windheeling moments for varying heights above the waterline. For other wind velocities, the values in Table 5 are multiplied by $(V/100)^2$.



Actual wind velocities at varying heights above WL for a nominal 100-knot wind at 33 ft above WL

FIGURE 9

Table 5 Heeling Moments (ft-tons) per Square Foot for a Nominal 100-Knot Wind

Height above WL, ft	Center of lateral resistance below waterline, ft: 2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
0–5	0.04	0.05	0.06	0.07	0.07	0.08	0.09	0.10	0.11	0.11	0.12	0.13	0.14	0.15	0.16	0.17	0.18	0.19
5–10	0.11	0.12	0.14	0.15	0.16	0.18	0.19	0.20	0.20	0.22	0.23	0.24	0.26	0.27	0.28	0.29	0.31	0.32
10–15	0.20	0.21	0.23	0.24	0.26	0.27	0.29	0.30	0.32	0.33	0.34	0.35	0.37	0.38	0.40	0.41	0.43	0.44
15–20	0.30	0.32	0.33	0.34	0.36	0.37	0.39	0.41	0.42	0.44	0.45	0.46	0.48	0.49	0.51	0.53	0.54	0.56
20–25	0.40	0.41	0.43	0.45	0.46	0.47	0.49	0.51	0.53	0.54	0.56	0.58	0.60	0.60	0.62	0.64	0.66	0.67
25–30	0.50	0.52	0.54	0.55	0.57	0.59	0.60	0.62	0.64	0.65	0.67	0.69	0.71	0.73	0.74	0.75	0.77	0.79
30–35	0.61	0.62	0.64	0.66	0.68	0.70	0.72	0.73	0.75	0.77	0.79	0.80	0.82	0.84	0.86	0.87	0.89	0.91
35–40	0.72	0.73	0.75	0.77	0.79	0.81	0.83	0.85	0.86	0.88	0.90	0.92	0.94	0.96	0.98	1.00	1.01	1.03
40–45	0.83	0.85	0.86	0.88	0.90	0.92	0.94	0.96	0.98	0.99	1.01	1.03	1.05	1.07	1.09	1.11	1.13	1.15
45–50	0.95	0.97	0.98	1.00	1.02	1.04	1.06	1.08	1.10	1.12	1.13	1.15	1.18	1.20	1.22	1.24	1.26	1.27
50–55	1.06	1.08	1.10	1.12	1.14	1.16	1.18	1.20	1.22	1.24	1.26	1.27	1.30	1.31	1.34	1.36	1.38	1.40
55–60	1.18	1.20	1.22	1.24	1.26	1.27	1.30	1.32	1.34	1.36	1.38	1.39	1.41	1.43	1.46	1.48	1.50	1.52
60–65	1.30	1.32	1.34	1.36	1.38	1.39	1.41	1.44	1.46	1.48	1.50	1.52	1.53	1.56	1.58	1.60	1.62	1.64
65–70	1.41	1.44	1.46	1.48	1.50	1.52	1.54	1.56	1.58	1.60	1.62	1.65	1.66	1.68	1.70	1.72	1.75	1.77
70–75	1.54	1.56	1.58	1.60	1.62	1.65	1.66	1.68	1.70	1.73	1.75	1.77	1.79	1.80	1.83	1.85	1.87	[illegible]
75–80	1.66	1.67	1.70	1.72	1.74	1.76	1.79	1.80	1.82	1.84	1.87	1.89	1.91	1.93	1.96	1.97	[illegible]	[illegible]
80–85	1.79	1.80	1.82	1.84	1.87	1.89	1.91	1.93	1.96	1.97	1.99	2.02	2.04	2.06	2.07	2.10	[illegible]	[illegible]
85–90	1.91	1.92	1.94	1.96	1.99	2.01	2.03	2.06	2.07	2.09	2.11	2.14	2.16	2.18	2.20	2.22	[illegible]	[illegible]
90–95	2.03	2.06	2.06	2.08	2.11	2.13	2.15	2.18	2.19	2.21	2.23	2.26	2.28	2.30	2.32	2.34	[illegible]	[illegible]
95–100	2.14	2.17	2.18	2.20	2.23	2.26	2.27	2.29	2.32	2.33	2.35	2.38	2.40	2.42	2.45	2.46	[illegible]	[illegible]

NOTE: To obtain the total heeling moment from this table, procedure is as follows:

(a) Divide sail area into 5-ft layers, starting from waterline.
(b) Determine number of square feet in each layer.
(c) Multiply area of each layer by appropriate figure from table and add products. This is heeling moment for a 100-knot wind.
(d) For wind velocities other than 100 knots, multiply moment by $(V/100)^2$.

On most ships, a first approximation using

$$\frac{0.0035\ V^2\ AL \cos^2\theta}{2240 \times \text{displacement}}$$

to represent the heeling arm without allowance for wind gradient, will establish that wind heel will not be governing and that no further calculations will be required.

The most accurate method of determing wind-pressure effects would be to conduct wind-tunnel tests for each design. This is not generally done since damage stability criteria are usually governing.

d. Criteria for Adequate Stability

The criteria for adequate stability under adverse wind conditions are based on a comparison of the ship's righting arm curve and the wind heeling arm curve, fig. 10.

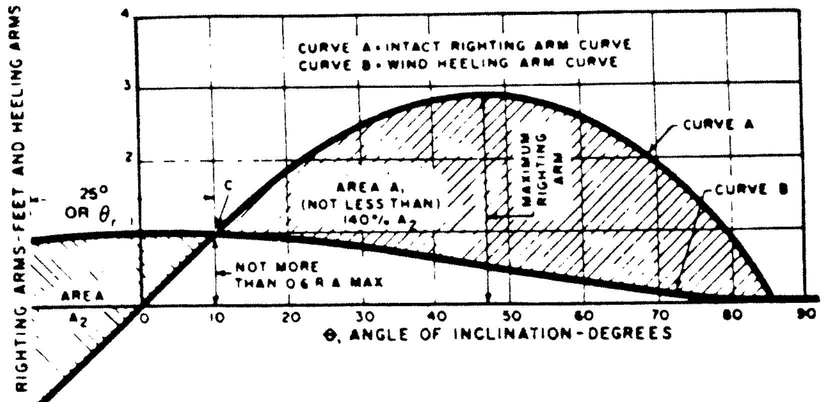


FIGURE 10

Stability is considered satisfactory if:

(1) The heeling arm at the intersection of the righting arm and heeling-arm curves (Point C) is not greater than six-tenths of the maximum righting arm; and

(2) Area A_1 is not less than 1.4 A_2 where area A_2 extends 25 deg or θ_r (if roll angle determined from model tests) to windward from Point C.

The foregoing criteria for adequate stability with respect to adverse wind and sea conditions are based on the following considerations:

(a) A wind heeling arm in excess of the ship's righting arm would cause the ship to capsize. The requirement that the heeling arm be not greater than six tenths of the maximum righting arm is intended to provide a margin for gusts, and for inaccuracies resulting from the approximate nature of the heeling-arm calculations.

(b) In the second criterion, the ship is assumed to be heeled over by the wind to Point C and rolling 25 deg or θ_r from this point to windward, the 25 deg being an arbitrary, but reasonable roll amplitude for heavy wind and sea conditions. Area A_2 is a measure of the energy imparted to the ship by the wind and the ship's righting arm in returning to point C. The margin of 40 percent in A_1 is intended to take account of gusts and for calculation inaccuracies.

2. Lifting of Heavy Weights Over the Side

a. Effect of Lifting Weights

Lifting of weights will be a governing factor in required stability only on small ships which are used to lift heavy items over the side. Lifting of weights has a double effect upon transverse stability. First, the added weight, which acts at the upper end of the boom, will raise the ship's center of gravity and thereby reduce the righting arm. The second effect will be the heel caused by the transverse moment when lifting over the side.

b. Heeling Arms

For the purpose of applying the criteria, the ship's righting-arm curve is modified by correcting VCG and displacement to show the effect of the added weight at the end of the boom. The heeling arm curve is calculated by the formula:

$$\text{Heeling arm} = \frac{Wa \cos\theta}{\Delta}$$

where

W = weight of lift, tons
a = transverse distance from centerline to end of boom, ft.
Δ = displacement, tons including weight of lift
θ = angle of inclination, deg.

c. Criteria for Adequate Stability

The criteria for adequate stability when lifting weights are based on a comparison of the righting arm and heeling arm curves, Fig. 11.

Stability is considered satisfactory if:

(1) The angle of heel, as indicated by point C, does not exceed 15 deg.

(2) The heeling arm at the intersection of the righting arm and heeling arm curves (point C) is not more than six tenths of the maximum righting arm; and

(3) The reserve of dynamic stability (shaded area) is not less than four tenths of the total area under the righting-arm curve.

The criteria for adequate stability while lifting weights are based on the following considerations:

(a) Angles of heel in excess of 15 deg will interfere with operations aboard the ship.

(b) The requirements that the heeling arm be not more than six-tenths of the maximum righting arm and that the reserve of dynamic stability be not less than four tenths of the total area under the righting-arm curve are intended to provide a margin against capsizing. This margin allows for possible overloading of the boom.

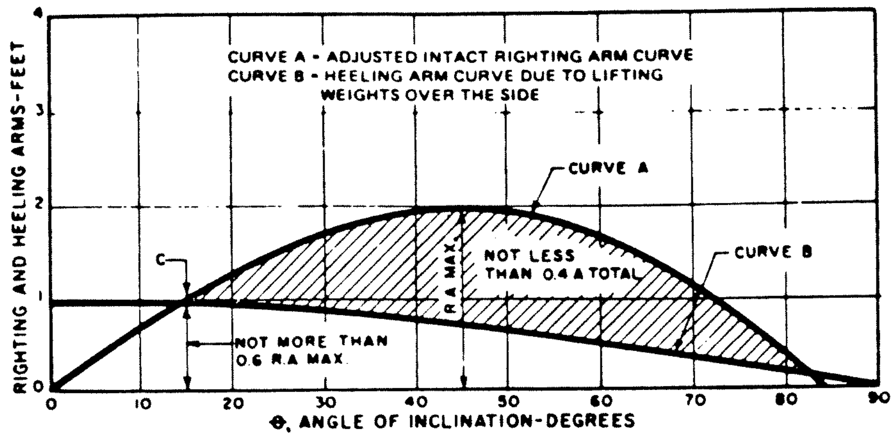


FIGURE 11

3. Tow-line Pull for Tugs

a. A ship engaged in towing activities is subject to heeling forces caused either by the tow line of the tug, or the forces imparted to the tow by the tug in attempting to maintain course of the tow or to turn the tow.

b. The U.S. Coast Guard formula for calculating the transverse heeling arm curve for tow line pull is used by the Navy as follows:

$$\text{Heeling Arm} = \frac{2N\,(SHP \times D)^{2/3} \times s \times h \times \cos\theta}{38\Delta}$$

where:

N = number of propellers
SHP = shaft horsepower per shaft
D = propeller diameter, feet
S = effective decimal fraction of propeller slip stream deflected by the rudder – assumed to be equal to that fraction of the propeller circle cylinder which would be intercepted by the rudder if turned to 45 degrees. Use s = 0.55 if no other value has been determined.
h = vertical distance from propeller shaft centerline at rudder to towing bitts, feet
Δ = displacement, tons
θ = angle of heel, degrees

c. Criteria for Adequate Stability

The same criteria as for lifting weights over the side shall apply except that the range of the righting arm curve shall terminate at the angle at which unrestricted down flooding may occur, or 40 degrees, whichever is less. The limit on range is to provide a margin of safety in the event a watertight door or vent duct is open and could be a pathway for serious down flooding due to wave and heel action.

4. Crowding of Personnel to One Side

a. Effect of Crowding of Personnel

The movement of personnel will have an important effect only on smaller ships which carry a large number of personnel. The concentration of personnel on one side of a small ship can produce a heeling moment which results in a significant reduction in residual dynamic stability.

b. Heeling Arms

The heeling arm produced by the transverse movement of personnel is calculated by:

$$\text{Heeling arm} = \frac{Wa}{\Delta} \cos\theta, \text{ ft.}$$

Where

W = weight of personnel, tons
a = distance from centerline of ship to center of gravity of personnel, ft.

Δ = displacement, tons
θ = angle of inclination, deg.

In determining the heeling moment produced by the personnel, it is assumed that all personnel have moved to one side as far as possible. The personnel occupies 2 sq ft of deck space.

c. Criteria for Adequate Stability

The criteria for adequate stability are based on the angle of heel, and a comparison of the ship's righting-arm and the heeling-arm curve, Fig. 12.

Stability is considered satisfactory if:

(1) The angle of heel, as indicated by point C, does not exceed 15 deg.

(2) The heeling arm at the interception of the righting arm and heeling arm curves (point C) is not more than six tenths of the maximum righting arm and

(3) The reserve of dynamic stability (shaded area) is not less than four tenths of the total area under the righting arm curve.

