DESIGN DATA SHEET
DDS 079-1

STABILITY AND BUOYANCY OF U.S. NAVAL SURFACE SHIPS

DEPARTMENT OF THE NAVY

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1. Section 1

1.1 REFERENCES


1.2 INTRODUCTION

The purpose of this Design Data Sheet (DDS) is to present the NAVSEA design practice for stability and buoyancy of U.S. Navy surface ships and craft.

This DDS is divided into three 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; and Part III deals with advanced marine vehicles in their waterborne displacement mode of operation.

1.3 DEFINITIONS

Ships and Craft - includes all U.S. Navy surface ships, service craft, and yard craft.
AP  Intersection of the design waterline and the centerline of the hull aft.
FP  Intersection of the design waterline and the stem.
LBP The distance between the AP and FP.
LWL Length on the waterline

1.4 SYMBOLS AND ABBREVIATIONS

HA  Heeling arm (ft)
RA  Righting arm (ft)
RAMAX Maximum righting arm value
\( \Delta \)  Displacement (long tons)
\( \Theta \)  Heel angle (degrees)
\( \Theta_R \) Rollback angle (degrees)
\( \Phi \) Angle at which down flooding occurs
HA_{EQUIL} Heeling arm at equilibrium
HA_{STATIC} Heeling arm at static equilibrium
A0
A1
A2
1.5 SUMMARY OF STABILITY AND BUOYANCY PERFORMANCE REQUIREMENTS FOR ALL U.S. NAVY SURFACE SHIPS

All types of naval ships and craft may be subjected to external influences as well as underwater damage. 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 herein. A summary of the governing stability and buoyancy criteria is presented at this point for ready reference.

The stability of the ship in the operating range is expressed by the stability curve for full load, minimum operating condition (or optimum battle condition) or the worst condition within the operating range for both the intact and damaged ship. The adequacy of stability is measured by comparing the intact righting arm curve with the hazard heeling arm curve. The static heel angle, the associated righting arm, and the reserve of dynamic stability are the factors which are examined.
2. STABILITY AND BUOYANCY REQUIREMENTS FOR CONVENTIONAL MONOHULLS

2.1 DESIGN PHILOSOPHY

The underlying philosophy in this design data sheet is that as ship size, military importance, and number of personnel increase, the degree of hazards to which it may be exposed increases. The larger the ship, the greater the possibility of a hazard occurring which would damage the extensive internal subdivision provided to enhance the ship’s ability to survive underwater damage. Therefore, stability and buoyancy commensurate with ship size, importance, etc. shall be provided. The design criteria presented herein represent stability standards based upon historical data. New designs shall satisfy these criteria, as a minimum.

2.2 DESIGN CONSIDERATIONS

2.2.1 General

For new designs, a naval architect must integrate the applicable stability and buoyancy standards and the given ship design and operational requirements. These often have conflicting demands. The features which generally favor stability and reserve buoyancy, such as a low center of gravity, adequate beam, optimum bulkhead arrangement, watertight integrity, absence of off center compartments, and adequate freeboard, are often in conflict with the demands of other characteristics. For instance: 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. The fact that consumption of liquid load generally results in a rise in the center of gravity must also be accounted for. If a design is based on the premise that there will be no sea water ballasting of empty oil tanks for normal operations, volume must be provided for sufficient clean ballast tankage to compensate for fuel usage.

2.2.2 Ability To Survive Underwater Damage

Ships are provided with watertight subdivision to halt the ingress of water into the ship after damage and to limit the spread of flooding. Increasing this subdivision greatly enhances a ship’s ability to remain afloat following damage. Since compartment size does not increase proportionally with increase in size of naval ships, larger ships possess a greater degree of subdivision. Some of the larger ships even have dedicated side protection features.
Naval ships may be classified as not having a side-protective subdivision system or as having such a system. Both types usually have an inner bottom which serves as tankage for liquids, and provides some protection against near-miss explosions under the hull. Generally, a side-protective system is not feasible on smaller ship types, so that most naval ships do not have 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 stability after damage unless the off center spaces formed by these bulkheads are kept full of liquids, or are cross-connected to ensure rapid cross-flooding.

For ships with a side-protective system, such as aircraft carriers and battleships, the system consists of outboard layers of longitudinal bulkheads forming compartments containing liquids, foam, or voids which can be readily flooded. Numerous transverse bulkheads form the fore-and-aft boundaries of these compartments. A full system may extend about two-thirds of the ship length and is intended to minimize flooding of inboard vital spaces which other wise might result from enemy torpedo action.

Bulkheads are normally carried watertight up 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 ship types, or a stepped deck. Therefore, the watertight envelope for intact stability extends to the bulkhead deck.

Decks and platforms, other than the weather deck, may have either a favorable or unfavorable effect on ability to survive damage. If damage occurs beneath a low watertight deck and the space below the deck floods completely, the effect is favorable because weight is added low in the ship and high flooding water is avoided. On the other hand, if damage occurs above a watertight deck and the flooding of spaces below is prevented, the effect is unfavorable since low flooding will not be obtained. Due to the uncertainty regarding 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 bulkhead deck throughout the ship's length is necessary to prevent flooding into undamaged spaces. Considerations other than reserve buoyancy or stability after damage determine whether other decks or platforms are to be made watertight, but the bulkhead deck, if different from the weather deck, is the upper boundary of the watertight envelope.

2.2.3 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 which contain equipment essential to the primary mission of the ship. Each of these spaces within the hull is
surrounded by a complete watertight or airtight envelope. Such protection might prevent flooding or contamination from nearby damage, thus preserving the function of the space. It is, therefore, necessary in the overall design to provide sufficient stability to overcome this adverse effect. Arranging the vital spaces to reduce potential unsymmetrical flooding will minimize this disadvantage.

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. The damage-control deck is located high in the ship and is the lowest deck having fore and aft access through watertight openings in the main transverse bulkheads.

2.2.4 Transverse Watertight Bulkhead Spacing And Penetrations

Main transverse subdivision bulkheads shall be any transverse bulkhead that is watertight for the full transverse and vertical extent of the hull envelope up to the bulkhead deck. For ships with a well deck, the main transverse subdivision bulkheads may be "U" shapes, but the watertight integrity is maintained by the watertight longitudinal bulkheads and well deck. This is illustrated in Figure 2-1.

![Figure 2-1 U Shaped Transverse Watertight Bulkhead](image)

The spacing of transverse watertight bulkheads, which is necessary to develop resistance to underwater attack, will often interfere with the optimum arrangement of the ship compartments, from other design perspectives. Since all of the main transverse bulkheads should extend continuously, from the keel up, all compartments on the various levels between two main transverse bulkheads are restricted to the same length. The optimum arrangement might require compartments of different lengths. 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. To be considered effective, main transverse watertight bulkheads shall be spaced a minimum distance apart of 10 feet + 0.03 LBP. Further explanation is provided in Section 2.5.3.4.1 Longitudinal Extent of Damage.

Penetrations through watertight subdivisions by piping, electric cable, ventilation ducts, and access openings, increase the weight, effort, and cost of these systems. The piping systems valves, access and ventilation closures, will then be designed for the life of the ship in accordance with the various damage control material conditions. Rapid access is hindered by the necessity for opening and re-securing watertight doors. The associated costs of these systems are minimal when compared to the benefits of the protection provided. However, there is a definite operational 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 in the midships region between the weather deck and the deck below. 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 non-watertight 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, the investigations 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 in order 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, 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 (V-Lines on bulkheads). Penetrations through these bulkhead areas may be non-watertight (see Figure 2-2) without introducing appreciable danger of progressive flooding into intact spaces if other considerations are 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 non-watertight 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 non-tight areas require permanent watertight closures, vent duct 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.

![Diagram of areas of allowable non-watertight transverse bulkhead penetration]

Figure 2-2 Areas of Allowable Non-Watertight Transverse Bulkhead Penetration

2.2.5 Longitudinal Watertight Bulkhead Penetrations

Watertight longitudinal bulkheads are to be avoided, if practicable, because of unsymmetrical flooding. Some types of ships such as well deck ships, oilers, etc. require the use of watertight longitudinal bulkheads. For these ships, the bulkheads should be arranged to minimize the possibility and amount of unsymmetrical flooding either by additional transverse subdivision, cross connection, or liquid loading requirements. In order to reduce unsymmetrical flooding potential, symmetrical off-center voids, non-vital dry spaces, or symmetrical tanks may be connected by cross flooding ducts. For ships with a well deck, there will be no penetrations of the longitudinal bulkheads which define the well, below the damage control deck. The damage control deck may be transversely stepped to the deck covering the well to provide athwartship access.

Penetrations through longitudinal watertight bulkheads are given the same considerations as are penetrations through transverse watertight bulkheads as described in the previous section.

2.2.6 Watertight Decks And Penetrations

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. Watertight subdivisions are designed to withstand a hydrostatic head corresponding to the level of assumed flooding water which may be loaded on the structure. 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 is protected against vent-duct flooding from below. This is done by extending the watertight ducts vertically above the flooding water level. 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 and they are included in the detail specifications for each ship design.