The criteria for adequate stability to resist the heeling effect of an eccentric personnel load are based on the following considerations:

(a) An angle of heel of 15 deg is considered the maximum acceptable from the standpoint of personnel safety.

(b) The requirements that the heeling arm be not more than six tenths of the righting arm and that the reserve of dynamic stability be not less than four tenths of the total area under the righting arm curve are intended to provide a margin against capsizing. This margin allows for possible overloading.

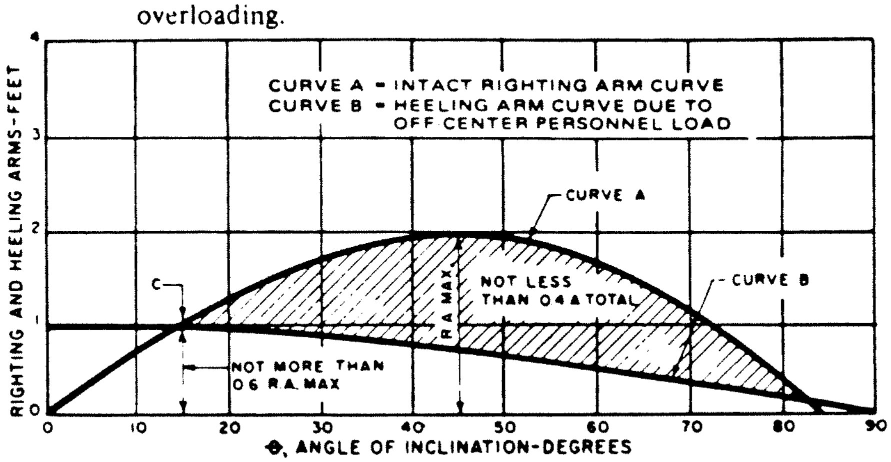


FIGURE 12

5. High Speed Turning

a. Heeling Arms Produced by Turning

The centrifugal force acting on a ship during a turn may be expressed by the formula:

$$\text{Centrifugal force} = \frac{Wv^2}{gR}$$

where

W = displacement of ship, tons
v = linear velocity of ship in the turn, ft/sec
g = acceleration due to gravity, ft/sec^2
R = radius of turning circle, ft.

The lever arm used in conjuction with this force to obtain the heeling moment is the vertical distance between the ship's center of gravity and the center of lateral resistance of the underwater body. This lever will vary as the cosine of the angle of inclination. The center of lateral resistance is taken vertically at the half draft.

If the centrifugal force is multiplied by the lever arm and divided by the ship's displacement, an expression for heeling arm is obtained.

$$\text{Heeling arm} = \frac{V^2 a}{gR} \cos \theta$$

where

a = distance between ship's center of gravity and center of lateral resistance (half draft) with ship upright, ft
θ = angle of inclination, deg

For all practical purposes R may be assumed to be one half of the tactical diameter. If the tactical diameter is not available from model or full-scale data, an estimate is made.

b. Criteria for Adequate Stability

The criteria for adequate stability in high-speed turns are based on the relationship between the righting-arm curve and the heeling arm curve, Fig. 13.

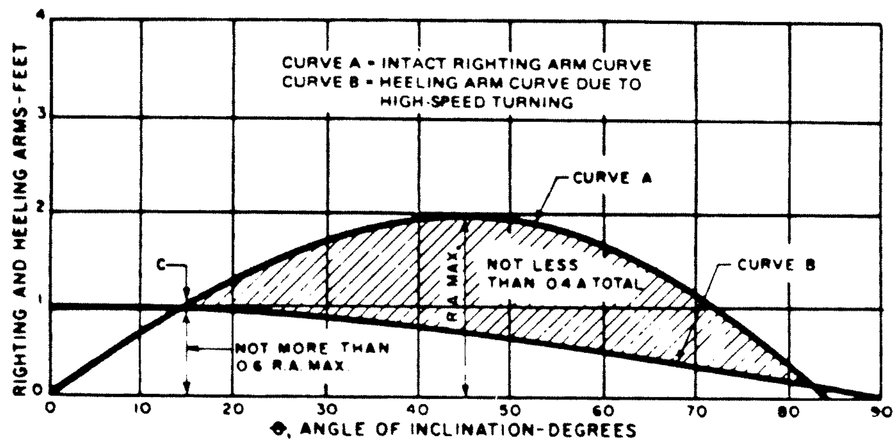


FIGURE 13

Stability is considered satisfactory if:

(1) The angle of steady heel, as indicated by point C, does not exceed 15 deg.

(2) The heeling arm at the intersection of the righting-arm and heeling-arm curves (point C) is not more than six tenths of the maximum righting arm.

(3) The reserve of dynamic stability (shaded area) is not less than four-tenths of the total area under the righting-arm curve.

The criteria for adequate stability with respect to high-speed turns are based on the following considerations:

(a) An angle of heel of 15 deg is considered the maximum acceptable from the standpoint of comfort. Personnel aboard would become apprehensive if the angle of heel were greater than 15 deg.

(b) The requirements that the heeling arm be not more than six-tenths of the maximum righting arm and that the reserve of dynamic stability be not less than four tenths of the total area under the righting-arm curve are intended to provide a margin against capsizing. This margin allows for the action of wind and waves, and for possible inaccuracies resulting from the empirical nature of the heeling-arm calculations.

6. Topside Icing

The criterion for topside icing is not as definitive as the other criteria. The reason for this is the inability to estimate an upper limit for accumulation of ice. Once ice has started to form, it will continue to accumulate under favorable conditions and the only recourse is to institute ice-removal measures or leave the area. High winds are likely to occur during periods of icing and it is appropriate to consider combined icing and wind effects. A new ship of destroyer size, which is capable of withstanding a 100-knot beam wind without ice, can withstand a beam wind of only 80 knots with an ice accumulation of 200 tons. A cruiser type in service, which can withstand a 90 knot beam wind without ice, can withstand a beam wind of only 78 knots with an accumulation of 600 tons of ice. The foregoing ice weights correspond roughly to a 6 in. coating on horizontal and vertical surfaces where ice would build up. An actual build-up of ice would of course be non-uniform, but the ice weights determined on the basis of a uniform 6-in. coating may be used in estimating maximum beam-wind velocity for which the stability criteria will be met. For destroyer sizes and above, the criteria will be met for a 78-knot wind in combination with topside icing. For smaller ships, topside icing results in a more significant reduction in righting arms and the allowable beam-wind velocity is accordingly less. For example, a 180-ft patrol ship, which can meet the wind criteria for a 75-knot beam wind without ice, will have to avoid beam winds in excess of 50 knots if there has been substantial ice accumulation. In the case of a smaller mine sweeper (L = 140 ft), 50 tons of topside ice reduces the maximum righting arm from 1.2 ft to about 0.7 ft with a reduction in range from 90 to 55 deg. The maximum allowable wind is reduced from 85 to about 40 knots.

The design approach to topside icing is to determine the maximum allowable beam winds combined with icing for a ship whose stability has been established from other governing criteria. The design would be considered satisfactory if the allowable wind at time of icing was in excess of winds which are likely to be encountered in the intended service.

The U.S. Department of Commerce Publication "Climatological and Oceanographis Atlas for Mariners" Volume I, North Atlantic Ocean (August 1959) provides a guide for expected winds in combination with icing. Winds up to Beaufort 9 (41-47K) are very likely to occur off the west coast of Greenland. Heavy to severe icing is expected to occur from 5 to 15 per cent of the time in February based on simultaneous occurence of winds equal to or greater than 34 knots and air temperatures equal to or less than 28° F. The Coast Guard recently reported that one of its ships on station in the same area, experienced 70-knot winds with severe ice accumulation.

A guide for estimating weight of ice accumulation is shown in Table 6 prepared for Wind-class ice-breakers.

Table 6 Icing-up Chart for Wind-Class Icebreakers

Iced area of ship	1	2	3	4	5	6	8	12	24	Area, in sq ft	Kg, ft	Dist. cent ice to ship's CL, ft
	Tons of Ice											
Main dk fwd of bkwtr	1.1	2.2	3.4	4.5	5.6	6.7	9.0	13.4	27.0	525	43.7	0
Main dk bkwtr to fr 66*	1.6	3.2	4.7	6.3	8.0	9.5	12.6	19.0	38.0	738	43.1	12
Main dk fr 66 to 127*	2.4	4.3	6.4	8.6	10.7	12.8	17.0	25.6	51.0	1000	41.1	20
Main dk fr 127 to aft*	3.6	7.3	10.9	14.6	18.2	21.8	29.1	43.6	87.0	1700	41.2	18
Lifelines, etc., fr 66 fwd*	0.6	1.3	2.0	2.6	3.2	3.8	5.1	7.6	15.3	300	44.0	15
Lifelines, etc., fr 66 aft*	1.0	2.1	3.1	4.1	5.2	6.2	8.2	12.4	24.7	480	44.0	20
Breakwater	0.6	1.3	1.9	2.6	3.2	3.8	5.1	7.6	15.3	300	44.0	0
5 in. mount (all sides)	0.9	1.7	2.6	3.4	4.3	5.1	6.4	10.2	20.4	400	48.0	0
Bhd (main dk) fr 66 fwd*	0.7	1.5	2.2	2.9	3.7	4.4	5.8	8.8	17.6	340	46.0	15
Bhd (main dk) fr 66 aft*	2.4	4.7	7.1	9.2	11.6	14.1	18.4	28.2	56.0	1100	44.0	18
Flight dk (plus netting)	6.4	12.8	19.2	25.6	32.2	38.4	51.2	77.0	144	3000	50.1	0
20MM (fwd & lifelines)*	0.5	1.0	1.5	2.0	2.6	3.7	4.1	6.1	12.0	240	50.2	9
01 deck*	1.3	2.6	3.8	5.1	6.4	7.7	10.2	15.4	31.0	600	50.1	20
Bhd (01 dk) fr 81 to 92*	1.0	1.2	2.9	3.9	4.8	5.8	7.7	11.5	23.0	450	53.0	10
Sky lookout (dk & bhd)*	0.8	1.5	2.3	3.1	3.9	4.6	6.2	9.2	18.0	360	57.0	15
Open bridge (40mm's)*	1.0	1.9	2.8	3.8	4.5	5.8	7.7	11.5	23.0	450	61.1	23
Bhd (open bridge)*	0.5	1.0	1.5	2.0	2.6	3.1	4.1	6.1	12.0	240	64.0	9
Top of pilot house	1.4	2.7	4.0	5.4	6.7	8.1	10.8	16.2	29.0	630	68.0	0
Main bat director	1.4	2.7	4.0	5.4	6.7	8.1	10.8	16.2	29.0	630	72.0	0
02 deck*	0.3	0.7	1.0	1.4	1.7	2.0	2.7	4.0	8.0	160	57.1	11
Misc fr 66 fwd*	0.2	0.4	0.6	0.8	1.0	1.2	1.5	2.0	4.0	80	43.0	10
Misc fr 66 aft*	0.4	0.9	1.3	1.7	2.2	2.6	3.5	5.2	11.0	200	46.0	15
Bhd (01 dk) fr 62 fwd*	0.6	1.2	1.8	2.4	3.0	3.6	4.8	7.2	14.0	280	53.0	15

* Indicates identical areas port and starboard.

Weights of ice for various thicknesses on topside areas are shown and may be used to approximate ice weights on other types of ships.

7. Conditions of Loading for Intact-Stability Analysis

The intact-stability criteria are applied to the ship for operating conditions between the previously defined full load and minimum operating conditions, or another operating condition which may have poorer stability than the minimum operating condition. The ship is expected to meet the standards for the loading condition which has the poorest stability in the foregoing operating range. An exception to this is the case of beam winds combined with rolling (with and without ice). In this case the ship is assumed to be liquid ballasted in accordance with liquid loading instructions (Case II, minimum operating, or Case IV, as appropriate). The foregoing assumption is reasonable since there will be sufficient advance storm warning. The effects of bad sea and weather conditions should evident to the operating personnel that they will initiate ballasting procedures.

79-1-c(10) Damage Stability Criteria

1. Design Versus Operational Criteria

Considerations for underwater damage standards fall into two catergories: i.e., design and operation. The design requirements determine the survival capabilities of the ship even when loading instructions have not been followed. They are based on an evaluation of the ship's power of survival; that is, the ability of the ship to withstand a major amount of damage, and still be sufficiently sea-worthy and operational either to proceed under its own power or to be towed to a safe area. Design requirements are established early in the design development and influence the selection of dimensions, form, subdivision, and arrangement.

Operational requirements are based on the assumption that loading instructions have been observed. In this case a minimum degree of offensive or defensive capability may remain, such as the ability to continue to operate weapons or aircraft. This includes the capability for a carrier of quickly correcting list to a value which will permit limited operations to continue. The maximum acceptable angle of heel is necessarily smaller than the design or survival condition.

Separate standards are used for ships such as aircraft carriers which have side protective systems and the smaller types which do not. This is due to the marked difference in the amount of damage which these two types can withstand, the nature of the flooding, and the means provided on ships with side-protective systems to counteract rapidly the effects of damage.

2. Underwater Damage - Ships With Side-Protective Systems

a. Effects of Damage

The outstanding feature of ships with side-protective systems is the inherent source of unsymmetrical flooding contained in the void layers. This flooding, being a considerable distance from the centerline of the ship, produces a large heeling moment, the effects of which are to cause the ship to list and to diminish the righting-arm curve throughout its significant extent. Counterflooding of similar voids on the opposite side of the ship can diminish greatly or eliminate the resulting list at a relatively small expense of reserve buoyancy.

From an operational standpoint, list due to flooding is of primary concern. This can interfere with ship and flight operations, and might lead to the abandoning of the ship long before there is any danger of foundering or capsizing. A large angle of heel with also place the side-protective system in a poor position to resist further torpedo attack since the ship is exposed to damage below the side-protective system on the high side and above it on the low side. The ship should, therefore, be capable of removing such list rapidly.

If the ship continues to receive damage, it will eventually be lost. Loss may occur through capsizing as a result of unsymmetrical flooding combined with overall loss of stability, or by foundering after reserve buoyancy has been expended through the effect of flooding and counterflooding. The ideal design is one in which the list could be held to a moderate value to the point where the reserve buoyancy is expended. The three characteristics which have a major effect on the ship's ability to survive extensive damage are transverse stability, reserve buoyancy, and provisions for avoiding unsymmetrical flooding, In making evaluations of the effect of extensive underwater damage, a large number of variables are involved such as:

(1) Location of hits.
(2) Size of charge
(3) Condition of ship at time of damage (stability, liquid loading, freeboard, etc.)
(4) Effectiveness of damage control measures.

For design purposes, criteria are established for (1) through (3) based on test data, war damage reports and design experience. For operational considerations, (4) is included.

b. Conditions of Loading.

For the purpose of applying the criteria for adequate stability and reserve buoyancy, ships with side protective systems are assumed to be in the optimum battle condition.

c. Criteria for Structural Damage for Determination of Flooding

Information on the effectiveness of side-protective systems against explosive damage is of a classified nature and, therefore, cannot be outlined here. It is sufficient to say that information exists on the extent of damage from various explosive charges on different types of bottom and side-protective systems. Because of the inherently large initial stability and reserve buoyancy, aircraft carriers can withstand multiple explosive hits. A pattern of multiple hits is selected which results in the greatest damage for the cases where the holding bulkhead remains intact and where it fails.

d. Criteria for Heel After Damage

The General Specifications for Ships of the U.S. Navy specify that equipment and machinery shall be designed and installed to operate satisfactorily with a permanent list up to 15 deg. This requirement is for continuous operation with no resulting damage or excessive wear. Under emergency conditions such as would occur when considering the power of survival of the ship, it can be assumed with a good probability that equipment would continue to function for some time at an angle of 20 to 25 deg. In the event that all equipment should cease to function as a result of structural damage, flooding, and so on, the ship could be towed to a safe area with a list of 20 deg. War-damage reports record cases where a list of 20 deg or more did not prevent damage-control efforts and salvage of ships. For purposes of establishing a criterion for survival, an acceptable upper limit is considered to be 20 deg. list. This applies to design investigations.

For operational purposes an angle of heel of 20 deg. is considered too great; therefore, the ship must have a means for quickly correcting the angle to one which will permit operations to continue. The term "quickly correcting" precludes consideration of possible sources of list correction such as transfer of fuel oil or jettisoning weights from the low side and virtually restricts the methods considered to counterflooding from the sea. For design purposes a ship with side-protective system would meet the standards of multiple hits if:

(1) Heel does not exceed 20 deg as a result of flooding caused by:

  (a) Simultaneous and spearated hits on one side which just fail to penetrate the holding bulkhead; and

  (b) Hits which penetrate the holding bulkhead.

(2) Arrangements exist for rapidly correcting list from damage outlined above to less than 5 deg.

e. Use of Damage Stability Curves

Damage stability curves are prepared which represent the foregoing cases of flooding before and after counterflooding. As previously mentioned, carriers have large reserve buoyancy, so that the angle of heel rather than the range of the damage-stability curve is governing. However, by inspection or actual calculation, the damage-stability curve is examined to establish that there exists a sufficient reserve of dynamic stability to withstand wind and rolling action. The method employed is similar to that outlined in the later section, "Ships Without Side Protective Systems."

f. Limiting Drafts

Limiting drafts for ships with side protective systems are governed by the required freeboard associated with the side protective system. Unlike ships without side protective systems, reserve buoyancy is not governing and therefore does not establish the limiting drafts for these types.

3. Underwater Damage – Ships Without Side-Protective Systems

a. Effects of Damage

On ships which do not have a side-protective system, underwater damage usually produces an immediate and substantial decrease in both stability and reserve buoyancy. Unlike the ships with-side-protective systems, the principal consideration immediately after underwater damage is survival of the ship rather than continuing in action, although considerations of ability to operate machinery and maintain crew confidence are also important. Wind and sea conditions are more important factors in survival after damage than in the case of larger ships. Since the smaller ships do not have the relatively fine subdivision found on carriers, judicious spacing of the main transverse bulkheads has a major effect on the ship's ability to survive extensive underwater damage.

It was noted earlier that in the case of a new design, there is an opportunity to approach the most advantageous location of main transverse bulkheads, subject to the limitations imposed by internal arrangements. On converted ships which were originally designed for some other service, the existing bulkhead locations are often not favorable from the standpoint of resisting extensive damage, and from a practical viewpoint, improvement is generally limited to the installation of additional bulkheads. As a result, the resistence to underwater damage which can be achieved in converted ships does not usually compare favorably with that in new designs.

b. Criteria for Compartmentation

The basis for determination of the extent of flooding is the length of damage to the shell at any point along the ship's length resulting from weapon attack or collision. In small ships, however, because of practical limitations, the criteria are based on the number of compartments flooded rather than on the length of shell opening.

The philosophy regarding ability to withstand underwater damage has been described as one whereby the more important ship (mission and size) is expected to survive a greater amount of damage than the less important ship (mission and size). Ships are thus grouped by length and type of mission.

(1) Criteria for New Designs

New designs without side protective systems shall meet the following design criteria for adequate subdivision to resist underwater damage:

(a) Seagoing craft less than 100 ft in length shall be capable of withstanding, as a minimum, the flooding of any single main compartment.

(b) Ships between 100 and 300 ft in length shall be capable of withstanding, as a minimum, the flooding of any two adjacent main compartments.

(c) Ships over 300 ft in length are divided into two categories:

Category I - Combatant types and personnel carriers such as hospital ships and troop transports.

Category II - All other types.

Category I. Ships over 300 ft in length shall withstand the following: (a) rapid flooding from a shell opening equal to 15 percent of the ship's length at any point fore and aft or (b) if practicable, rapid flooding from a weapon attack (largest charge) at any point along the ship's length if such an opening exceeds 15 percent LBP.

Category II. Ships over 300 ft in length shall be capable of withstanding the flooding from a shell opening equal to 12.5 percent of the ship's length. The value used for ship's length in these criteria is the length between perpendiculars.

(2) Criteria for Conversions from Merchant Types

For converted merchant ships it may not always be feasible, even though possible, to bring the ships up to the standards set for new designs. The following relaxations from the new design standards are acceptable, if it is not feasible to meet the standards for new designs:

(a) Post World War II ships intented primarily for carrying cargo such as AE, AF, and AK will be satisfactory if they meet the two-compartment standard. For World War II ships, a one-compartment standard is acceptable.

(b) Merchant ship conversions to amphibious force flagships, tenders, repair ships, minecraft, aircraft carriers and personnel carriers such as AH, LKA, AP, and LPA will be satisfactory if they can withstand an opening in the shell equal to 12.5 percent of the ship's length.

c. Reserve Buoyancy Requirements

(1) Limiting Drafts

The standard floodable length curves are used early in a design in establishing transverse bulkhead spacing and estimating the limiting subdivision drafts. As the design progresses, and the arrangement becomes firm, allowable subdivision limiting drafts (forward and aft) are determined by trim line calculations. The investigation is narrowed to flooding those groups of adjacent compartments forward and aft for which there would be the greatest combination of sinkage, trim and also heel, if appropriate as a result of the extent of damage described in preceding paragraphs. The ship is assumed to be in a full-load condition, with all tanks full for the shell to shell flooding case, using appropriate permeability factors. If governing, flooding on one side is taken to take heel effect into account, with tanks loaded in such a manner as to produce unsymmetrical flooding consistant with liquid loading instructions. The final trim line shall not be above a margin line at side which is 3 in. below the bulkhead deck.

Limiting drafts are assigned on the basis of reserve buoyancy unless strength or speed requires a lower draft. In rare cases, damage stability may be the basis for establishing a limiting draft.

Where limiting drafts based on allowable reserve buoyancy are considerably deeper than the expected full load drafts, limiting drafts below the maximum allowable may be selected in order to relax some of the watertight closure requirements for bulkhead penetrations and weather openings.

(2) Calculation of Flooding Water Levels

For a given ship arrangement and a set of limiting drafts, it is possible to determine a final trim line after flooding of any group of adjacent compartments. The ship is assumed to start at the limiting drafts with full loads including full tanks, and to experience shell-to-shell flooding, except as noted above. Trim lines are determined for each group of compartments which could be flooded by a shell opening specified in the criteria.

(a) Flooding Water Levels on Bulkheads.

For any boundary bulkhead, such as in Fig. 14, the trim lines after the specified damage are determined. This establishes the maximum height the ship settles without heeling as a result of shell-to-shell flooding. Allowances for heel due to unsymmetrical flooding, roll and wave action are applied in the manner outlined in Fig. 15.

i. Ship is assumed to have a static heel of 15 deg as a result of unsymmetrical flooding:

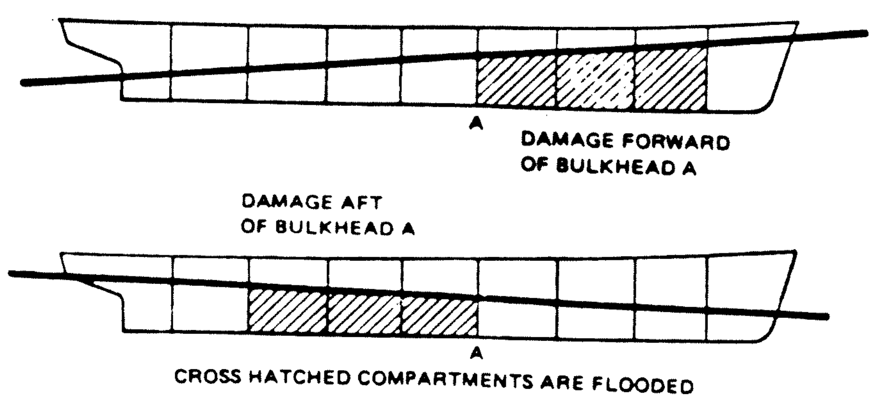


FIGURE 14

ii. Ship is assumed to be rolling an angle of θ of the magnitude given in Fig. 16.

iii. A rise of 4 ft is assumed to represent the wave action. For simplicity, the 4 ft for wave action is generally taken for all ship sizes. This has the effect of imposing a greater requirement on smaller ships, contrary to the stated philosophy that larger ships are expected to withstand greater hazards. In those cases where a significant hardship is imposed on a small ship, consideration for use of a smaller wave action should be made, subject to NAVSEA approval.

In figure 15, waterline DE corresponds to the deepest trim line on bulkhead A and includes the 15 deg static heel, the roll angle θ, and the 4 ft wave action. Segment HF is part of the waterline due to roll on the opposite side corresponding to DE. The cross-hatched triangle or V, FGH, is the area on bulkhead A which should be above the flooding water level and through which nontight penetrations would be acceptable. As a practical matter, nontight penetrations are limited to vent ducts without permanent closures. The periphery of the vent-duct penetration is watertight to permit air testing when temporary closures are installed.

The curve in Fig. 16 is the source of roll angle, θ to be used in determining flooding water levels depicted in Fig. 15. The values, plotted against ship displacement, are not the result of theoretical calculations. They simply represent reasonable roll amplitudes which ships of varying displacements, damaged or intact, are likely to exhibit in moderate seas where the wave action is 4 ft. or less.

(b) Flooding Water on Decks

The determination of areas on the weather deck (or bulkhead deck, if different) where non-tight penetrations are acceptable, is carried out in a manner similar to that employed for bulkheads. There is one difference to keep in mind. In the case of bulkheads, the bulkhead in question is serving as an intact flooding boundary. The greatest height of water over the deck area in question is serving may result from flooding a group of compartments not adjacent to that area. This waterline becomes the basis for applying the 15 deg initial list, roll angle θ, and the 4 ft wave action as shown in Fig. 15. Where ventilation penetrations occur outboard of the V-lines for the deck, the penetration may be made watertight by installing a watertight closure at the deck or by carrying the ventillation duct watertight up to its intersection with the V-line. The weather deck (and bulkhead deck, if different) is otherwise watertight as discussed earlier.