2.2.7 Permeability

Table 2-1 shows nominal permeabilities which shall be used in the calculations. Modifications of the above values are acceptable for special cases. In case of damage involving oil tanks, an exchange of sea water and oil must be taken into account if this results in a condition which is less favorable than when assuming the tanks are intact. Where flooding involves cross-connected oil tanks, the most severe assumption regarding exchange of density liquids shall 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 on the side away from damage assumed to be changing from a partial oil condition to 100 percent oil.
Table 2-1  Compartment Permeabilities

<table>
<thead>
<tr>
<th>Type of Compartment</th>
<th>Full Load Condition</th>
<th>Minimum Operating Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Living spaces</td>
<td>0.95</td>
<td>0.95</td>
</tr>
<tr>
<td>Offices, radio rooms, I.C. rooms</td>
<td>0.95</td>
<td>0.95</td>
</tr>
<tr>
<td>Shops</td>
<td>0.90</td>
<td>0.90</td>
</tr>
<tr>
<td>Pump rooms</td>
<td>0.90</td>
<td>0.90</td>
</tr>
<tr>
<td>Steering gear</td>
<td>0.90</td>
<td>0.90</td>
</tr>
<tr>
<td>Auxiliary machinery</td>
<td>0.85</td>
<td>0.85</td>
</tr>
<tr>
<td>Stores and provisions</td>
<td>0.80 to 0.90</td>
<td>0.95</td>
</tr>
<tr>
<td>Refrigerator spaces</td>
<td>0.80</td>
<td>0.90</td>
</tr>
<tr>
<td>Empty tanks and voids</td>
<td>0.98</td>
<td>0.98</td>
</tr>
<tr>
<td>Magazines:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Powder</td>
<td>0.60</td>
<td>0.95</td>
</tr>
<tr>
<td>Small arms ammunition</td>
<td>0.60</td>
<td>0.95</td>
</tr>
<tr>
<td>Small arms</td>
<td>0.80</td>
<td>0.95</td>
</tr>
<tr>
<td>Handling rooms</td>
<td>0.80</td>
<td>0.95</td>
</tr>
<tr>
<td>Torpedo stowage</td>
<td>0.70</td>
<td>0.95</td>
</tr>
<tr>
<td>Cargo</td>
<td>0.60 to 0.80</td>
<td>0.95</td>
</tr>
<tr>
<td>Rocket stowage</td>
<td>0.80</td>
<td>0.95</td>
</tr>
<tr>
<td>Chain locker</td>
<td>0.65</td>
<td>0.65</td>
</tr>
<tr>
<td>Gasoline in cans</td>
<td>0.40</td>
<td>0.95</td>
</tr>
<tr>
<td>Machinery plant:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gas turbine</td>
<td>0.85</td>
<td>0.85</td>
</tr>
<tr>
<td>Diesel</td>
<td>0.85</td>
<td>0.85</td>
</tr>
<tr>
<td>Conventional steam:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lower half engine room</td>
<td>0.70</td>
<td>0.70</td>
</tr>
<tr>
<td>Upper half engine room</td>
<td>0.90</td>
<td>0.90</td>
</tr>
<tr>
<td>Fire room</td>
<td>0.90</td>
<td>0.90</td>
</tr>
</tbody>
</table>

Special space permeability is calculated as appropriate.

2.2.8  Provision For Carrying Liquids

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. Clean ballast tanks, located low in the ship, which are filled as oil and fresh water are consumed, will aid in maintaining a low center of gravity. The size and shape of the tank determine the free-surface effect. Small athwartships dimensions of tanks reduce free surface effect. Avoiding empty off-center tanks will reduce a potential source of unsymmetrical flooding in the event of underwater damage. Although this describes the optimum tankage
design, such a tankage arrangement is not always feasible because of limited space, and other design considerations.

A common arrangement of the tanks is one with the oil tanks located low in the ship. Standard liquid loading instructions in the past have required ballasting of empty oil tanks. Pollution requirements no longer permit ballasting of empty oil tanks as a normal operational procedure, therefore the low center of gravity is not easily maintained.

If the damaged ship stability criteria can not be satisfied for certain groups of compartments due to unsymmetrical flooding in off-center deep oil tanks, a possible solution may be to redesign the wing tanks to U-shaped tanks thereby eliminating the possibility of unsymmetrical flooding in the critical group of compartments. It is necessary to establish that the resulting free surface of the intact U-shaped tank does not cause another group of compartments to become critical in the stability of the damaged ship. The large added free surface of the U-shaped tanks shall be evaluated for all intact stability criteria. The assumptions used in designing the ship shall be communicated to the operators in the form of liquid loading instructions.

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 these liquids, there is usually insufficient margin to permit a significant reduction in stability, particularly in the case of damaged ship 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. It must also be noted that special instructions govern the use of liquids in ships with side protective systems, so that maximum resistance to the effects of explosions will be maintained.

2.2.9 Cross Connections

Cross-connections are employed in off-center, double-bottom oil tanks where they are necessary to reduce potential unsymmetrical flooding. The baffle is carried sufficiently high to prevent transference of oil during normal rolling of the ship. Appropriate venting is provided. If these tanks are empty at the time one tank is bilged, automatic rapid counter flooding will occur.

2.2.10 Stranding

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 previously described under 2.2.2 Ability To Survive Underwater Damage apply. However, the designer shall consider the unfavorable situation when the double bottom, consisting of voids or empty
tanks, remains intact and a damage results in extensive flooding from a shell opening above the inner bottom.

2.2.11 Collision Damage

The case of collision damage involving considerable sideshell opening has been previously covered in "Ability To Survive Underwater Damage" (2.2.2). 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 shall serve as a collision bulkhead for purposes of limiting flooding to the bow compartment. It shall be located approximately five percent abaft the forward perpendicular.

2.2.12 Inclining Experiment Criteria Tolerance

The inclining experiment is the classical naval architectural exercise used to determine the KG of the ship. Because it is an experiment it is subject to the same uncontrollable variations due to tolerances in data taking, etc., as is any engineering experiment. Due to the importance of the KG in determining the safety of the ship in service, and due to the possibility that even the most careful experiment will underestimate the actual KG of the ship, it has been NAVSEA policy to determine a reasonable tolerance for these inclining experiment variations for a particular type of ship. Although the tolerance may be plus or minus for any given experiment, the value is always assumed to be positive, because of the safety implications of over estimating a ship's stability. This tolerance is included in all stability calculations. A typical value for past ships is as follows:

Destroyers = 0.25 feet in full load condition.
2.3 LOADING CONDITIONS

2.3.1 General

Certain standard conditions of loading are pertinent in applying criteria. The standard loading conditions are defined in Naval Ships' Technical Manual NSTM 096, Reference A. 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 may require investigation to ensure that the stability criteria are satisfied for the worst loading condition.

2.3.2 Full Load

As the name implies, the full load condition corresponds to full load (departure) condition, as per NSTM 096 with the ship carrying the full allowance of variable loads and cargo. Full Load conditions are outlined in Table 2-2.

2.3.3 Minimum Operating Condition

The minimum operating condition describes the ship after an extended period at sea and is usually the condition of lowest stability consistent with following the liquid loading instructions. Minimum operating load conditions are outlined in Table 2-3.

2.3.4 Optimum Battle Condition

This loading condition applies to ships with side-protective systems and is equivalent to the minimum operating condition for ships without side-protective systems (Table 2-3), except as shown in Table 2-4 below.

2.3.5 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 a full load of oil instead of one-third oil plus two-thirds clean water. Another example is if a ship which is designed to carry large amounts of cargo may be in a worst loading condition for stability with zero cargo and a full load of ship's fuel, provisions, and stores, etc., than when loaded with full cargo and the ship's fuel, provisions, stores, etc., in the minimum operating condition. For UNREP ships, allowance must be made for the pre-staging of some cargo on the transfer deck. The designer should consider the worst loading condition when applying the stability criteria.
Table 2-2  Loads In Full Load Condition for Ships Ballasting Clean Ballast Tanks

<table>
<thead>
<tr>
<th>ITEM</th>
<th>LOADS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crew and effects</td>
<td>Wartime complement</td>
</tr>
<tr>
<td>Provisions and personnel stores</td>
<td>Complement * # of days endurance. Quantities not to exceed available capacity. 30 day limit on chill stores. Medical and troop stores in normal amounts.</td>
</tr>
<tr>
<td>General Stores</td>
<td>All stores other than personnel stores which are consumable. Based on Design Characteristics.</td>
</tr>
<tr>
<td>Ammunition</td>
<td>Full allowance of ammunition with maximum quantities in ready-service stowage and remainder in magazines. For missiles and torpedoes, least favorable quantity and disposition is assumed.</td>
</tr>
<tr>
<td>Lube Oil</td>
<td>Storage tanks are 95% full, settling tanks are empty.</td>
</tr>
<tr>
<td>Reserve feed and Fresh water</td>
<td>All tanks 100% full.</td>
</tr>
<tr>
<td>Diesel Oil (other than for propulsion)</td>
<td>All tanks 95% full. Overflow tanks filled as necessary for endurance. Contaminated oil settling tanks (COST) are empty.</td>
</tr>
<tr>
<td>Aviation or vehicle fuel</td>
<td>All tanks are 95% full.</td>
</tr>
<tr>
<td>Airplanes and aviation stores</td>
<td>Full design complement of aircraft, empty. Full allowance of repair parts and stores. Distribution of aircraft shall be most unfavorable from stability standpoint.</td>
</tr>
<tr>
<td>Cargo</td>
<td>Includes all items of ammunition, stores, provisions, fuel water, etc. which are normally carried for issue to other activities.</td>
</tr>
<tr>
<td>Propulsion fuel</td>
<td>All tanks 95% full.</td>
</tr>
<tr>
<td>Anti-roll tanks</td>
<td>Operating level</td>
</tr>
<tr>
<td>Sewage Holding Tanks (CHT)</td>
<td>Empty</td>
</tr>
<tr>
<td>Water ballast tanks</td>
<td>Empty</td>
</tr>
</tbody>
</table>
Table 2-3  Loads In Minimum Operating Condition for Ships Ballasting Clean Ballast Tanks

<table>
<thead>
<tr>
<th>ITEM</th>
<th>LOADS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crew and effects</td>
<td>Same as Full Load</td>
</tr>
<tr>
<td>Provisions and personnel stores</td>
<td>One-third of Full Load</td>
</tr>
<tr>
<td>General Stores</td>
<td>One-third of Full Load</td>
</tr>
<tr>
<td>Ammunition</td>
<td>One-third of full-load ammunition with maximum quantities in ready-service stowages and remainder in magazines. For missiles and torpedo least favorable quantity and disposition is assumed.</td>
</tr>
<tr>
<td>Lube Oil</td>
<td>One-third full load</td>
</tr>
<tr>
<td>Reserve feed and Fresh water</td>
<td>Two-thirds full load</td>
</tr>
<tr>
<td>Diesel Oil (other than for propulsion)</td>
<td>One-half full load on ships below destroyer size; one-third full load on larger ships.</td>
</tr>
<tr>
<td>Aviation or vehicle fuel</td>
<td>One-third of full load. Compensating fuel sea water ballast (or ballast water in empty tanks) is taken as remainder the load.</td>
</tr>
<tr>
<td>Airplanes and aviation stores</td>
<td>Same as full load</td>
</tr>
<tr>
<td>Cargo</td>
<td>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.</td>
</tr>
<tr>
<td>Propulsion fuel</td>
<td>One-third full load with remaining tanks loaded in accordance with liquid loading instructions.</td>
</tr>
<tr>
<td>Anti-roll tanks</td>
<td>Operating level</td>
</tr>
<tr>
<td>Sewage Holding Tanks (CHT)</td>
<td>Full</td>
</tr>
<tr>
<td>Water ballast tanks</td>
<td>Empty*</td>
</tr>
</tbody>
</table>