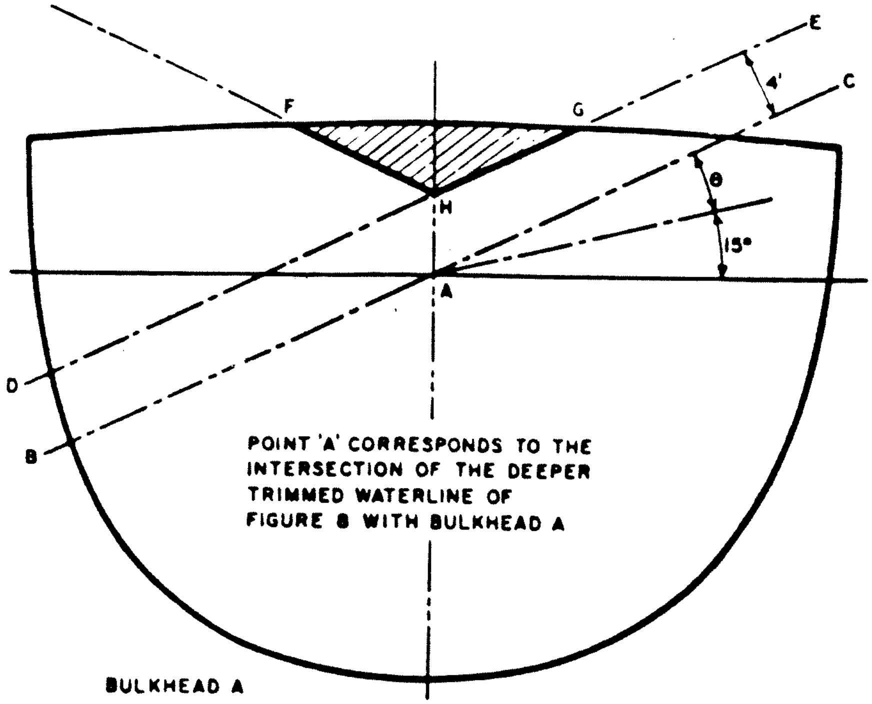


FIGURE 15

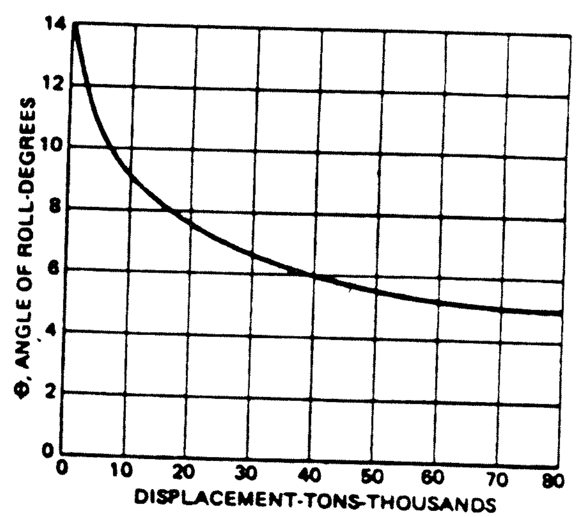


FIGURE 16

d. Summary of Reserve Buoyancy Requirements – For Ships Without Side-Protective Systems

The limiting drafts for underwater flooding are generally based on shell-to-shell flooding with a criterion that the final static waterline be below the margin line. In some cases, unsymmetrical flooding rather than shell-to-shell flooding could result in a deeper final waterline at the side. It should be noted that the groups of compartments which establish the limiting drafts are usually at the third or quarter points of the ship's length. As such, the trim effect of additional flooding in the shell-to-shell assumption generally results in greater sinkage at the side than would result from unsymmetrical flooding.

The effect of unsymmetrical flooding, as well as rolling and wave action are taken into account in determining the flooding levels on boundary bulkheads and over the bulkhead deck. The use of roll-angle values and the 4 ft wave action indicates that the ship after damage is not expected to withstand the same degree of sea and weather hazards as the undamaged ship.

4. Damage-Stability Criteria – Ships Without Side-Protective Systems

a. Extent of Damage

(1) Longitudinal Extent

The compartment standard of the length of hit as described previously determines the longitudinal extent of flooding. In the compartment case, flooding, from bounding bulkhead to bounding bulkhead for the group of compartments considered, measures the extent of the flooding. In the case where length of hole applies (percentage of length or specific weapon attack) flooding extends to the nearest bounding bulkhead at each end of the damage.

(2) Transverse Extent

The maximum extent of flooding is assumed to be that caused by damage penetration to, but not including, any centerline bulkhead. A lesser transverse penetration of damage is assumed where it would result in poorer damage stability than for the centerline condition. This could occur where considerable low intact buoyancy remained after flooding.

(3) Vertical extent

In regard to vertical extent of damage, it is assumed that all decks and platforms in way of the damaged are opened because of the marked adverse effect of the resulting high flooding, free surface, and possible unsymmetrical flooding. Although there have been cases where decks have held after torpedo damage, it is considered unduly optimistic to assume that any will hold. Therefore, all decks and platforms in way of damage to the shell are assumed to be ruptured. Damage to the inner bottom may be favorable because of the low flooding involved or unfavorable because the unsymmetrical flooding produced outweighs the gain to additional low weight. The less favorable assumption as to the condition of the inner bottom is used, Fig. 17.

b. Loading Conditions in Damage Stability Evaluation

The standard loading conditions for ships without side-protective systems have been described previously as the "Full-Load Condition" and the "Minimum Operating Condition." Two categories for the minimum operating condition have been outlined, one for ships which have been designed to ballast empty oil tanks, and one for ships designed to operate without ballasting empty oil tanks under normal conditions. Cases I and II apply to the first category and Cases III and IV apply to the second category. Case I assumes that full compliance with liquid loading instructions does not occur. Case II assumes full compliance with liquid loading instructions. Case III depicts the ship under normal liquid loading without ballasting of empty oil tanks, while case IV depicts an emergency wind or sea condition where sea water in empty oil tanks is accepted. Stability curves after damage are developed for the full-load condition (modified for slack or empty tanks) and the minimum operating condition, or another operating condition which may have worse stability as previously discussed. In all cases, the slack and empty tanks are so distributed as to result in the least favorable damage stability.

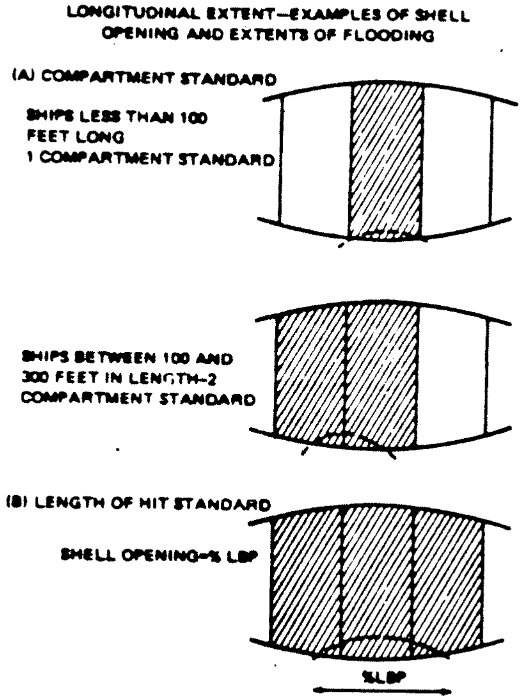


FIGURE 17(a)

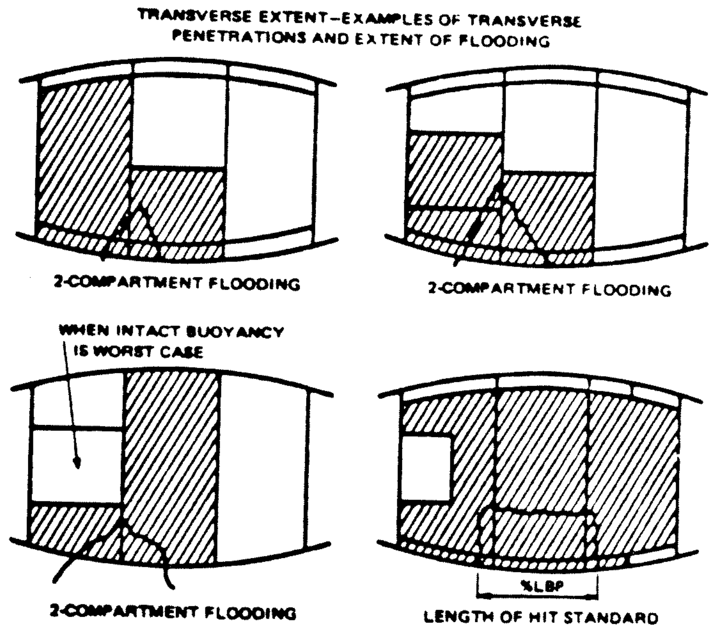


FIGURE 17(b)

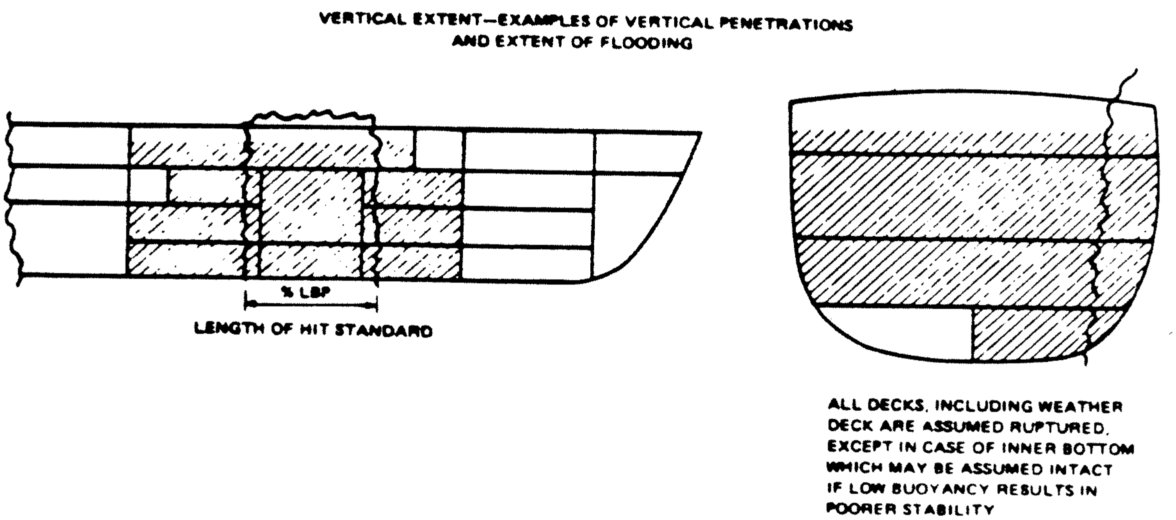


FIGURE 17(c)

For new designs, damage-stability criteria shall be met in full-load and minimum operating conditions (both cases I and II, or both cases III and IV, as appropriate).

For conversions, the criteria shall be met in full-load and minimum operating (Case II) conditions.

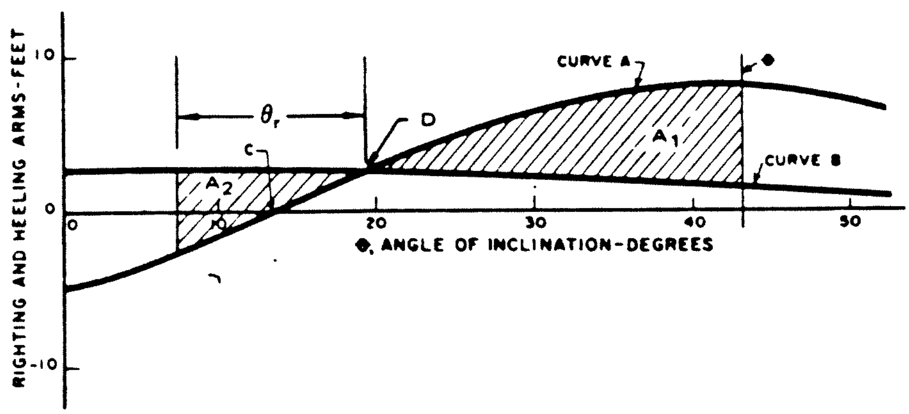


FIGURE 18

c. Damage Stability Curves

Curve A in Fig. 18 is statical stability curve for the damaged ship with the assumed damage previously described for the full load condition and the minimum operating condition (Case I - IV, as appropriate for new designs. Case II for conversions). A reduction of righting arm equal to 0.05 cos θ is included in curve A to account for unknown unsymmetrical flooding or transverse shift of loose material.

Curve B is a beam-wind heeling arm curve which has been calculated by the method outlined in the section "Wind Heeling Arms." Wind velocity for curve B is obtained from Fig. 19.

d. Criteria for Adequate Damage Stability

Two factors are considered in evaluating adequate damage stability.

(1) Angle of Heel After Damage

Referring to Fig. 18, damage stability is satisfactory if the initial angle of heel, point C, does not exceed 15 deg for operational requirements (Cases II, III, and IV loading as appropriate), and does not exceed 20 deg for design requirements (Case I loading).

(2) The dynamic stability available to absorb the energy imparted to the ship by moderately rough seas in combination with beam winds is a measure of adequacy of the stability after damage. Again referring to Fig. 18, angle θ is

45 deg or the angle at which unrestricted flooding into the ship would occur, whichever is less. The angle θ_r is the expected angle of roll into the wind from point D for the assumed wind and sea state. Subject to later verification by experience and model testing, θ_r will be obtained from Fig. 16.

To insure adequate dynamic stability $A_1/A_2 \geq 1.4$.

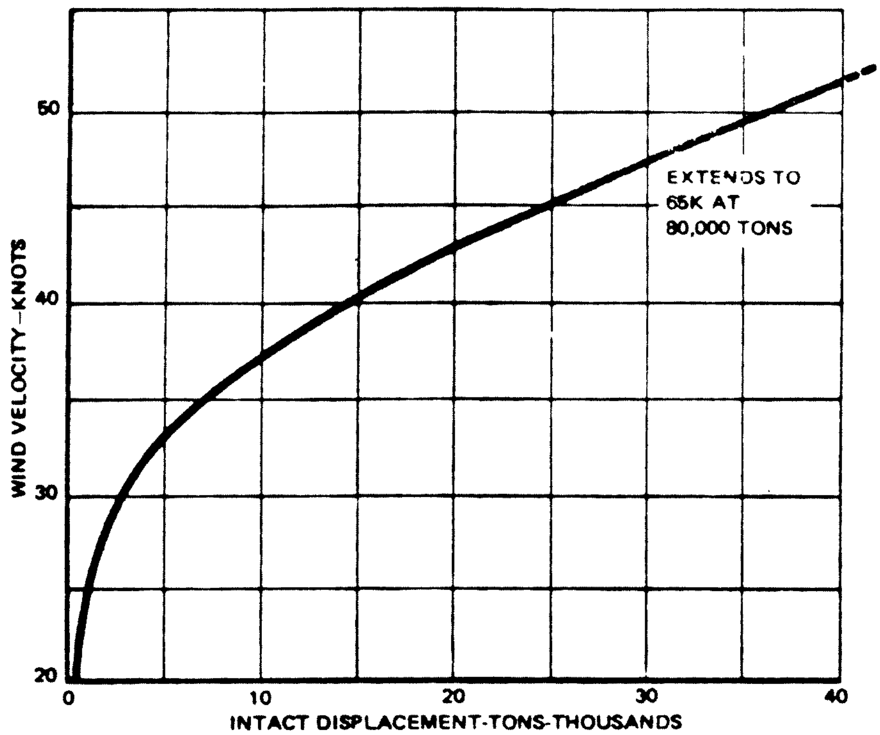


FIGURE 19

In damage, wind of lesser velocity than in the intact condition is assumed. The analysis of adequate stability, thereafter is the same in the damaged case. For most ship designs, the criterion of angle of heel will be governing. On some smaller types, the reserve dynamic-stability criterion may become governing. The required stability for this case, however, would not be significantly greater than for the case of angle of heel.

079-1-c(11) <u>Summary of Stability and Buoyancy Criteria For Intact and Damaged Ship</u>

It may be useful at this point, to summarize briefly the criteria which have been presented.

1. For the intact ship, criteria have been developed for:

   a. Beam winds combined with rolling (wind velocities depend on intended service of ship).

b. Lifting of heavy weights over the side.

c. Tow line pull for tugs.

d. Crowding of Personnel to one side.

e. High-speed turning.

f. Topside icing.

Conditions of loading which determine the available stability have been defined.

The adequacy of stability is measured by comparing the intact righting-arm curve with the heeling-arm curve. The static heel angle, the associated righting arm, and the reserve dynamic stability are the factors which are examined.

2. For the case of underwater damage, the extent of the assumed damage varies with the size and function of the ship. Another distinction is whether a ship does or does not have a side-protective system. Ships with side-protective systems such as carriers, usually have considerable reserve buoyancy so that the extent of damage is measured in terms of multiple torpedo hits. The limiting criteria are the static heel after damage and the heel after counterflooding. For ships without side-protective systems, the longitudinal extent of damage is expressed as the number of compartments flooded for smaller ships, or the flooding which results from a shell opening. The shell opening is expressed as a percentage of length between perpendiculars, or as a specific length determined by a weapon attack. The governing stability criteria are the angle of heel after damage and the reserve dynamic stability to withstand beam winds and rolling in the damaged condition. Reserve-buoyancy calculations for the assumed damage lead to the establishment of limiting drafts (subdivision drafts) forward and aft.

Consideration is given to the stability required for survival of the ship, and for the case where limited operations can be continued. Righting arm curves after damage are used in making the foregoing determinations for adequacy of stability after damage.

PART III

079-1-d. Part III ADVANCED MARINE VEHICLES (IN WATERBORNE DISPLACEMENT MODE)

079-1-d (1) Introduction

The types of ships which fall into this category are hydrofoils, air cushion vehicles (ACV - soft sidewall craft), air cushion surface effect ships (SES - hard sidewall craft), and small waterplane area twin hull (SWATH). See Fig. 20. Catamaran ships which are not considered as "advanced marine vehicles" are also included in this category because the stability and buoyancy analyses for this type are similar to that for SES.

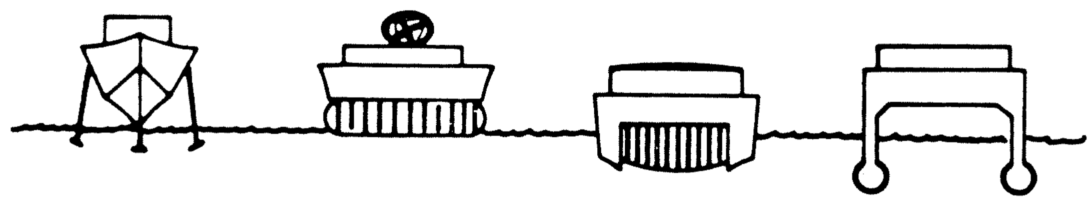


FIGURE 20

Some of the hull forms and sizes in the "advanced marine vehicle" category are so new that the stability and buoyancy criteria presented here should be considered as first cut objectives which may represent compromises so as not to prematurely reject a design solely on the grounds of failing to meet anticipated desired stability and buoyancy standards. New design requirements will be specified, as appropriate, to indicate acceptable departures from the standard described herein.

Stability and buoyancy standards presented here apply only to the case when the craft or ship is in a hullborne displacement mode. Thus for the "flying" types such as hydrofoils, air cushion vehicles and surface effects types, concern is limited to off-foil or off-cushion operations. How the vehicles reached the displacement mode is of no consequence for our purposes except to the extent that shell openings may have resulted from striking objects at high flying speeds. Even with our limited operating experience with high performance types, it has become evident that the displacement mode may represent a significant portion of the total operation. Transiting to the area of high speed operation, inability to "fly" because of mechanical problems, shell damage sustained during the high speed operation or during the displacement mode are several examples when adequate stability and buoyancy in the displacement mode are important considerations.

079-1-d (2) Hazards

The hazards to which conventional hull types may be subjected, which were outlined in Part II, may also have an impact on the high performance types and thus impose a requirement for adequate stability and buoyancy to resist the effects of these hazards. Additionally, there are special problems peculiar to some of these vehicles which may arise, all of which must be considered in the stability and buoyancy analysis. Examples of such problems are: low freeboard with the hazard of shipping and trapping sea water, large center of gravity shift due to extension or retraction of foils, weight constraints which might limit the number of watertight bulkheads, thin shell structure which is susceptible to greater shell opening from impact with debris at high flying speeds or from collisions, and for the low waterplane catamaran types the potential for large unsymmetrical flooding. The types of hazards noted in Part II are listed below for:

1. Intact Ship

   Hazards associated with the intact ship:

   a. Beam winds combined with rolling
   b. Lifting of heavy off-center weights
   c. Tow line pull
   d. Crowding of personnel to one side
   e. High speed turning
   f. Topside icing

2. Damaged Ship

   Hazards associated with the flooded damaged ship where the flooding may be the result of stranding (moderate or extensive flooding), collision (moderate or extensive flooding) or enemy explosive action (extensive flooding) are:

   a. Beam winds combined with rough seas
   b. Progessive flooding
   c. Shifting of cargo or items which might produce significant heel or trim.

079-1-d (3) Design Philosophy

As in the case of conventional monohulls the basic stability and buoyancy design philosophy for advanced marine vehicles is that as the ship becomes larger or more important from a military standpoint, or carries large numbers of personnel, the degree of hazard to which it may be exposed is considered to increase and adequate stability and buoyancy are provided accordingly. The objective for Advanced Marine Vehicles is to provide these ships with the same stability and reserve buoyancy capabilities as their equivalent monohull ships. Since length/beam or length/displacement ratios of high-performance types are significantly different from conventional monohulls, "equivalent" is chosen more on the basis of displacement and mission capabilities than length and must be evaluated for each case.

079-1-d (4) Criteria for Advanced Marine Vehicles

The stability and buoyancy criteria which are detailed in the following paragraphs are intended to provide the high performance craft and ships with capabilities to withstand the previously discussed hazards to which they may be exposed. The criteria reflect the design philosophy and the design practices discussed in earlier paragraphs.

The criteria also represent standards which are attainable in good designs and do not significantly increase the cost of the ship.

It is important to note that the measurements of adequate stability and buoyancy are based on static condition calculations with allowances made for dynamic effects of wind, sea, and ship rolling. While this method of analysis is not rigorous, it represents the best state-of-the art techniques currently available to naval architects. The method has merit in that it provides a measure of relative capability of ships of similar size and service, is easy to follow, and provides useful guidelines to naval as well as private designers.

079-1-d (5) Loading Conditions

In view of the great divergence among high-performance types as to size and operational requirements, specific loading details are not provided. Instead, the following guidelines should be followed:

1. The complete spectrum of loading conditions should be considered. Stability and buoyancy should be analyzed for at least the full load condition (departure condition), and a minimum operating condition (corresponding to the ship which has been at sea for a considerable time with depleted loads). Additionally, any other loading condition should be investigated which is likely to result in poorer stability than the full load or minimum operating conditions.

2. Loads in the full load condition should correspond to the full allowances of departure. Variable loads in the minimum operating condition should be taken at one-third of their full load, except in the case of larger ships with high capacity distillers where water may be taken two-thirds of full load.

3. For those types where off-center loading of cargo is likely, this adverse effect should be considered in developing and analyzing stability.

4. Pollution abatement considerations will prevent sea-water ballasting of empty oil tanks in new designs. Where clean ballast tanks are provided, ballast water may be taken as a load as necessary for adequate trim, immersion and stability.

5. For hydrofoils with retractable foils each loading condition should be considered both in a "foils up" and "foils down" case, as considerable changes in KG and buoyancy characteristics occur as the foils are retracted.

079-1-d (6) Intact Stability Criteria

The stability of the ship is expressed by the intact stability curves for the above mentioned loading conditions. Certain periods may exist, such as during refueling, when the ship has poorer than normal stability. In such extreme unusual cases, the ship is not expected to withstand all the hazards previously outlined. It would be prudent therefore to carry out operations such as refueling under relatively favorable wind and sea conditions and in areas considered safe from enemy action.

In all cases of stability analysis the righting-arm curves shall reflect the combined trim and heel effects. Computer programs are available for doing this.

1. Beam Winds Combined with Rolling

   a. Effects of beam winds: This hazard is considered to be caused by two factors. One is a beam wind applied to the ship in still water. The second is the wave action causing rolling motion. The beam wind to be selected is from Part II and is repeated below in Table 7.

   It is based on the ship's mission and its required areas of operation. The extent of rolling is assumed to be caused by fully arisen seas based on the sea state required by the ship's characteristics. The selected local beam wind will generally be much in excess of the winds normally associated with the required sea state. Little information is available at this time about actual rolling behavior of various high performance types in different sea states. For a given design, the assumed rolling should be based on model tests or the best data available for previous ships of the same or similar type.

b. Wind heeling arms: The discussion in Part I on wind heel calculations and velocity gradients as a function of the height above waterline apply to high performance types. The formula to be used for calculating wind heeling arms due to wind is

$$H.A. = \frac{0.004\ V^2\ A\ l\ \cos^2\theta}{2240 \times \text{displacement}}$$

Where A = projected sail area, sq. ft.
l = lever arm from center of lateral resistance (assumed at half draft) to centroid of sail area, ft.
V = normal wind velocity, knots
θ = Angle of indination, degrees

In cases where beam winds combined with rolling may be governing, the velocity gradient curve and the strip method described in Part I should be used.