* Ships fitted with separate saltwater ballast tanks may include in the minimum operating condition, water ballast which is in excess of the capacity required to compensate for fuel usage below the one-third fuel level.
Table 2-4  Loads In Optimum Battle Operating Condition for Ships Ballasting Clean Ballast Tanks

<table>
<thead>
<tr>
<th>ITEM</th>
<th>LEVEL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ammunition</td>
<td>Same as full load</td>
</tr>
<tr>
<td>Provisions and General Stores</td>
<td>Two-thirds full load</td>
</tr>
<tr>
<td>Lube oil, diesel oil, aviation fuel</td>
<td>Two-thirds full load</td>
</tr>
<tr>
<td>Fuel oil and sea water ballast</td>
<td>In accordance with Liquid Loading Instructions except that service</td>
</tr>
<tr>
<td></td>
<td>tanks are half full, and one pair of storage oil tanks per machinery</td>
</tr>
<tr>
<td></td>
<td>box is assumed to be empty</td>
</tr>
<tr>
<td>All other Items</td>
<td>Refer to Table 2-3</td>
</tr>
</tbody>
</table>

2.3.6 Modifications To Critical Loading Condition

In the stability analysis, the above-mentioned loading conditions are modified to an assumed condition after a few hours steaming. Normally, the fuel service tanks are considered half full, and the potable and reserve feed water tanks are reduced to two-thirds of full load. For ships without distillers, the water tanks are half full. In addition, the fuel in the storage tankage is reduced some amount depending on ship size and number of main machinery plants. For each machinery plant, one centerline on a pair of wing storage tanks is assumed slack. It should be noted that liquid loading instructions are developed by analyzing the ship in the critical operating condition. Ballasting to compensate for empty tanks and loss of low weight is specified in the Liquid Loading Instruction.
2.4 HAZARDS

Naval ships are designed with the capacity to withstand the effects of certain hazards and external influences. These may impact the stability of the intact ship, or the stability of the damaged ship. The following hazards are to be considered independently of the other hazards:

a. The intact ship may experience the following hazards:

1. Beam winds combined with rolling.
2. Lifting of heavy off-center weights.
3. Towline forces.
4. Crowding of personnel to one side.
5. High-speed turning.
6. Topside icing.

b. The damaged ship may experience the following hazards:

1. Beam winds combined with rolling.
2. Progressive flooding.
3. Shifting of cargo.
2.5 STABILITY STANDARDS

2.5.1 General

The material which follows covers the specific criteria applicable to the ship in the intact ship condition and the ship after damage. When a ship meets the specified criteria, 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. The stability and buoyancy criteria specified herein are the minimum criteria that must be satisfied. When other considerations such as speed, arrangement, and cost permit, the minimum criteria should be exceeded. The adequacy of stability is measured by comparing the intact righting arm curve with the hazard heeling arm curve. The static heel angle, the associated righting arm, and the reserve of dynamic stability are the factors which are examined.

2.5.2 Intact Ship Stability

The stability of the ship in the operating range is expressed by the stability curve for full load, minimum operating condition (or optimum battle condition), or the worst condition within the operating range for both the intact and damaged ship. The criteria are outlined in the subsections which follow.

2.5.2.1 Beam winds Combined With Rolling

2.5.2.1.1 Effect of Beam Winds and Rolling

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

2.5.2.1.2 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 2-5.
Table 2-5  Wind Velocities Used In Intact Stability Calculations Service

<table>
<thead>
<tr>
<th>Ocean and Coastwise:</th>
<th>Wind Velocity (Knots)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) Ships which must be expected to weather the full force of tropical cyclones. This includes all ships which will move with the amphibious and striking forces.</td>
<td>100</td>
</tr>
<tr>
<td>(b) Ships which will be expected to avoid the centers of tropical disturbances.</td>
<td>80</td>
</tr>
<tr>
<td>Coastwise:</td>
<td></td>
</tr>
<tr>
<td>(a) Ships and craft which will recalled to protected anchorages if winds over Force Eight are expected.</td>
<td>60</td>
</tr>
</tbody>
</table>

2.5.2.1.3 Wind Heeling Arms

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

\[ P = \frac{C \cdot \rho \cdot V^2}{2g} \]

where:

\( C \) = dimensionless coefficient for ships
\( \rho \) = air density (mass per volume)
\( V \) = wind velocity (knots)
\( g \) = acceleration due to gravity (ft/sec\(^2\))

There is considerable uncertainty regarding the value of \( C \). The variation of the wind velocity at different heights above the waterline is shown in Figure 2-3. The most widely used formula for \( P \), has been:

\[ P = 0.004 \cdot V^2 \]

where:

\( V \) = velocity (knots)
\( P \) = pressure (lb/ft\(^2\))

The heeling arm due to wind, is expressed, in English units, as follows:

\[ HA_{WIND} = 0.004 \cdot \frac{V^2 \cdot AL \cdot \cos^2(\Theta)}{2240 \cdot \Delta} \]
where:

\[ \begin{align*}
A & = \text{projected sail area, square feet} \\
L & = \text{lever arm from half draft to centroid of "sail area" (feet)} \\
V & = \text{nominal wind velocity (knots)} \\
\Theta & = \text{angle of inclination (degrees)} \\
\Delta & = \text{ship displacement, in long tons}
\end{align*} \]

When full scale velocity gradient effects are to be accounted for, an average coefficient value of 0.004 may be used in conjunction with the velocity gradient curve, Figure 2-3. The curve in Figure 2-3 is a composite of various values given in the literature. The nominal velocity is assumed to occur at about 33 feet above the waterline. Use of Figure 2-3 for determining the value of \( V \) in the formula for heeling arm due to wind, properly favors the smaller ships which normally would be the most affected by the velocity gradient and would also be somewhat sheltered from the wind by the accompanying waves. Table 2-6 has been prepared as an aid in determining wind heeling moments for a nominal 100 knot wind, for varying heights above the waterline. For other wind velocities, the values in Table 2-6 are multiplied by \( (V/l00)^2 \).

On most ships, a first approximation using the above formula for \( H_{\text{WIND}} \) to estimate the heeling arm, without allowance for wind gradient, will establish whether or not wind heel will be a governing criterion and whether or not any further calculations will be required. The most accurate method of determining wind-pressure effects would be to conduct wind-tunnel tests for each design.

Figure 2-3  Wind Velocity Gradient
### Table 2-6 Wind Heeling Factors for a 100 Knot Wind

Heeling Moment (Ft-Tons) Per Square Foot For A Nominal 100-Knot Wind

<table>
<thead>
<tr>
<th>Ship Center of Lateral Resistance Below Waterline (Ft)</th>
<th>Height above WL (Ft)</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>15</th>
<th>16</th>
<th>17</th>
<th>18</th>
<th>19</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0-5</td>
<td>0.04</td>
<td>0.05</td>
<td>0.06</td>
<td>0.07</td>
<td>0.08</td>
<td>0.09</td>
<td>0.10</td>
<td>0.11</td>
<td>0.11</td>
<td>0.12</td>
<td>0.13</td>
<td>0.14</td>
<td>0.15</td>
<td>0.16</td>
<td>0.17</td>
<td>0.18</td>
<td>0.19</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5-10</td>
<td>0.11</td>
<td>0.12</td>
<td>0.14</td>
<td>0.15</td>
<td>0.16</td>
<td>0.18</td>
<td>0.19</td>
<td>0.20</td>
<td>0.20</td>
<td>0.22</td>
<td>0.23</td>
<td>0.24</td>
<td>0.26</td>
<td>0.27</td>
<td>0.28</td>
<td>0.29</td>
<td>0.31</td>
<td>0.32</td>
</tr>
<tr>
<td></td>
<td>10-15</td>
<td>0.20</td>
<td>0.21</td>
<td>0.23</td>
<td>0.24</td>
<td>0.26</td>
<td>0.27</td>
<td>0.29</td>
<td>0.30</td>
<td>0.32</td>
<td>0.33</td>
<td>0.34</td>
<td>0.35</td>
<td>0.37</td>
<td>0.38</td>
<td>0.40</td>
<td>0.41</td>
<td>0.43</td>
<td>0.44</td>
</tr>
<tr>
<td></td>
<td>15-20</td>
<td>0.30</td>
<td>0.32</td>
<td>0.33</td>
<td>0.34</td>
<td>0.36</td>
<td>0.37</td>
<td>0.39</td>
<td>0.41</td>
<td>0.42</td>
<td>0.44</td>
<td>0.45</td>
<td>0.46</td>
<td>0.48</td>
<td>0.49</td>
<td>0.51</td>
<td>0.53</td>
<td>0.54</td>
<td>0.56</td>
</tr>
<tr>
<td></td>
<td>20-25</td>
<td>0.40</td>
<td>0.41</td>
<td>0.43</td>
<td>0.45</td>
<td>0.46</td>
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**NOTE:** To obtain the total heeling moment using this table, follow the procedure below:

(a) Divide the "sail" area into 5-foot layers, starting from the waterline.
(b) Determine the number of square feet in each layer.
(c) Multiply the area of each layer by the appropriate factor from the above table and add the products. This sum is the heeling moment for a 100 knot wind.
(d) For wind velocities other than 100 knots, multiply the moment by \((V/100)^2\)
(e) The ship Center of lateral resistance is usually near the half draft.
2.5.2.1.4 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, as illustrated in Figure 2-4, where the range of the righting arm curve terminates at the angle of unrestricted down flooding. If analysis shows that the ship can survive this flooding a composite righting arm may be used. The "points" and "areas" referred to below are those depicted in Figure 2-4.

![Intact Stability - Beam Winds with Rolling](image-url)

Figure 2-4 Intact Stability - Beam Winds w/ Rolling
Stability is considered to be satisfactory if:

a. The heeling arm at the intersection of the righting arm and heeling arm curves, \( \Theta \) equilibrium or Point C, is not greater than six-tenths of the maximum righting arm:

\[
H_{\text{EQUIL}} \leq 0.6 \times R_{\text{MAX}} \quad \text{or} \quad H_{\text{EQUIL}} / R_{\text{MAX}} \leq 0.6
\]

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.

b. Area A1 is not less than 1.4 \( A_2 \), where area \( A_2 \) extends either 25 degrees or \( \Theta_R \) (if roll angle determined from model tests) to windward from Point C:

\[
1.40 \times A_2 \leq A_1 \quad \text{or} \quad A_1 / A_2 \geq 1.40
\]

In the second criterion, the ship is assumed to be heeled over by the wind to Point C and rolling 25 degrees or \( \Theta_R \) from this point to windward, where 25 degrees is a 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 account for gusts and waves.