For ships with large beams such as the SWATH and other platform types, the projected sail area increases with angle of heel so as to require taking this into account However, even with the increased sail area, no problem with regard to beam winds combined with rolling is expected for these wide types because of the very large righting arms typical of these types.

For hydrofoils, the required beam wind from Table 7 must be met with the foils extended and with the foils retracted.

Table 7 Wind Velocities

Service	Minimum * wind velocity for design purposes (knots)	Minimum Acceptable** wind velocity for ships after 5 years in service (knots)
1. Ocean		
(a) Ships which must be expected to weather full force of tropical cyclones. This includes all ships which will move with the amphibious and striking forces	100	90
(b) Ships which will be expected to avoid centers of tropical disturbances	80	70
2. Coastwise		
(a) Ships which will be expected to weather full force to tropical cyclones	100	90
(b) Ships which will be expected to avoid centers of tropical disturbances, but to stay at sea under all other circumstances of weather	80	70
(c) Ships which will be recalled to protected anchorages if winds over Force 8 are expected	60	50
3. Harbor	60	50

* Ships built to Ship specifications dated subsequent to 1 August 1975 shall meet this wind throughout service life.

** Ships built to Ship specifications dated prior to 1 August 1975 shall meet this wind after five years of service

c. <u>Criteria for Adequate Stability</u>

When the heeling arms due to wind heel are superimposed on the plot of the ship's righting arms as shown on figure 21 and an assumption is made for the angle of the ship's rolling into the wind, θ_r, the following must be satisfied:

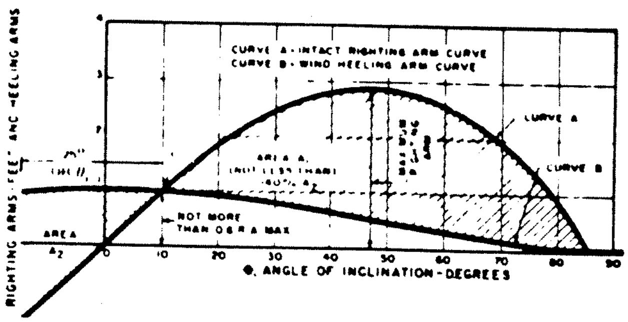


FIGURE 21

(1) The heeling arm at the intersection of the heeling arm and righting-arm curves (point C) must not exceed six tenths of the maximum righting arm.

(2) Area A_1 is not less than 1.4 A_2 where A_2 extends θ_r degrees to windward from point C. As noted earlier, θ_r should be determined by model tests or from the best data available from earlier ships of this type. θ_r is the roll angle associated with fully arisen seas associated with the required sea state specified in the characteristics.

Limited experience to date indicates that certain air cushion types in the displacement mode exhibit considerable damping in their rolling and that a value of 15° for θ_r is more typical than the 25° used in Part I.

d. <u>Rationale for the Above Criteria</u>

(1) The six tenths of the maximum righting arm is intended to provide a margin for gusts as well as the inaccuracies in the calculations.

(2) Area A_2 is a measure of the energy imparted to the ship by the wind and the ship's righting arm in returning to point C. The margin of 40% in A_1 is intended to take account of gusts and for calculation inaccuracies.

2. <u>Lifting of Heavy Weight Over the Side</u>

a. <u>Effect of Lifting Weights</u>: Lifting of weights will be a governing factor in required stability only on small ships which are used to lift heavy items over the side. Lifting of weights has a double effect upon transverse stability. First, the added weight, which acts at the upper end of the boom, will raise the ship's center of gravity and thereby reduce the righting arm. The second effect will be the heel caused by the transverse moment when lifting over the side.

b. <u>Heeling Arms</u>: For the purpose of applying the criteria, the ship's righting arm curve is modified by correcting VCG and displacement to show the effect of the added weight at the end of the boom. The heeling arm curve is calculated by the formula:

$$\text{Heeling Arm} = \frac{Wa \cos \theta}{\Delta}, \text{ ft.}$$

where

W - weight of lift, tons
a = transverse distance from centerline to end of boom, ft.
Δ = displacement, tons including weight of lift
θ = angle of inclination, deg

c. <u>Criteria for Adequate Stability</u>

The criteria for adequate stability when lifting weights are based on a comparison of the righting arm and heeling arm curves, figure 22. The following must be satisfied:

(1) The angle of heel, as indicated by point C, does not exceed 15 deg.

(2) The heeling arm at the intersection of the righting-arm and the heeling-arm curves (point C) is not more than six tenths of the maximum righting arm, and

(3) The reserve of dynamic stability (shaded area) is not less than four tenths of the total area under the righting arm curve.

d. <u>Rationale for the Above Criteria</u>

(1) Angles of heel in excess of 15 deg will interfere with operations aboard the ship.

(2) The requirements that the heeling arm be not more than six tenths of the maximum righting arm and that the reserve of dynamic stability be not less than four tenths of the total area under the righting-arm curve are intended to provide a margin against capsizing. This margin allows for possible overloading of the boom.

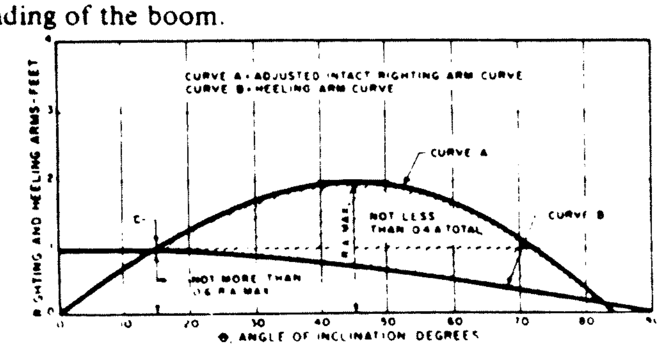


FIGURE 22

3. Tow Line Pull

It is unlikely that high-performance types will be used as towing vehicles. In the event that such a design requirement arises, the heeling arm formula for tow line pulls given in part II needs to be adapted to reflect the high-performance propulsion configuration when in the displacement mode. No specific methodology is presented here. Guidance will be provided to the designer, if necessary, on a case basis.

4. Crowding of Personnel to One Side

a. Effect of Crowding of Personnel

The movement of personnel will have an important effect only on smaller ships which carry a large number of personnel. The concentration of personnel on one side of a small ship can produce a heeling moment which results in a significant reduction of residual dynamic stability.

b. Heeling Arms

The heeling arm produced by the transverse movement of personnel is calculated by:

$$\text{Heeling arm} = \frac{Wa}{\Delta} \cos\theta \quad , \text{ft}$$

where:

W = weight of personnel, tons
a = center of gravity of personnel, ft
Δ = displacement, tons
θ = angle of inclination, deg

In determining the heeling moment produced by the personnel, it is assumed that all personnel have moved to one side as far as possible. Each person is assumed to occupy 2 sq ft of deck space.

C. Criteria for Adequate Stability

The criteria for adequate stability are based on the angle of heel, and a comparison of the Ship's righting arm and the heeling arm curve, figure 22. The following must be satisfied:

(1) The angle of heel, as indicated by point C, does not exceed 15 deg.

(2) The heeling arm at the intersection of the righting-arm and heeling-arm curves (point C) is not more than six tenths of the maximum righting arm, and

(3) The reserve of dynamic stability (shaded area) is not less than four tenths of the total area under the righting-arm curve.

d. Rationale for the Above Criteria

(1) The angle of heel of 15 deg. is considered the maximum acceptable from the standpoint of personnel safety.

(2) The requirements that the heeling arm be not more than six tenths of the righting arm and that the reserve of dynamic stability be not less than four tenths of the total area under the righting-arm curve are intended to provide a margin against capsizing. This margin allows for possible overloading.

5. High-Speed Turning

a. Heeling Arms Produced by Turning

The centrifugal force acting on a ship during a turn may be expressed by the formula

$$\text{Centrifugal force} = \frac{Wv^2}{gR}, \text{ tons}$$

Where

W = displacement of ship, tons
v = linear velocity of ship in the turn, ft/sec
g = acceleration due to gravity, ft/sec^2
R = radius of turning circle, ft

The lever arm used in conjuction with this force to obtain the heeling moment is the vertical distance between the ship's center of gravity and the center of lateral resistance of the underwater body. This lever will vary as the cosine of the angle of inclination. The center of lateral resistance is taken vertically at the half draft.

If the centrifugal force is multiplied by the lever arm and divided by the ship's displacement, an expression for heeling arm is obtained:

$$\text{Heeling arm} = \frac{V^2 \, a \cos\theta}{gR}, \text{ ft.}$$

Where

a = distance between ship's center of gravity and center of lateral resistance (half draft) with ship upright, ft.

θ = angle of inclination, deg

For all practical purposes R may be assumed to be one half of the tactical diameter. If the tactical diameter is not available from model or full scale data, an estimate is made.

b. Criteria for Adequate Stability

The criteria for adequate stability in high-speed turns are based on the relationship between the righting-arm curve and the heeling-arm curve, figure 22. The following must be satisfied.

(1) The angle of steady heel as indicated by point C does not exceed 15 deg.

(2) The heeling arm at the intersection of the righting-arm and heeling-arm curves (point C) is not more than six tenths of the maximum righting arm.

(3) The reserve of dynamic stability (shaded area) is not less than four tenths of the total area under the righting-arm curve.

c. Rationale for the Above Criteria

(1) An angle of heel of 15 deg is considered the maximum acceptable from the standpoint of comfort. Personnel aboard would become apprehensive if the angle of heel were greater than 15 deg.

(2) The requirements that the heeling arm be not more than six tenths of the maximum righting arm and that the reserve of dynamic stability be not less than four tenths of the total area under the righting-arm curve are intended to provide a margin against capsizing. This margin allows for the action of winds and waves and for possible inaccuracies resulting from the empirical nature of the heeling arm calculations.

It should be noted that data on velocities and turning circle radii for some of the high performance types are lacking at this time. As data on turning characteristics becomes available, the significance of this potential problem will indicate if consideration must be given to increasing the righting arms at small angles (a metacentric height (GM) increase is one way) in an actual design. There is also a possibility that anti-roll devices of some kind may be used to reduce motion in a seaway and could serve to counter whatever heel in turns might develop.

6. Topside Icing

Unless specific operation in potential ice areas is specified in the characteristics for a new design, the amount of topside icing a ship may accumulate and still have satisfactory stability in intact conditions is determined after the design has been fixed. As noted in Part II, the design approach to topside icing is to determine the maximum allowable beam winds combined with icing for a ship whose stability has been established from other governing criteria. The design would be considered satisfactory if the allowable wind at time of icing was in excess of winds which are likely to be encountered when operating in an icing area.

As a preliminary estimate of ice accumulation, two cases are studied; one assumes three inches, and the other, six inches of ice on horizontal and vertical surfaces on the weather deck and above. For these weights of ice, determine the beam winds for which the ship would satisfy the previously outlined criteria for beam winds combined with rolling. The approximate specific volume for accumulated ice may be taken as 39.5 cubic feet per ton.

079-1-d (7) Damage Stability and Buoyancy Criteria

1. Extent of Damage

Although the sizes (length) and mission categories of high performance types fall within the groupings listed in Part II for conventional monohulls, the relative "worth" of the high performance types cannot be considered on the basis of the length alone as was noted earlier. Based on the concept of withstanding the same damage as an "equivalent" conventional ship, the extent of flooding damage for high performance ships must be considered on a case basis. For all cases of damage studied, a vertical extent of damage should be assumed such that all watertight decks are ruptured. Since configurations vary widely among high performance types, the following general categories are used to illustrate the principles outlined above:

a. Hydrofoils: As the full forms of hydrofoils generally resemble conventional hulls, the damage required for conventional ships is used directly.

b. Small (less than 100 ft in length) Air Cushion Types (ACV or SES)

To date, their construction has generally consisted of a honeycomb-like network of small compartments. The conventional ship requirements that ships under 100 feet withstand flooding of one compartment, or two compartments for ships between 100 feet and 300 feet, cannot reasonably apply to this type of construction. Another factor to consider is the light weight shell construction and the great possibility of sustaining rip damage. The following assumed damages apply for the small air cushion vehicles:

The worst of the following two cases of damage shall be taken:

(1) Longitudinal shell opening of 10% of the flotation box length or eight feet, whichever is greater, with transverse damage up to the centerline. Damage should be selected in that part of the craft which results in the poorest stability. See figure 23.

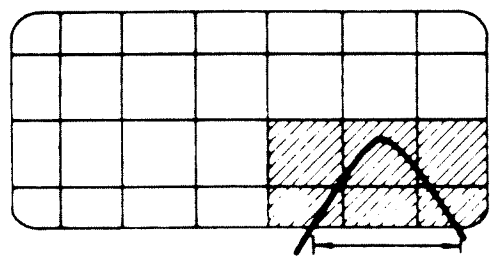


FIGURE 23

(2) Longitudinal shell opening of 15% of the flotation box length or eight feet, whichever is greater, with the transverse damage extending up to, but not including, longitudinal bulkheads located more than 20% of the beam inboard of the shell at maximum beam of the hard structure. As in (1) above, damage is located to produce the poorest stability, see figure 24.

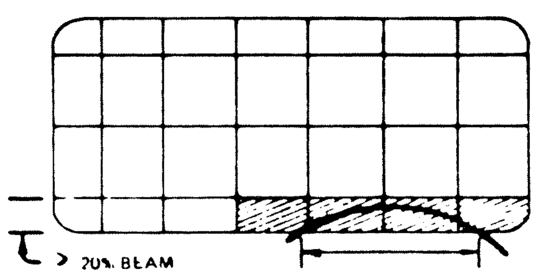


FIGURE 24

c. Large (over 100 ft in length) Air Cushion Types (ACV or SES)

Recently ships which range in length from 225 ft to 470 feet with beams in the 100 feet range have been studied. Displacements have varied from 2200 tons to 4400 tons. The objective for the large SES ships (as well as the small waterplane area twin hull (SWATH) type to be discussed later) is to determine equivalent monohull counterparts and establish the same criteria as for the conventional counterparts. The difficulty arises in making the selection of an equivalent counterpart. Length is not a suitable measure since SES and SWATH types, because of their great beams, are shorter than their conventional counterparts. Displacement may be a better measure of "worth', although the relatively few SES types considered to date do not provide a conclusive sample of this approach. The stated mission, including manning and endurance, may be elements which lead to equivalencies. A plot of length-of-hit vs. displacement for major ship types is shown on figure 25, as an example of an approach in determining an appropriate damage hole size.

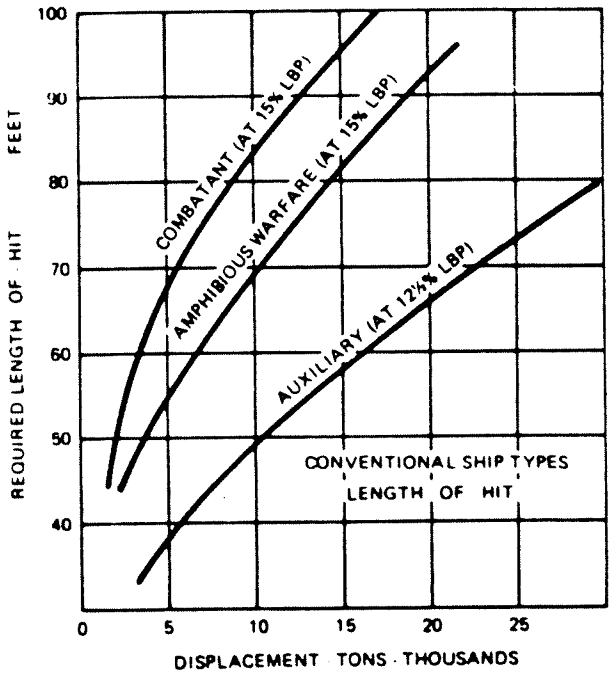


FIGURE 25

For large air cushion types, the worst of the following cases of damage shall be taken:

(1) Longitudinal Damage

A shell opening equal in length of 15% of the design waterline length (including seals) or the length-of-hit for the counterpart monohull, whichever is greater, with transverse extent to the centerline. See figure 26.

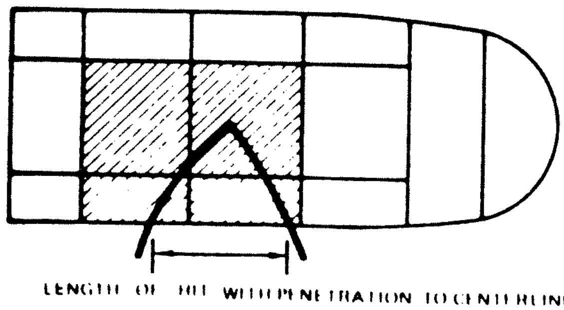


FIGURE 26

(2) Longitudinal damage of the side shell equal to 50% of the design waterline length (including seals) with a transverse extent to the first longitudinal bulkhead inboard of the shell. See figure 27. The transverse penetration shall be no less than 10% of the beam.

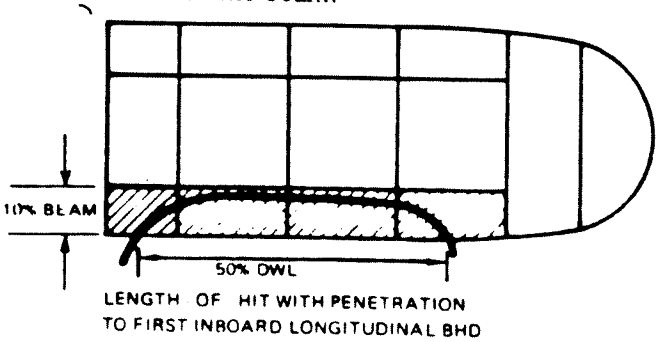


FIGURE 27

For SES types with a length of approximately 200 ft, the 15% length-of-hit above will generally result in at least a two-compartment capability. This compares with the two-compartment requirement for conventional ships of 100 to 300 ft. SES types of greater length will generally require a length-of-hit similar to equivalent conventional ships of over 300 ft.

d. Low Waterline Catamaran Type (LWP) or Small Waterplane Area Twin Hull Type (SWATH)

This design is characterized by a catamaran form consisting of low cylindrical buoyant forms which support narrow vertical struts which provide the small waterplane. A large platform sits on the port and starboard struts with its bottom a predetermined height above the waterline based on sea state requirements. Various experimental studies have been investigated with lengths varying from 90 to 500 ft. and extreme beams varying from 50 ft to 200 ft. Corresponding displacements range from 200 to 40,000 tons.

While the SWATH has considerable reserve buoyancy and stability, it is very easy to heel and trim to large angles as a result of underwater flooding because of the small waterplane of the struts and the large amount of off-center flooding when damage occurs on one side. See figure 28.

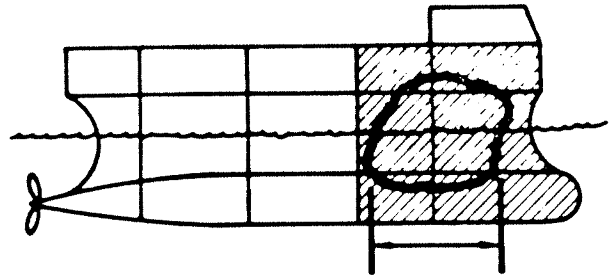


FIGURE 28

The large amount of reserve buoyancy in the upper hull ensures survival. However, the large combined heel and trim angles as a result of underwater off-center flooding are in themselves a hazard, causing difficulties in fulfilling the SWATH's mission, in ship control, in damage control efforts, in towing the damaged ship home if all power is lost, and in the ship personnel's sense of security.

The design objective approach of SWATH is the same as previously discussed for the large SES, namely, to identify an equivalent conventional monohull type and provide the SWATH with the same capability to withstand underwater flooding as its equivalent conventional type.

e. Catamarans (Other than SWATH)

These types should be treated in the same manner as the large SES.

2. Criteria for Adequate Damage Stability for High Performance Ships

Two main factors are considered in evaluating adequate damage stability. Refer to figure 29.

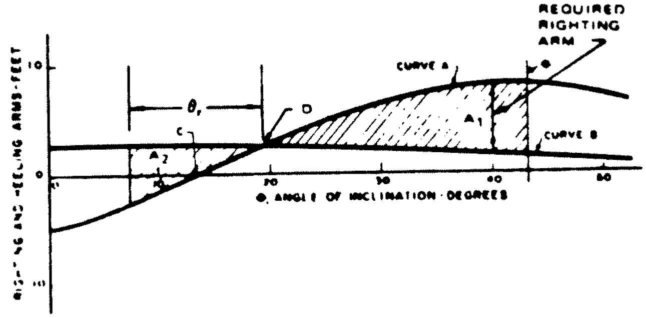


FIGURE 29

Curve A is the damage stability curve for the ship with damage specified for the type. Curve A includes trim effects and represents the ship in its poorest stability condition.

a. Angle of Heel After Damage

Damage stability is satisfactory if the initial angle of heel, point C, does not exceed 15 degrees (except for SWATH types where point C shall not exceed 20 degrees, as noted below). The combined static heeled-trimmed waterline corresponding to point C shall not submerge the bulkhead deck.

b. Dynamic Stability Associated with Wind-Heel Combined with Rolling

The dynamic stability available to absorb the energy imparted to the ship by moderately rough seas in combination with beam winds is a measure of adequacy of stability after damage. Curve B is the wind heeling curve for the beam wind specified in the ship's characteristics or from figure 30.

Angle θ is 45 degrees or the angle at which unrestricted flooding into the ship would occur, whichever is less. Curve A is assumed to terminate at angle θ.

θ_r is the expected angle of roll into the wind from point D for the assumed wind and sea state noted above. There is little current information on the rolling characteristics of some of the high performance types after shell damage. Subject to later verification by experience and model testing, θ_r shall be taken as indicated below in the sections on specific criteria for each high performance type.

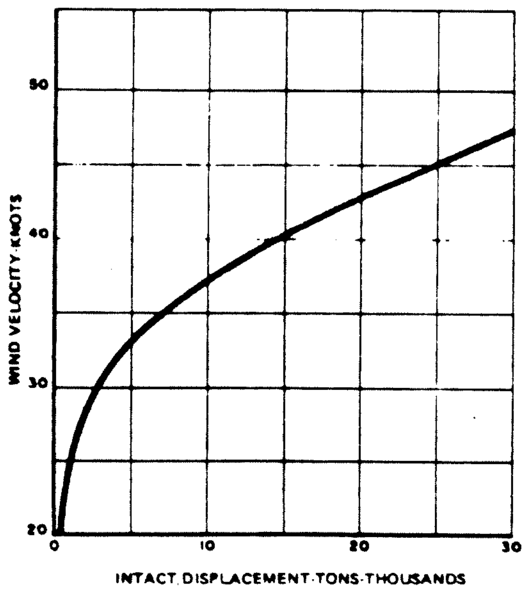


FIGURE 30

The adequacy of required dynamic stability is measured by comparing areas A_1 and A_2.

In types where the damage righting arms are small, as for hydrofoils, a minimum acceptable righting arm value is specified.

c. Requirements

Since the high performance types have considerably different hull forms and characteristics, the required values of figure 29 for θ, maximum heel angle (point C), A_1/A_2, and the minimum righting arm are shown below for each of the following general categories:

(1) Hydrofoils

The worst case of foils extended or retracted must be satisfied. Otherwise the hydrofoil behaves as a conventional hulltype.

Referring to figure 29, the following must be satisfied:

(a) $\theta_r = 15^\circ$ or the angle determined from roll tests of the undamaged hull in the sea states specified by the ship's characteristics.

(b) Initial heel angle (point C) $\leq 15^\circ$

(c) A_1/A_2 must ≥ 1.4

(d) Minimum acceptable righting arm above heeling arm = 0.3 feet

(e) Final heeled-trimmed static waterline shall not submerge the bulkhead deck.

(2) Small Air Cushion Vehicles (ACV or SES)

Model tests conducted on these types, such as the amphibious assault landing craft (AALC), indicated that there was considerable damping of roll motions in sea states which approximated those specified in the craft's characteritics. Typical roll angles were about 15 degrees. Of interest also is the large initial stability and the small range due to the small freeboard to the bulkhead deck. This results in a steep righting-arm curve after damage but with small range. There is considerable area (energy) between the wind-heeling-arm curve and the righting-arm curve as the craft heels into the wind (area A_2 of figure 29) which has to be absorbed by area A_1. In view of the large roll damping characteristics exhibited by this type, allowance is made for the energy dissipated due to damping as the craft returns from the roll into the wind, and a required ratio of 1.0 has been selected for A_1/A_2. This is considered equivalent to a required value of 1.4 for monohull forms with small damping characteristics.

Referring to figure 29, the following must be satisfied:

(a) $\theta_r = 15^\circ$ or the angle determined from roll tests of the undamaged hull in the sea states specified in the craft's characteristics.

(b) Initial heel angle (point C) $\leq$ 15 degrees

(c) A_1/A_2 1.0

(d) Minimum acceptable Righting Arm above heeling arm = 0.3 feet

(e) Final static heeled-trimmed waterline shall not submerge the bulkhead deck.

The damage righting-arm curve shown in figure 29 shall include the effects of off-center (transverse and longitudinal) location of cargo as specified in the characteristics.

(3) Large Air Cushion Types (ACV or SES):

The large ACV or SES are assumed to have large roll damping characteristics as in the case of the small ACV. The criteria listed below are the same as for the small ACV. Experience to date indicates that because of the large reserve buoyancy and stability of the subdivided platform, the criterion which governs is the requirement that the final static heeled-trimmed waterline shall not submerge the bulkhead deck (usually the upper weather deck of the platform).

Referring to figure 29, the following must be satisfied:

(a) $\theta_r = 15$ degrees or the angle determined from roll tests of the undamaged hull in the sea states specified in the ship characteristics.