2.5.2.2 Lifting of Heavy Weights Over the Side

2.5.2.2.1 Effects of Lifting Weights

Lifting of weights will be a governing factor in required stability only on ships which are used to lift heavy items over the side. Lifting of weights has a double effect upon transverse stability. The first effect is that 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 is the heel caused by the transverse moment when lifting a weight over the side.

2.5.2.2.2 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 as follows:

\[
H_{A_{\text{HEAVYLIFT}}} = \frac{W a \cos(\Theta)}{\Delta}
\]

where:

\( W \) = weight of lift (tons)

\( a \) = transverse distance from centerline to end of boom (feet)
\[ \Theta = \text{angle of inclination (degrees)} \]
\[ \Delta = \text{displacement plus the weight of lift (tons)} \]

2.5.2.2.3 Criteria for Adequate Stability

The criteria for adequate stability when lifting weights over the side are based on a comparison of the righting arm and heeling arm curves as illustrated in Figure 2-5.

![Diagram of Intact Stability](image)

**INTACT STABILITY**
**LIFTING OF HEAVY WEIGHTS OVER THE SIDE**

Stability is considered satisfactory if:

a. The limiting angle of heel (as indicated by Point C) shall not exceed 15 degrees, or the angle at which one-half the freeboard submerges, which
ever angle is smaller. Angles of heel in excess of 15 degrees will interfere with operations aboard the ship.

\[ \Theta_{\text{EQUIL}} \leq 15 \text{ degrees or } 1/2 \text{ freeboard} \]

b. The heeling arm at the intersection of the righting arm and heeling arm curves, \( \Theta \) equilibrium or Point C, is not more than six-tenths of the maximum righting arm:

\[ H_{A\text{EQUIL}} \leq 0.6 * R_{A\text{MAX}} \quad \text{or} \quad H_{A\text{EQUIL}} / R_{A\text{MAX}} \leq 0.6 \]

c. The reserve of dynamic stability (area A1) is not less than four-tenths of the total area, A0, under the righting arm curve.

\[ 0.4 * A_0 \leq A_1 \quad \text{or} \quad A_1 / A_0 \geq 0.4 \]

The requirements of paragraphs b. and c. above are intended to provide a margin against capsizing. This margin allows for possible boom overloading.

2.5.2.3 Towline Pull for Tugs

2.5.2.3.1 Effect of Towline Force

A ship engaged in towing may be subject to heeling forces caused either by forces imparted to the towline by the tow, or by tripping forces due to the tug attempting to maintain course of the tow or to turn the tow.

2.5.2.3.2 Heeling Arm

The U.S. Coast Guard formula for calculating the transverse heeling arm for towline pull is used by the Navy and is as follows:

\[ HA_{\text{TOW}} = \frac{2N * (SHP * D)^{2/3} * S * H * \cos(\Theta)}{38 \Delta} \]

where:

- \( N \) = number of propellers
- \( SHP \) = shaft horsepower per shaft
- \( D \) = propeller diameter (feet)
- \( S \) = decimal fraction of propeller slip stream effectively deflected by the rudder (assumed to be equal to that fraction of the propeller circle "cylinder" which would be intercepted by the rudder at a 45 degree rudder angle. Use \( S = 0.55 \) if no other value has been determined.)
H = vertical distance from propeller shaft centerline, at rudder centerline, to towing bitts (feet)

Δ = ship’s displacement (L-tons)

Θ = angle of heel (degrees)

2.5.2.3.3 Criteria for Adequate Stability

The criterion for adequate stability during towing operations are based upon a comparison of righting arm and heeling arm, where the range of the righting arm curve terminates at the angle at which unrestricted down flooding may occur, Φ, or at 40 degrees, whichever is less, as shown in Figure 2-6. The limit on righting arm range is to provide a margin of safety in the event that a watertight door or vent duct might be open and might provide a pathway for serious down flooding due to wave action and heeling action.

**Figure 2-6 Intact Stability - Tow Line Pull**

[Diagram showing righting and heeling arms with key points and areas labeled: Maximum Righting Arm, Point C, HAequil, RAmax, Heeling Arm Curve, A0 Area, A1 Area.]

Heel Angle (Degrees)

Righting and Heeling Arms (Feet)

Figure 2-6 Intact Stability - Tow Line Pull
Stability is considered satisfactory if:

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

\[ \Theta_{EQUIL} \leq 15 \text{ degrees} \]

b. The heeling arm at the intersection of the righting arm and heeling arm curves, \( \Theta_R \) equilibrium or Point C, is not more than six-tenths of the maximum righting arm,

\[ HA_{EQUIL} \leq 0.6 \times RA_{MAX} \quad \text{or} \quad HA_{EQUIL} / RA_{MAX} \leq 0.6 \]

c. The reserve of dynamic stability (area A1) is not less than four-tenths of the total area, A0, under the curve.

\[ 0.4 \times A0 \leq A1 \quad \text{or} \quad A1 / A0 \geq 0.4 \]

2.5.2.4 Crowding of Personnel to one Side

2.5.2.4.1 Effect of Crowding of Personnel

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

2.5.2.4.2 Heeling Arm

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

\[ HA_{CROWD} = \frac{Wa \cos(\Theta)}{\Delta} \]

where:

- \( W \) = weight of personnel (tons)
- \( a \) = distance from centerline of ship to center of gravity of personnel (feet)
- \( \Delta \) = displacement (L-tons)
- \( \Theta \) = angle of inclination (degrees)

In determining the heeling moment produced by the personnel, it is assumed that all personnel have moved to one side of the main deck or above and as far outboard as possible.
2.5.2.4.3 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 curves, as illustrated in Figure 2-7.

**INTACT STABILITY**

**THE EFFECT OF CROWDING OF PERSONNEL TO ONE SIDE**

Stability is considered to be satisfactory if:

a. The angle of heel, as indicated by point C, does not exceed 15 degrees. An angle of heel of 15 degrees is considered to be the maximum acceptable from the standpoint of personnel safety.

\[ \Theta_{\text{EQUIL}} \leq 15 \text{ degrees} \]
b. The heeling arm at the intersection of the righting arm and heeling arm curves, Θ equilibrium or Point C, is not more than six-tenths of the maximum righting arm

\[ H_{A\text{EQUIL}} \leq 0.6 \times R_{A\text{MAX}} \quad \text{or} \quad H_{A\text{EQUIL}} / R_{A\text{MAX}} \leq 0.6 \]

c. The reserve of dynamic stability (area A1) is not less than four-tenths of the total area, A0, under the righting arm curve.

\[ 0.4 \times A_0 \leq A_1 \quad \text{or} \quad A_1 / A_0 \geq 0.4 \]

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.

2.5.2.5 High-Speed Turns

2.5.2.5.1 Effect of High-Speed Turns

Heel in a high-speed turn will be a governing factor in required stability only on highly maneuverable ships. The heel towards the outside of the turn is affected by the velocity in the turn and the turning radius associated with that velocity. The maximum heel is often associated with rudder angles less than full rudder due to the decreased speed in the tightest turns. The stability may differ due to the direction of the turn because most high-speed ships respond differently depending on the direction of the rudder and propeller thrusts at the higher speeds and rudder angles.

This criterion is not normally a critical one because all factors involved are under the direct control of ships force permitting some discretion in operation if calculations indicate some combinations of turn direction, rudder angle, or approach speed should be avoided.

2.5.2.5.2 Heeling Arms

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

\[ \text{Centrifugal Force} = \frac{\Delta v^2}{gR} \]

where:

\[ \Delta = \text{displacement of ship (L-tons)} \]
\[ v = \text{steady-state velocity of ship in the turn (ft/sec)} \]
\[ g = \text{acceleration due to gravity (32.2 ft/sec}^2) \]
R = radius of turning circle (ft)

The lever arm used, in conjunction 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 assumed to be at the half-draft. If the centrifugal force is multiplied by the lever arm and divided by the ship's displacement, the following expression for heeling arm is obtained:

\[
HA_{HS\text{TURN}} = \frac{V^2 a \cos(\Theta)}{gR}
\]

where:

\( a \) = distance between ship's center of gravity and center of lateral resistance with ship upright (ft)

\( \Theta \) = angle of inclination (degrees)

For the high-speed turn, R is assumed to be one-half of the tactical diameter. If the tactical diameter and the steady-state velocity in the turn are not available from model or full-scale data, estimates of these quantities must be made.

2.5.2.5.3 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, as illustrated in Figure 2-8.

Stability is considered to be satisfactory if:

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

\[ \Theta_{\text{EQUIL}} \leq 15 \text{ degrees} \]

b. The heeling arm at the intersection of the righting arm and heeling-arm curves, \( \Theta \) equilibrium or Point C, is not more than six-tenths of the maximum righting arm.

\[ HA_{\text{EQUIL}} \leq 0.6 \times RA_{\text{MAX}} \quad \text{or} \quad HA_{\text{EQUIL}} / RA_{\text{MAX}} \leq 0.6 \]

c. The reserve of dynamic stability (area A1) is not less than four-tenths of the total area, A0, under the righting arm curve.

\[ 0.4 \times A0 \leq A1 \quad \text{or} \quad A1 / A0 \geq 0.4 \]
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.

An angle of heel of 15 degrees is considered to be the maximum acceptable from the standpoint of personnel comfort. Personnel would become apprehensive if the angle of heel were greater than 15 degrees.
2.5.2.6 Topside Icing

2.5.2.6.1 Effects of Topside Icing

The primary effect of topside icing is to raise the center of gravity of the ship; in addition, "unevenly distributed" topside ice will result in heel and trim angle.

The criteria for adequate stability under adverse wind and topside icing are based on a comparison of the ship's righting arm curve and the wind heeling arm curve for the ship in the minimum operating load condition with appropriate water ballast tanks full. The ballast tanks which shall be filled in the icing condition are those which can be filled without causing excessive trim by the bow, when the ship is severely iced. This will normally allow only for the after water ballast tanks to be filled.

2.5.2.6.2 Heeling Arm

Figure 2-9 is a guide to the weight of ice that ships over 1000 tons are expected to be capable of carrying, as a function of the ship's displacement. For ships under 1000 tons, assume the weight of ice to be 10 percent of the displacement.

![Weight of Ice to Carry](image)

Figure 2-9 Weight of Ice Ship is Expected to Carry
The majority of ice build up is likely to occur on the forecastle deck and arises from wind blown spray. It is generally accepted that ice build up occurs over the forward one-third of the overall length of the ship. The center of gravity of the ice may be assumed to be located on the centerline one-third of the overall length forward of midships and 4 feet above the weather deck. The wind velocity to be used for stability assessments under icing conditions is 70 knots except for coastwise ships which will be recalled to protective anchorages if winds over force eight are expected, and all harbor service craft. For coastwise ships and service craft, the wind velocity to be used is 45 knots.

2.5.2.6.3 Criteria for Adequate Stability

![Intact Stability Diagram](image)

Figure 2-10 Intact Stability - Icing with Beam Winds and Rolling

Stability is considered satisfactory if as defined in Figure 2-10:

a. \( H_{AEQUIL} \leq 0.6 \times R_{MAX} \) or \( H_{AEQUIL} / R_{MAX} \leq 0.6 \)

b. \( 1.4 \times A_2 \leq A_1 \) (A2 being defined for an angle of 25 degrees)
2.5.3 Damaged Ship Stability

2.5.3.1 General

Consideration is given to the stability required for survival of the ship, and also for the case where limited operations can be continued. Righting arm curves after damage are used to determine adequacy of stability after damage. Reserve-buoyancy calculations based on the assumed damage result in the establishment of limiting drafts (subdivision drafts) forward and aft. The discussion which follows will first present standards applicable to all conventional Navy monohull ships and craft. Next the standards for ships without side-protective systems will be presented, and finally, the standards for ships with side-protective systems, will be presented.

For the case of underwater damage, the extent of the assumed damage varies with the size and function of the ship, and depends on whether or not the ship has a side-protective system. The difference in damage assumptions for ships with and without side-protective systems is due to the marked difference in the amount of damage which these two types of ships can withstand, and also to the nature of the flooding, and to the means provided on ships with side-protective systems for rapidly counteracting the heeling effects of damage.

2.5.3.2 Reserve Buoyancy Requirements

2.5.3.2.1 Limiting Drafts

The standard floodable length curves are used early in a design to establish transverse bulkhead spacing and to estimate 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 down to flooding those groups of adjacent compartments throughout the ship for which there will be the worst combination of sinkage and trim (and heel if appropriate) as a result of the extent of damage. The ship is assumed to be in a full-load condition, with all tanks full, for the shell to shell flooding case; average permeability factors shall be used. If appropriate, flooding on one side should also be investigated in order to take heel into account, with tanks loaded in such a manner as to produce unsymmetrical flooding consistent with liquid loading instructions. The final trim line shall not be above the margin line at side; the margin line is defined as being three inches below the bulkhead deck.

Limiting drafts are assigned on the basis of reserve buoyancy or damaged ship stability requirements, unless strength or other considerations require a lower draft. Where limiting drafts based on available reserve buoyancy are considerably greater than the estimated full load drafts, limiting drafts which are less than the maximum allowable may be selected in order to relax some of the watertight closure requirements for bulkhead penetrations and weather openings.
2.5.3.2.2 Calculation of Flooding Water Levels (V-Lines)

For a given ship arrangement and a given set of limiting drafts, it is possible to determine a final trim line after flooding 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, or unsymmetrical flooding, whichever represents the worst case. Trim lines are determined for each group of compartments which could be flooded by the shell opening specified in the criteria.

2.5.3.2.2.1 Flooding Water Levels on Bulkheads

The highest water level that can be expected on any particular intact main transverse watertight bulkhead, when that bulkhead serves as a confining boundary to flooding which the ship is expected to be capable of surviving, is Flooding Water Level I (FWL-I). For any boundary bulkhead, such as is illustrated in Figure 2-11, the trim lines are determined after accounting for the specified damage. The trim lines establish the maximum drafts to which the ship settles as a result of symmetrical, shell-to-shell flooding.

Figure 2-11 Flooding Water Levels on Bulkheads (FWL-I)
Allowances for heel due to unsymmetrical flooding, rolling and wave action are illustrated in Figure 2-12 and are applied as follows:

a. Ship is assumed to have a static heel of 15 degrees as a result of unsymmetrical flooding.

b. Ship is assumed to be rolling an angle of the magnitude given in Figure 2-13. The curve in Figure 2-13 is the source of roll angle, $\Theta_R$, to be used in determining flooding water levels depicted in Figure 2-12. The values plotted in Figure 2-13 are not the result of theoretical calculations; rather they represent reasonable roll amplitudes which ships of varying displacements are likely to exhibit in moderate seas, significant wave heights of four feet or less.

c. A water level rise of four feet is assumed to represent the wave action. For simplicity, the four feet for wave action is assumed for all ship sizes. This has the effect of imposing a relatively greater requirement on smaller ships, which is contrary to the stated philosophy that larger ships are expected to withstand greater hazards. If this
assumption imposes a significant design penalty on small ships, consideration may be given to the use of a smaller wave action, subject to NAVSEA approval.

In Figure 2-12, waterline DE corresponds to the deepest trim line on bulkhead A and includes the 15 degrees static heel, the roll angle $\Theta_R$, and the four feet of wave action. Segment HF is part of the water-line due to roll on the opposite side and 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 non-tight penetrations would be acceptable. Non-tight penetrations are limited to vent ducts without permanent closures. The periphery of the vent duct penetration is made water-tight in order to permit compartment air testing; temporary duct closures are installed during such tests.

ROLLBACK ANGLES FOR MONOHULLS AFTER DAMAGE

![Rollback Angle Graph](image)

Figure 2-13 Rollback Angle, $\Theta_R$, For Monohulls After Damage

2.5.3.2.2.2 Flooding Water on Decks

The highest water level that can be expected above the bulkhead deck at any particular intact watertight subdivision after any flooding elsewhere in the ship which the ship is expected to be capable of surviving is Flooding Water Level II (FWL-II).
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 determination of the area of non-tight penetration of 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, whereas, in the case of decks, the greatest height of water over the deck area in question may result from flooding a group of compartments which are not adjacent to the deck area of greatest height of water. This waterline becomes the basis for applying the 15 degrees initial list, roll angle $\Theta_R$, and the four feet wave action as shown in Figure 2-11. 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 ventilation duct watertight up to its intersection with the V-line. The weather deck (and bulkhead deck, if different) is otherwise watertight as discussed earlier. All accesses through the watertight bulkhead deck shall be within the V-lines. If the penetration is outside the V-lines, this opening shall be trunked such that the opening is within the V-lines.

2.5.3.3 Underwater Damage for Ships Without Side-Protective Systems

2.5.3.3.1 Provisions for Cross-Connecting

In order to reduce unsymmetrical flooding potential, symmetrical off-center voids, non-vital dry spaces, or symmetrical tanks may be connected by cross-flooding ducts. The space shall be on the high side and wholly or substantially below the waterline when the ship is floating at her damaged waterline, with a 15 degree heel for ships without side-protective systems, or with a 5 degree heel for ships with side-protective systems. The ducts are watertight and designed for the same head as the design head of the watertight bulkheads bounding the spaces.

Cross-flooding ducts are sized to provide nearly complete counter flooding of dry off-center spaces within two to five minutes. The approximate required duct cross-sectional area is determined as follows:

$$A = \frac{Q}{cVt}$$

where:

- $A$ = cross-sectional area of duct (square feet)
- $Q$ = volume of space to be flooded (cubic feet)
- $c$ = Orifice constant (0.6)
- $t$ = time (120 to 300 seconds)
- $V$ = velocity of water in duct (feet per second) or $\sqrt{2gh}$ where:
The time "t" in the formula below is preferably 120 seconds, but can be increased to 300 seconds, if necessary, to obtain a duct of reasonable size. An example of a cross-connection for double-bottom tanks is shown in Figure 2-14.

\[
\text{Duct Area} = \frac{\text{Inner Bottom Tank (P)} + \text{Inner Bottom Tank (S)}}{2}
\]

Figure 2-14 Cross Connection for Double-Bottom Tanks
2.5.3.3.2 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 to 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 aircraft carriers and large combatants, judicious spacing of the main transverse bulkheads can have a major effect on the ship's ability to survive extensive under water 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; from a practical viewpoint, improvements are generally limited to the installation of additional bulkheads. As a result, the resistance to under water damage which can be achieved in converted ships does not usually compare favorably with that achievable in new designs.

2.5.3.3.3 Loading Conditions for Damaged-Ship Stability Evaluation

The loading conditions used for damaged ship stability evaluation have been previously discussed. In all cases, the slack & empty tanks are distributed so as to result in the least favorable damaged ship stability.

2.5.3.3.4 Extent of Damage

2.5.3.3.4.1 Longitudinal Extent of Damage

The extent of flooding is a function of the length of damage to the shell, at any point along the ship's length which results from weapon at tack or collision. The criteria for length of damage is dependent upon the mission and the size of the ship. A ship of greater military importance and size is required to survive a greater extent of damage than are ships of lesser military importance.

For ships less than 300 feet long, because of practical limitations, the longitudinal extent of damage is based upon the number of compartments flooded. As previously mentioned, main transverse watertight bulkheads shall be spaced a minimum distance apart of 10 feet plus 0.03 LBP in order to be considered effective, as shown in Figure 2-15. Larger ships are required to survive a longitudinal extent of damage which is based on a percentage of ship length.
\[ \delta \geq 3m + 0.03 \times \text{LBP} \text{ (or 10.5m if less)} \]

Bulkhead 4 is considered effective for flooding to the right.

Bulkhead 5 is considered effective for flooding to the left.

Damage resulting in any flooding between bulkheads 4 & 5 is assumed to involve at least bulkhead 4 or 5.

Flooding between bulkheads 3 & 6 is considered as two compartment flooding.

Figure 2-15 Minimum Spacing of Bulkheads

Regardless of whether the longitudinal length of damage is based upon the number of compartments damaged or as a percentage of the ships’ length, flooding is assumed to extend to the next bounding bulkhead at each end of the damage. These two different methods of defining longitudinal extent of flooding are illustrated in Figure 2-16.
One Compartment Standard

Two Compartment Standard

% LBP Length of Hit

Figure 2-16 Longitudinal Extent of Damage and Flooding
2.5.3.3.4.1.1 Criteria for New Designs

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

a. Sea-going craft less than 100 feet in length shall be capable of withstanding, as a minimum, the flooding of any single main compartment.

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

c. Ships over 300 feet in length are divided into two categories:

1. Category I - Combatant Types and Personnel Carriers such as Hospital Ships and Troop Transports.

   Ships over 300 feet in length (LBP) shall withstand the following:
   (a) rapid flooding from a shell opening equal to 0.15 LBP at any point forward 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 0.15 LBP.

2. Category II - All Other Types.

   Ships with LBP > 300 feet shall be capable of withstanding the rapid flooding from a shell opening equal to 0.125 LBP.