(b) Initial angle of heel (point C) $\leq$ 15 degrees

(c) $A_1/A_2 \geq 1.0$

(d) Minimum acceptable Righting Arm above heeling arm = 0.3 feet (Note This requirement will generally not be governing for this type)

(e) Final static heeled-trimmed waterline shall not submerge the bulkhead deck.

(4) SWATH Types

The criteria for adequate damage stability for SWATH are based on the same analysis as for the large ACV. As noted earlier, SWATH has considerable reserve buoyancy and stability but is subject to large initial heel and trim angles resulting from flooding on one side. The governing criteria for SWATH will generally be the limit on the initial angle of heel, ability to counterflood to reduce the static heel angle to an acceptable value, and the requirement that the final static heeled-trimmed waterline be below the bulkhead deck (generally the upper weather deck of the platform). Twenty degrees has been selected as a limit on the initial heel angle. This is based on the consideration that angles in excess of 20 degrees would cause premature abandonment of SWATH. Static heel after counterflooding is based on the mission of SWATH. High roll damping is assumed for SWATH forms.

Referring to figure 29, the following must be satisfied:

(a) $\theta_r = 15$ degrees or the angle determined from roll tests of the undamaged hull in the sea states specified in the ship's characteristics.

(b) Initial angle of heel (point C) $\leqslant$ 20 degrees.

(c) Counterflooding capability to reduce static heel angle to $\leqslant$ 5 degrees for an aircraft carrier mission and $\leqslant$ 15 degrees for a non-aircraft carrier mission.

(d) A_1/A_2 1.0

(e) Minimum acceptable Righting Arm above heeling arm = 0.3 (not a factor for this type)

(f) Final static heeled-trimmed waterline shall not submerge the bulkhead deck.

(5) Catamaran Types (Other than SWATH)

This type is included in Part III rather than in Part II because of its similarity to the larger SES in a displacement mode. Those types are therefore treated in a manner similar to SES.

3. Criteria for Adequate Reserve Buoyancy

a. Limiting Drafts - Limiting drafts are established for high performance types for the same reasons as for conventional types, namely:

(1) To provide sufficient reserve buoyancy so that the margin line will not be submerged after the ship sustains an amount of underwater flooding designated for the type. Limiting drafts assigned on this basis are called subdivision limiting drafts.

(2) To permit the ship to meet the specified hullborne speeds or satisfy the lift requirements for the "flying" mode.

(3) To avoid overloading which would exceed strength limits.

The assigned limiting drafts are based on whichever of the above considerations governs. For high performance types, considerations (1) and (2) will usually govern.

For the high performance types having catamaran forms, the damage stability calculations are used to determine limiting drafts rather than the usual floodable length and trim line calculations applicable to the shell-to-shell flooding for conventional monohull types. As noted earlier, a criterion for satisfactory damage stability for the catamaran types is that the margin line shall not be submerged for the worst damaged static heeled-trimmed waterline.

Limiting drafts for hydrofoil types, which have conventional monohull forms, are determined by floodable length and trim line calculations for shell-to-shell flooding case. Where unsymmetrical flooding is possible, this case must be investigated to determine whether limiting drafts should be established on this basis to prevent submerging the margin line.

b. Flooding Water Levels

Flooding water levels should be determined in a manner similar to that described in Part II in order to determine the watertight and closure requirements for penetrations through watertight bulkheads and decks and for weather openings. The objective is to prevent flooding into otherwise undamaged compartments when the ship has sustained underwater flooding in an amount specified for the type.

PART IV

079-1-e. Part IV CALCULATION METHODS

Although the purpose of this design data sheet is to describe criteria, a brief reference to the required stability and buoyancy calculations follows:

1. Computer Program

The NAVSEA Hull Ship Characteristics Program (SHCP) is used to develop the upright, trimmed and heeled functions for the ship in the intact and damage conditions. This program or an equivalent computer program or hand calculation must be used. In cases where SHCP is not used, NAVSEA review and approval of the alternate method is required.

2. Permeabilities

Table 8 and figure 31 below show nominal permeabilities which shall be used in the calculations. Modifications to the above values are acceptable for special cases. In case of damage involving oil tanks, an exchange of seawater and oil must be taken into account if this is more severe than assuming the tanks intact. Where flooding involves cross-connected oil tanks, the most different severe assumption regarding exchange of density liquids must still be taken. When sea water is assumed to displace oil in cross-connected tanks, the exchange shall be limited to the tank on the damaged side with the tank away from damage going from a partial oil condition to 100% oil.

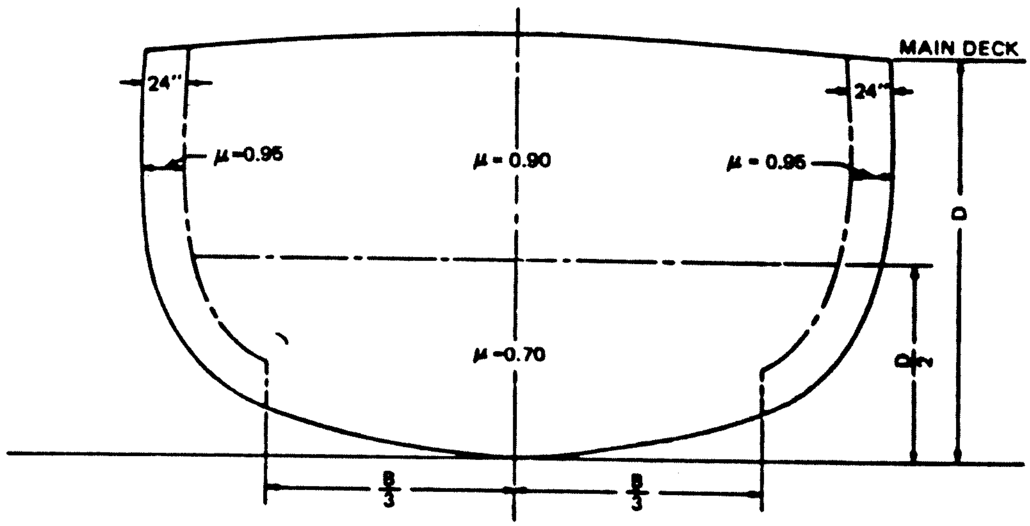
TABLE 8.

Type of compartment	Permeability	
	Full load condition	Light operating condition
Living spaces	0.95	0.95
Offices, radio rooms, I. C. rooms	.95	.95
Shops	.90	.90
Pump rooms	.90	.90
Steering gear	.90	.90
Auxiliary machinery	.85	.85
Stores and provisions	0.80 to .90	.95
Magazines:		
Powder	.60	.95
Small arms ammunition	.60	.95
Small arms	.80	.95
Handling rooms	.80	.95
Torpedo stowage	.70	.95
Cargo	0.60 to .80	.95
Rocket stowage	.80	.95
Chain locker	.65	.65
Gasoline in cans	.40	.95

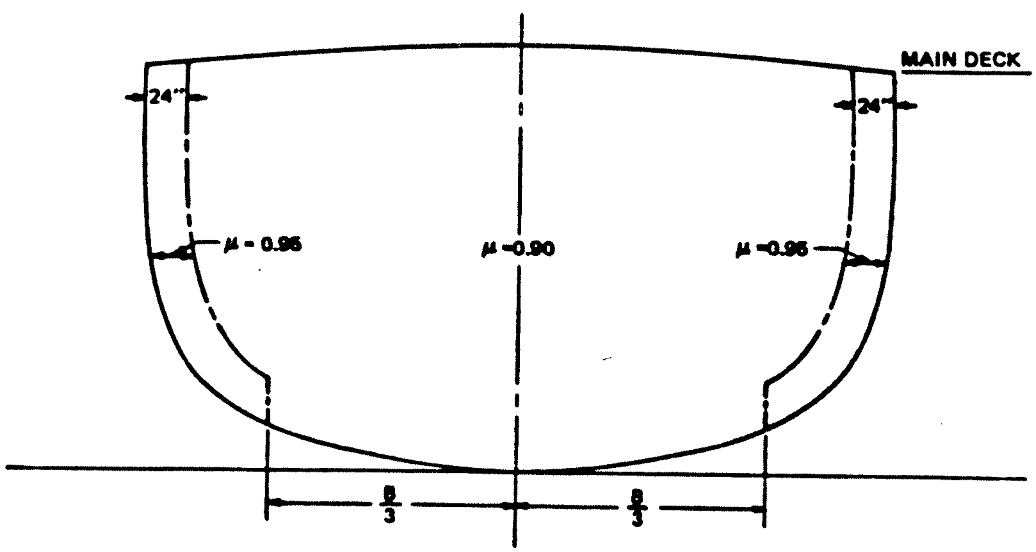
AVERAGE PERMEABILITY

(VALUES IN SKETCH FOR STEAM PLANT)

ENGINE ROOM



AFTER FIRE ROOM



NOTE: FOR GAS TURBINE AND DIESEL MACHINERY LET $\mu = 0.85$ FROM SHELL TO SHELL AND BOTTOM TO DECK

FIGURE 31

3. Righting Arm Curves

The righting arm curves (intact and damage) shall reflect the case of trim coupled with heel at each angle of inclination.

4. Trim Lines and Limiting Drafts

The effect of heel, when governing, shall be reflected in the trim line limiting draft outputs.

5. Limiting Drafts and Limiting KG

The output data for each ship design shall include limiting drafts, limiting KG solid (expressed in full load), flooding water levels (V lines) on bulkheads and over the decks. The limiting KG value is determined from the righting arm curve (intact or damage) for the poorest stability condition which governs. A limiting KG solid is determined for this case and then the difference of loads (weight and vertical moment) between full load and the governing case is added to the governing case to obtain the limiting KG solid for full load.

6. Comparison of Stability and Buoyancy Limits with Weight Estimate or Inclining Data

Cases for which a limiting KG (solid, full load) are developed are as follows:

a. Damage stability
b. Intact stability (other than wind)
c. Intact beam wind (new design)
d. Intact beam wind (after five years in service)

KG margins and allowances relative to the Contract Design Weight Estimates (CDWE) or inclining experiments are shown below. These are in addition to the normal design and construction margins included in the C.D.W.E. Typical values for destroyer and cruiser size ships are given; exact values will be specified for each ship.

		KG Margin or Allowance
e.	Inclining experiment allowance	0.25 ft.
*f.	Service Life	0.50 ft. (Typical Destroyer Value)
g.	Future Growth vertical moment	Amount remaining at time of calculation

Note: The service life margin is expected to be consumed during the life of the ship by authorized or unauthorized vertical moment changes. For this purpose a straight line depletion is assumed for a 20 year life.

A comparison of the limiting KG values and the Contract Design Weight Estimate or inclining experiment FULL LOAD KG (solid) adding the following margins as noted to determine adequacy of stability:

Limiting KG Case	Margins or allowance added to the CDWE or inclining experiment Full Load KG (solid)
Damage Stability	e, f, and g
Intact Stability (other than wind)	e, f, and g

Intact beam wind (new designs)	e, f*, and g
Intact beam wind (service)	e, f, and g

*"Margin f" shall be added to ships built to Ship Specifications dated subsequent to 1 August 1975.

Cases for which limiting drafts or limiting displacements are developed:

	Case	Limit Developed
a.	Subdivision	Subdivision drafts
b.	Intact or Damage Stability	Displacement
c.	Strength	Displacement
d.	Speed	Displacement

Displacement Margins relative to D.C.W.E. or inclining experiments are shown below and are in addition to the normal design and construction margins included in the D.C.W.E.

e.	Service life margin	5% of Full Load Displacement or the amount specified
f.	Future Growth margin	Amount remaining at time of calculations

Note: The service life margin shall be assumed to be consumed during the life of a ship by authorized or unauthorized weight changes. A straight line depletion is assumed over a 20 year life.

A comparison of the limiting drafts and displacements is made with the C.D.W.E. or inclining experiment full load, adding the following margins as noted to determine adequacy:

Case	Margins added to C.D.W.E. or inclining experiment Full Load
Subdivision	e, f
Intact or Damage Stability	e, f
Strength	e, f
Speed	treated on a case basis

The designer should be congnizant of historical information which indicates that there are increases in displacement and rises in KG during the various stages of design (feasibility, concept, preliminary, and contract). Thus, adequacy of a design from stability and buoyancy standpoints should be based on allowances for these weight and KG changes which may be expected during remaining design periods. Specific values to be used will be furnished by the Navy.

REFERENCES

079-1-f. References

1. "Stability and Buoyance Criteria for U. S. Naval Surface Ships" - Sarchin & Goldberg, SNAME, November 1962

2. "Stability and Buoyancy Criteria for Low Waterplane Catamarans" - Goldberg & Tucker, Society of Aeronautical Weight Engineers, May 1972

3. "Current Status of U. S. Navy Stability and Buoyancy Criteria for Advanced Marine Vehicles" – Goldberg & Tucker, A1AA/SNAME, February 1974

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