2.5.3.3.4.1.2 Criteria for Merchant Ship Conversions

For converted merchant ships it may not always be reasonable 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. Ships intended primarily for carrying cargo such AE, AR, and AK-type ships, 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 flag- ships, 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% of LBP.

2.5.3.3.4.2 Transverse Extent of Damage

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 will result in poorer damaged-ship stability than for the penetration to centerline condition. This latter case can occur where considerable low intact buoyancy remains after flooding, as illustrated in Figure 2-17.
Figure 2-17 Transverse Extent of Damage and Flooding
2.5.3.3.4.3 Vertical Extent of Damage

It is assumed that all decks and platforms in way of the damage to the shell are ruptured because of the 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 remain intact. Damage to the inner bottom may either be favorable, because of the low flooding involved or the reduction of free surface effect in the case of damaged tankage, or unfavorable, because the unsymmetrical flooding produced out weighs the gain to additional low weight. The less favorable assumption as to the condition of the inner bottom shall be used. The above considerations are illustrated in Figure 2-18.
2.5.3.3.5 Damaged Ship Stability Curves

The righting arm curve in Figure 2-19 is a representative righting arm for a damaged ship. A reduction of righting arm equal to 0.05(\text{feet})\times\cos(\Theta) is included in righting arm to account for unknown unsymmetrical flooding and transverse shift of loose material.

The beam-wind heeling arm curve which has been calculated by the method outlined in Section 2.5.2.1.3 Wind Heeling Arms. In a damaged condition, it is assumed that the ship experiences a wind of lesser velocity than in the intact condition. The wind velocity used to develop the wind heeling arm curve is obtained from Figure 2-21. The analysis of adequate stability, thereafter is the same as in the intact 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.

2.5.3.3.6 Criteria for Adequate Damaged-Ship Stability

The criteria for adequate stability are based on a comparison of the ship's righting arm and heeling arm curves, as illustrated in Figure 2-19. The range of the righting arm curve terminates at the angle of unrestricted down-flooding or 45 degrees, whichever occurs first.
The following criteria shall be satisfied:

a. Damaged ship stability is satisfactory if the initial angle of heel after damage, (Point D, Figure 2-19), does not exceed 15 degrees.

\[ \Theta_{\text{STATIC}} \leq 15 \text{ degrees} \]

b. 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. The reserve of dynamic stability (area A1) shall not be less than 1.40 times the energy imparted to the ship by rough seas and beam winds (Area A2). The \( \Theta_r \) value used in the calculation shall be based on experience and model testing, or from Figure 2-13.

\[ 1.40 \times A2 \leq A1 \quad \text{or} \quad A1 / A2 \geq 1.40 \]

c. The area A1 is not less than the amount determined from Figure 2-20.

d. The value of the maximum righting arm minus the value of the wind heeling arm at the same angle of heel shall be greater than 0.25 feet.

\[ 0.25 \text{ feet} \leq R_{\text{MAX}} - HA \]

e. After damage, the trim and heel angles at the equilibrium position shall not submerge the margin line.
### DAMAGED STABILITY

**REQUIRED A1 AREA**

<table>
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<th>Displacement (Long Tons / 1000)</th>
<th>Constant at 1.8 above 60,000 Long Tons</th>
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**Figure 2-20 Required Area for Damaged Ship Stability**

### Wind Velocities versus Intact Displacement

<table>
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<th>Extends to 65 Kts at 80,000 Long Tons</th>
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<td>70</td>
<td>Extends to 65 Kts at 80,000 Long Tons</td>
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</tbody>
</table>

**Figure 2-21 Wind Velocities versus Intact Displacement**
2.5.3.4 Underwater Damage for Ships With Side-Protective Systems

2.5.3.4.1 Effects of Damage

The outstanding feature of ships with side-protective systems is the inherent possibility of unsymmetrical flooding due to flooding the void and liquid layers. This flooding, being a considerable distance from the centerline of the ship, produces a large heeling moment which causes the ship to list and diminishes reserve dynamic stability characteristics. Counter flooding of similar voids on the opposite side of the ship can decrease 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 make it necessary to abandon the ship long before there is any danger of foundering or capsizing. A large angle of heel will 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 rapidly counter flooding to decrease or eliminate this list.

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 effects of flooding and counter flooding. The ideal design is one in which the list can be held to a moderate value up to the point where the reserve buoyancy is expended. Evaluating the effect of extensive underwater damage, includes investigating a number of variables such as the location of hits, the size of charge, and the condition of the ship at the time of damage (stability, liquid loading, freeboard, etc.)

2.5.3.4.2 Loading Conditions

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.

2.5.3.4.3 Extent of Damage

Information on the effectiveness of side-protective systems against explosive damage is of a classified nature and, therefore, cannot be discussed herein. 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 their inherently large initial stability and reserve buoyancy, aircraft carriers and large combatants can withstand multiple explosive hits. The stability and buoyancy criteria for ships with side-protective systems assume multiple hits on one side for the case where the holding bulkhead is not pierced and also for the case where the holding bulkhead is ruptured.
2.5.3.4.4 Heel After Damage

Equipment and machinery in ships of the U.S. Navy is designed and installed to operate continuously, without incurring damage or excessive wear, with a permanent list of up to 15 degrees. Under emergency conditions, when considering the survivability of the ship, it can be assumed that equipment would continue to function for a short time at heel angles greater than 15 degrees. In the event that all equipment should cease to function as a result of structural damage or flooding, the ship could be towed to a safe area with a list of up to 20 degrees. War-damage reports record cases where a list of 20 degrees or more did not prevent damage-control efforts and salvage of ships. For purposes of establishing a criterion for survival, the acceptable upper limit of list is considered to be 20 degrees; this criterion applies to design investigations. For operational purposes, a heel angle of 20 degrees is considered to be too large; therefore, the ship must have a means for quickly correcting the heel 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 that of counter flooding from the sea. For design purposes a ship with a side-protective system is considered to be satisfactory with respect to heel after damage from multiple hits if:

a. Heel angle does not exceed 20 degrees as a result of flooding caused by:
   1. Hits on one side which fail to penetrate the holding bulkhead.
   2. Hits which penetrate the holding bulkhead

b. Arrangements exist for rapidly correcting list which results from the damage outlined above, to less that 5 degrees.

2.5.3.4.5 Damaged Ship Stability Curves

Righting arm curves for damaged ships are prepared to represent the foregoing cases of flooding before and after counter flooding. As previously mentioned, aircraft carriers have large reserve buoyancy, so that the angle of heel rather than the range of the damaged-ship stability will govern; however, by inspection or actual calculations, the damaged-ship stability is examined to establish that there exists a sufficient reserve of dynamic stability to withstand wind and rolling action. In damaged condition it is assumed that the ship experiences a wind of less velocity than in the intact condition (Figure 2-21). 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.
2.5.3.4.6 Criteria for Adequate Damaged Ship Stability

**DAMAGED STABILITY**
**BEAM WINDS COMBINED WITH ROLLING**

The following criteria shall be satisfied:

a. The initial heel angle resulting from damage on one side shall not exceed 20 degrees, provided that the ship has the capability for rapidly reducing the initial heel angle to less than 5 degrees via tankage.

b. After damage, the trim and heel angles in the equilibrium position shall not submerge the margin line.

c. Damaged-ship stability is satisfactory if the initial angle of heel after damage (Point D in Figure 2-22), does not exceed 15 degrees.

d. The dynamic stability available shall be able to absorb the energy imparted to the ship by moderately rough seas in combination with beam
winds. Again referring to Figure 2-22, angle $i$ is 45 degrees or the angle at which unrestricted flooding into the ship will occur, whichever is less. The angle $\Theta_R$ is the expected angle to roll into the wind from Point D for the assumed wind and sea state. Subject to later verification by experience and model testing, the $\Theta_R$ value used in the calculation shall be obtained from Figure 2-13. In order to insure adequate dynamic stability, the reserve dynamic stability (area $A_1$), shall not be less than 1.40 times the energy imparted to the ship by rough seas and beam winds.

\[ 1.4 \times A_2 \leq A_1 \quad \text{or} \quad A_1 / A_2 \geq 1.40 \]

e. The area $A_1$ is not less than the amount determined from Figure 2-20.

f. The value of the maximum righting arm minus the wind heeling arm, value at the same angle of heel, shall be greater than 0.25 feet.

\[ 0.25 \leq R_{\text{MAX}} - H_A \]

2.5.3.4.7 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 usually not governing and therefore does not establish the limiting drafts for these types.
3. ADVANCED MARINE VEHICLES ON WATERBORNE DISPLACEMENT MODE

3.1 INTRODUCTION

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 ships (SWATH). Typical cross sections of these advanced marine vehicles are depicted in Figure 3-1. Catamaran ships, which are not normally considered as "advanced marine vehicles" are also included in this category because the stability and buoyancy analysis for this type are similar to that for SES type of vehicle.

3.2 DESIGN PHILOSOPHY

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 baseline criteria, only. If a new design can not meet the stability criteria, the criteria as well as the ship design may need to be re-evaluated. The criteria described herein attempt to anticipate the desired stability and buoyancy standards for high performance vehicles. New design requirements will be specified if acceptable departures from these standards are indicated on the basis of further operational experience.

The stability and buoyancy standards presented here apply only to the case where the craft or ship is in a hull-borne displacement mode. Thus for the "flying" types such as hydrofoils, air cushion vehicles and surface effects types, the concern herein 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 hull-borne 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 examples of the conditions under which adequate stability and buoyancy in the displacement mode must be provided.

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 "equivalent" monohull ships. Since length/ beam or length/ displacement ratios of high-performance types are significantly different from conventional monohulls, "equivalent"
ships are determined more on the basis of displacement and mission capabilities than length; such determinations are made on a case basis.

Figure 3-1 Advanced Marine Vehicles
3.3 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 are provided:

a. 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 which may define a worse stability condition, compared to the Full Load or Minimum Operating Conditions, should be investigated. Temporary loading conditions such as a refueling condition, may exist where the stability of the ship is not sufficient to withstand all of the hazards. These temporary load conditions should be avoided if there is knowledge of a possible hazard, i.e., an approaching storm with high winds and seas.

b. Loads in the Full Load Condition should correspond to the full allowances for departure. Variable loads in the Minimum Operating Condition should be assumed to be at one-third of the full load value, except in the case of large ships with high capacity distillers, where water load may be assumed to be at two-thirds of the full load value.

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

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

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

3.4.1 General

The hazards to which high performance vehicles may be subjected are all those which apply to conventional ships and, in addition, some which are peculiar to Advanced Marine Vehicles.

3.4.2 Intact Ship

The intact ship may experience the following hazards:

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

3.4.3 Damaged Ship

The ship may have underwater damage from:

a. Stranding.
b. Collision.
c. Enemy explosive action.

3.4.4 Flooded Ship

The flooded ship may experience the following hazards:

a. Beam winds combined with rolling.
b. Progressive flooding.
c. Shifting of cargo.

3.4.5 Hazards To High Performance Ships

Examples of problems resulting from the inherent design characteristics of high performance ships are:

a. Low freeboard with the hazard of shipping and trapping sea water.
b. Large center of gravity shift due to extension or retraction of foils.
c. Limited number of watertight bulkheads (due to weight considerations).
d. Thin shell structure, which is susceptible to relatively large shell openings from impact with debris at high speeds or from collisions.
e. Potential for large unsymmetrical flooding for SWATH and catamaran types.
3.5 DESIGN STANDARDS FOR ADVANCED VEHICLES

3.5.1 General

The stability and buoyancy criteria are intended to provide the high performance craft and ships with capabilities to withstand hazards to which they maybe exposed. The criteria reflect the design philosophy and the design practices 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 design as well as to private designers.

3.5.2 Intact Ship Stability Criteria

The intact-ship criteria applicable to high performance vehicles are as follows:

3.5.2.1 Beam winds Combined with Rolling

3.5.2.1.1 General

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 on the best data available for previous ships of the same or similar type.

3.5.2.1.2 Wind Heeling Arm

The discussion in Section 2 on wind heel calculations and velocity gradients (Section 2-15) as a function of the height above waterline also applies to high performance vehicles.

For ships with large beam such the SWATH and other platform types, the projected sail area increases with angle of heel, and this function should be considered. Even with the increased sail area, no problem with regard to beam winds combined with rolling is expected for such vehicles because of the very large righting arms vehicles which are typical.

For hydrofoils, the capability to withstand the appropriate beam wind (see Table 2-5) shall be provided with the foils extended and also with the foils retracted.
3.5.2.1.3 Criteria for Adequate Stability

When the heeling arm due to wind heel is superimposed on the plot of the ship's righting arm, as shown on Figure 3-2, and when an assumption is made for the rollback angle, $\Theta_R$, the following criteria shall be satisfied:

a. The heeling arm at the intersection of the heeling arm and righting arm curves, $\Theta$ equilibrium or Point C, shall not exceed six-tenths of the maximum righting arm.

$$H_{AEQUIL} \leq 0.6 \times R_{AMAX} \quad \text{or} \quad \frac{H_{AEQUIL}}{R_{AMAX}} \leq 0.6$$
b. Area $A_1$ is not less than $1.4 \times A_2$, where $A_2$ extends $\Theta_R$ degrees to windward from Point C. $\Theta_R$ is the roll angle associated with fully arisen seas associated with the required sea state specified in the vehicle's characteristics.

$$1.4 \times A_2 \leq A_1 \quad \text{or} \quad A_1 / A_2 \geq 1.40$$

As noted earlier, $\Theta_R$ should be determined by model tests or from the best data available from earlier ships of this type. 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 degrees for $\Theta_R$ is more typical than the 25 degrees used in for conventional ships (see Section 2.5).

3.5.2.2 Lifting of Heavy Weights Over the Side

3.5.2.2.1 Effect of Lifting Heavy Weights

The criteria for adequate stability when lifting weights are based on the angle of heel and on the relationship between the righting arm and heeling arm curves, as illustrated in Figure 3-2.

3.5.2.2.2 Criteria for Adequate Stability

The following criteria shall be satisfied:

a. The angle of heel, as indicated by point C, shall not exceed 15 degrees.

$$\Phi_{EQUIL} \leq 15 \text{ degrees}$$

b. The heeling arm at the intersection of the righting arm and the heeling arm curves, $\Theta$ equilibrium or Point C, shall not be more than six-tenths of the maximum righting arm.

$$H_{A\text{EQUIL}} \leq 0.6 \times R_{\text{A\text{MAX}}} \quad \text{or} \quad H_{A\text{EQUIL}} / R_{\text{A\text{MAX}}} \leq 0.6$$

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

$$0.4 \times A_0 \leq A_1 \quad \text{or} \quad A_1 / A_0 \geq 0.4$$

3.5.2.3 Towline Pull

It is unlikely that high-performance vehicles will be used for towing. In the event that such a design requirement arises, the heeling arm formula for tow line pull given in Section 2.5.2.3 needs to be adapted to reflect the characteristics of the high-performance propulsion configuration in the displacement mode. No specific
methodology is presented here. Guidance will be provided by NAVSEA to the designer, if necessary, on a case basis.

3.5.2.4 Crowding of Personnel to One Side

3.5.2.4.1 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. 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 two square feet of deck space.

3.5.2.4.2 Criteria for Adequate Stability

The criteria for adequate stability are based on the angle of heel, and on the relationship between the ship’s righting arm and the heeling arm curve, as illustrated in Figure 3-2. The following criteria shall be satisfied:

a. The angle of heel, as indicated by point C shall not exceed 15 degrees.

\[ \Theta_{\text{EQUIL}} \leq 15 \text{ degrees} \]

b. The heeling arm at the intersection of the righting arm and heeling arm curves, \( \Theta_{\text{equilibrium}} \) or Point C, shall not be more than six-tenths of the maximum righting arm,

\[ H_{\text{A\ EQUIL}} \leq 0.6 \times R_{\text{MAX}} \quad \text{or} \quad H_{\text{A\ EQUIL}} / R_{\text{MAX}} \leq 0.6 \]

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

\[ 0.4 \times A_0 \leq A_1 \quad \text{or} \quad A_1 / A_0 \geq 0.4 \]

3.5.2.5 High-Speed Turns

3.5.2.5.1 General

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 arm at small angles (a metacentric height (GM) increases in 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.
3.5.2.5.2 Criteria for Adequate Stability

The criteria for adequate stability in high-speed turns are based on the steady angle of heel and on the relationship between the righting arm curve and the heeling arm curve, as illustrated in Figure 3-2. The following criteria shall be satisfied:

a. The angle of steady heel, as indicated by point C, shall not exceed 15 degrees.

\[ \theta_{\text{EQUIL}} \leq 15 \text{ degrees} \]

b. The heeling arm at the intersection of the righting arm and heeling arm curves, \( \theta \) equilibrium or Point C, shall not be more than six-tenths of the maximum righting arm.

\[ H_{\text{EQUIL}} \leq 0.6 \times R_{\text{MAX}} \quad \text{or} \quad H_{\text{EQUIL}} / R_{\text{MAX}} \leq 0.6 \]

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

\[ 0.4 \times A_0 \leq A_1 \quad \text{or} \quad A_1 / A_0 \geq 0.4 \]

3.5.2.6 Topside Icing

Unless specific operation in potential ice areas is specified in the characteristics for a new design, the amount of topside icing which a ship may accumulate and still have satisfactory stability in intact conditions is determined after the design characteristics have been fixed. As noted in Part II, the design approach to the determination of the effects of topside icing, is to define the maximum allowable beam winds which will be combined with icing for a ship whose stability characteristics have been established from other governing criteria. The design shall be considered to be satisfactory if the allowable wind at time of icing is 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 of ice on horizontal and vertical surface on the weather deck and above and the other assumes six inches. For these weights of ice, the beam wind velocities which the ship will still satisfy the criteria for "beam winds combined with rolling" are determined. The approximate specific volume for accumulated ice may be taken as 39.5 cubic feet per ton.
3.5.3 Damaged-Ship Stability

3.5.3.1 Reserve Buoyancy Requirements

3.5.3.1.1 Limiting Drafts

Limiting drafts are established for high performance vehicles for the same reasons as for conventional ships namely:

a. To provide sufficient reserve buoyancy so that the margin line will not be submerged after the ship sustains a specified amount of flooding. Limiting drafts assigned on this basis are called subdivision-limiting drafts.

b. To permit the ship to achieve the specified hull borne or "flying" mode speeds.

c. To avoid overloading which would cause strength limits to be exceeded.

The assigned limiting drafts shall be based on whichever of the above considerations governs. For high performance vehicles, considerations a. and b. will usually govern.

For the high performance ships with a catamaran hull form, damaged-ship stability calculations shall be used to determine limiting drafts rather than the floodable length and trim line calculations (applicable to shell-to-shell flooding) for conventional monohull types. A criterion for determination of the limiting draft for catamaran ships is that the margin line shall not be submerged below the static heeled/trimmed waterline, which result from the worst-case damaged-ship condition.

Limiting drafts for hydrofoil ships which have conventional monohull forms are normally to be determined by floodable length and trim line calculations for the case of shell-to-shell flooding. When unsymmetrical flooding is possible, this case shall be investigated to determine whether or not limiting drafts should be established on this basis.

3.5.3.1.2 Flooding Water Levels

Flooding water levels shall be determined in a manner similar to that described in Part II, in order to determine the watertightness and closure requirements for penetrations through watertight bulkheads and decks. The objective of watertight penetrations and closure devices is to prevent flooding into otherwise undamaged compartments when the ship has sustained underwater flooding in the amount specified for the type.
3.5.3.2 Extent of Damage

3.5.3.2.1 General

The extent of damage which a high performance vessel shall withstand without violating any of the stability criteria shall be decided on a case basis. The longitudinal extent of damage will be defined according to ship type and vessel length, since configurations vary widely among the high performance ship types. The assumed vertical extent of damage shall be such as to cause the rupture of all watertight decks, for all cases.

3.5.3.2.2 Hydrofoil Ships

As the hull forms of hydrofoil ships generally resemble conventional hulls, the extent of damage specified for conventional ships shall be used.

3.5.3.2.3 Surface Effect (Skirted and Rigid-Sidewall) Vehicle/Ships (SES)

3.5.3.2.3.1 Small SESs

Description

To date, the construction of small surface effect vehicles has generally consisted of a honeycomb like network of small compartments; therefore, imposing a one or two compartment longitudinal extent of damage cannot reasonably apply to a surface effect vehicle with this type of construction. Further, lightweight shell construction promotes the possibility of sustaining rip damage unfortunately, the specified extent of damage shall occur be assumed to occur where it results in the worst case for stability.

Extent of Damage

The following extent of damage which results in the worst stability shall be used:

a. Longitudinal damage consisting of shell openings of 10 percent of the flotation box length, or an eight foot shell opening, whichever is greater, combined with transverse damage to the center line, as illustrated in Figure 3-3(a).

b. Longitudinal damage consisting of shell openings of 15 percent of the flotation box length, or an eight foot shell opening, whichever is greater, combined with the transverse damage extending to, but not including, longitudinal bulkheads which located more than 20 percent of the beam inboard from the shell at the maximum beam of the hard structure, as illustrated in Figure 3-3(b).
Length of Hit
10% LFB or 8 Feet

Figure 3a - Extent of Damage  Condition 1

20% Beam
Length of Hit
15% LFB

Figure 3b - Extent of Damage  Condition 2

Figure 3-3 Small Air Cushion Vehicles - Extent of Damage
3.5.3.2.3.2 Large SESs

General

High performance ships which range in length from 225 feet to 470 feet and feature beams in the 100 foot range have been studied; the displacements of such ships have varied from 2,200 tons to 4,400 tons. The appropriate length of damage for large surface effect ships established by determining an equivalent conventional ship and then using the same criteria as for the conventional counterparts. The difficulty arises in making the selection of an equivalent conventional ship. Length is not a suitable measure of equivalency since SES because of their great beam, are relatively short. Displacement may be a better basis for comparison, although the relatively few SES types considered to date do not conclusively validate this approach. Perhaps the stated mission, especially considering manning level and endurance, can be used to establish the equivalent conventional ship. A plot of "sustainable" length-of-damage vs. displacement, for major ship types, is shown in Figure 3-4; the data can, perhaps, be used to determine length of damage for large SES.

![Figure 3-4 Required Sustainable Length of Damage for Ship Missions](image)

### Required Sustainable Length of Damage

- **Combatant @ 15%**
- **Amphibious Warfare @ 15%**
- **Auxiliary @ 12.5%**

Displacement (Long Tons / 1000)
Extent of Damage

For large surface effect ships, the worst of the following cases of damage shall be assumed:

a. A shell opening equal in length to 15 percent of the design waterline length (including seals) or the length-of-damage for the equivalent conventional ship, whichever is greater, and extending transversely to the centerline, as illustrated in Figure 3-5(a).

b. A shell opening equal to 50 percent of the design waterline length (including seals), and extending transversely to the first longitudinal bulkhead inboard of the shell, as illustrated in Figure 3-5(b). For this case, the transverse penetration shall be no less than 10 percent of the beam.

For surface effect ships with a length of approximately 200 feet, the ability to sustain a 0.15 LWL shell opening will generally result in at least a two-compartment damage, and, as such, is comparable to the two-compartment flooding requirement for conventional ships of 100 to 300 feet. Surface effect ships larger than 300 feet will, in general, be required to sustain shell opening length equal to that required for the equivalent conventional ship with a length greater than 300 feet.
Figure 5a - Extent of Damage: Condition 1

15% DWL Length of Damage

Figure 5b - Extent of Damage: Condition 2

50% DWL Longitudinal Length of Damage
Penetration to 1st Transverse Bulkhead

50% DWL Length Damage

Figure 3-5 Large Air Cushion Vehicles - Extent of Damage
3.5.3.2.4 Small-Waterplane Area Twin Hull (SWATH) Ships and "Conventional" Catamaran Ships

3.5.3.2.4.1 Description

SWATH ships are characterized by a catamaran form consisting of completely submerged cylindrical hulls which support narrow vertical struts with relatively small waterplane area. A large platform sits on the port and starboard struts; the bottom of the platform is set at a predetermined height above the waterline, based on the ship's operational sea state requirements. Various experimental studies have been investigated with ship lengths varying from 90 feet to 500 feet and ship beams varying from 50 feet to 200 feet. Corresponding displacements range "conventional" catamarans from 200 tons to 40,000 tons.

3.5.3.2.4.2 Design Considerations

The SWATH ship has considerable reserve buoyancy and stability-potential in the platforms. However, the small waterplane area of the struts, in conjunction with the off-center flooding from damage on one side, results in large angles of heel and trim, as illustrated in Figure 3-6. The large heel and trim angles are in themselves a hazard, causing mission-related operations difficulties and difficulties with respect to ship control, damage control, the sense of security of the crew, and towing (if necessary) of the damaged ship.

Figure 3-6 SWATH - Extent of Damage
3.5.3.2.4.3 Approach to Provision of Adequate Stability

SWATH

The approach to selection of extent of damage for SWATH ships is to identify an equivalent conventional monohull ship and to provide the SWATH with the same capability to withstand underwater flooding as the equivalent conventional ship. The selection of an equivalent ship shall be based on the considerations presented in Section 3.5.

Catamaran

These ships should be treated in the same manner as large surface effect ships; the considerations are listed in Section 3.5.
3.5.3.3 Damaged-Ship Stability For High-Performance Ships

DAMAGED STABILITY
BEAM WINDS COMBINED WITH ROLLING

Righting Arm Curve
Heeling Arm Curve

Point D
Point C
A2
A1

Righting Arm Maximum
RAmax - HA

Figure 3-7 Damaged Ship - Righting Arm and Heeling Arm

3.5.3.3.1 General

The angle of heel after damage and the reserve of dynamic stability shall be considered in evaluating the adequacy of damaged-ship stability.

3.5.3.3.2 Angle of Heel After Damage

Referring to Figure 3-7, the damaged-ship righting arm curve is for the ship with damage specified for the type. It includes trim effects and represents the ship in its poorest stability condition. Damaged-ship stability is considered to be satisfactory if the initial angle of heel, Point D, does not exceed 15 degrees (except for SWATH ships where Point D shall not exceed 20 degrees, as noted below). The combined static heeled/trimmed water line corresponding to Point D shall not submerge the bulkhead deck.
3.5.3.3.3 Dynamic Stability Associated with Wind Heel Combined with Rolling

The reserve of dynamic stability available to absorb the energy imparted to the ship by moderately rough seas in combination with beam winds is a measure of the adequacy of stability after damage. The heeling arm curve for the beam wind is specified in the ship's operational requirements or determined from Figure 3-8. The angle $\Phi$ is 45 degrees, or the angle at which unrestricted flooding into the ship would occur, whichever is less. The righting arm curve is assumed to terminate at angle $\Phi$.

The expected angle of roll, $\Theta_R$ into the wind from Point C is determined for the assumed wind and sea state. There is little information on the rolling characteristics of some of the high performance types after shell damage. Subject to later verification by experience and model testing, $\Theta_R$ shall be taken as indicated below in the sections on specific criteria for each type of high performance ship. The adequacy of required dynamic stability is measured by comparing areas A1 and A2.

In cases where the damaged-ship righting arms are small, such as for hydrofoils, a minimum acceptable righting arm value shall be specified.

![Wind Velocities versus Intact Displacement](figure3-8.png)
3.5.3.3.4 Criteria for Damaged Ship Stability

Since the high performance ship hull forms differ considerably, the criteria for each of the several general categories are specified below:

3.5.3.3.4.1 Hydrofoils

The worst configuration of the ship with foils extended or retracted shall satisfy the criteria. Otherwise the hydrofoil behaves as a conventional hull type.

Referring to Figure 3-7, 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 by the ship's operational requirements.

b. Initial heel angle (Point D) $\leq 15$ degrees.

c. The reserve dynamic stability, $A_1$ shall not be less than $1.4$ times the energy imparted to the ship by rough seas and beam wind

$$1.4 \times A_2 \leq A_1 \quad \text{or} \quad A_1 / A_2 \geq 1.4$$

d. At the maximum value of the righting arm, the difference between the righting arm and the heeling arm at that same angle of heel, must be greater than $0.3$ feet

$$0.3 \leq R_{A_{\text{MAX}}} - H_A$$

e. The final heeled/trimmed static waterline shall not submerge the bulkhead deck.

3.5.3.3.4.2 Small Air Cushion Vehicles (ACV)

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 operational requirements. Typical roll angles were about 15 degrees. These vessels have large initial stability and a low range of stability due to the small freeboard to the bulkhead deck. This results in a righting arm curve, after damage, which is steep but has 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 3-7) which has to be absorbed by area $A_1$. In view of the large roll damping characteristics exhibited by this type of ships, an allowance must be made for the energy dissipated due to damping as the craft returns from the roll into the wind; a required ratio of 1.0 has been selected for $A_1/A_2$. This is considered to be equivalent to a required value of 1.4 for conventional monohull forms with small damping characteristics.

Referring to Figure 3-7, 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 operational requirements.

b. Initial heel angle (Point D) $\leq 15$ degrees.

c. $A_2 \leq A_1$.

d. At the maximum value of the righting arm, the difference between the righting arm and the heeling arm at the same angle of heel shall be greater than 0.3 feet

$$0.3 \leq R_{\text{AMAX}} - H_A$$

e. The final static heeled/trimmed waterline shall not submerge the bulkhead deck.

3.5.3.3.4.3 Large Surface Effect Ships (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 3-7, the following must be satisfied:

a. $\theta_R = 15$ degrees or the angle determined form roll test of the undamaged hull in the sea states specified in the ship’s operational requirements.

b. Initial angle of heel (Point D) $\leq 15$ degrees.

c. $A_2 \leq A_1$.

d. At the maximum value of the righting arm, the difference between the righting and the heeling arm at the same angle of heel shall be greater than 0.3 feet.

$$0.3 \leq R_{\text{AMAX}} - H_A$$

e. Final static heeled/trimmed waterline shall not submerge the bulkhead deck.
3.5.3.3.4.4 SWATH Ships

The criteria for adequate stability after damage for SWATH ships are based on the same analysis as for the large ACV. As noted earlier, SWATH ships have considerable reserve buoyancy and stability but are subject to large initial heel and trim angles resulting from flooding on one side. The governing criteria for SWATH ships will generally be the limit on the initial angle of heel, the static heel angle after counter flooding, 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 could cause premature abandonment of SWATH ship. The static heel angle after counter flooding is based on the mission of the SWATH ship. High roll damping is assumed for SWATH hull forms.

Referring to Figure 3-7, 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 operational requirements.

b. Initial angle of heel (Point D) $\leq 20$ degrees.

c. Static heel angle after counter flooding of less than 5 degrees for an aircraft carrier mission and less than 15 degrees for a non-aircraft carrier mission.

d. $A2 \leq A1$.

e. At the maximum value of the righting arm, the difference between the righting arm and the heeling arm at the same angle of heel shall be greater than 0.3 feet

$$0.3 \leq R_{\text{MAX}} - HA$$

3.5.3.3.4.5 Catamaran Ships

This type is included in Part III rather than in Part II because of its similarity to the large surface effect ships in a displacement mode. The catamaran ships therefore treated in a manner similar to the large surface effect ships.