SECTION 5

Jim Yagle

Stability

Jim Yagle graduated from the University of Michigan in 1988 with a B.S.E. degree in Naval Architecture and Marine Engineering. He worked for Elliott Bay Design Group for 9 years as a naval architect and is now with Delta Marine Industries. Mr. Yagle's area of expertise is vessel stability. He has performed inclining experiments and stability analyses on a variety of vessels including the 76' oceanographic vessel for the University of Connecticut, a 100' fisheries vessel for the National Biological Service, and fishing boats from 70' longliners to 270' factory trawlers.

The stability of a vessel refers to its ability to float upright and is governed primarily by the two major forces exerted on any floating object: buoyancy and weight. As long as the buoyancy is greater than the weight, the vessel will float. How well it floats, i.e. how resistant it is to tipping over (its stability), is dictated by where these two basic forces act on the vessel.

Buoyancy

The buoyancy of a vessel is determined by the shape of the immersed hull form. The larger the hull, the more weight it can support. Stability, however, is dictated by the distribution of that hull volume. For example, beam has a much larger impact on stability than length. As a general rule, the wider the vessel, the more stable it is. A deeper hull will also be more stable than a shallow one. The center of buoyancy is the point at which all the vectors of the floating forces of the vessel can be said to act vertically upward.

The designer usually has a great deal of control of a vessel's stability characteristics while it is still being designed. Good practice includes designing a stability margin into the hull before the vessel is built. Unfortunately, features that make a vessel more stable are often in direct conflict with the other aspects of the design. While it may be tempting to simply enlarge the beam to increase stability, this will also increase construction cost as well as increase the propulsion resistance of the hull. Increased resistance in turn drives up fuel consumption and operating costs over the life of the vessel. As with all good designs, a balance between the design criteria and operational requirements must be reached.

Weight

The hull, machinery, outfitting, and cargo load determine vessel weight. As vessel cargo load is increased, the hull will settle deeper in the water until the buoyancy equals the weight. While this may intuitively seem to increase stability, adequate freeboard is also essential. Freeboard is the distance between the water and the working deck of the vessel. If the deck edge goes under water when the vessel heels, the danger of capsizing is increased. An overloaded vessel will have too low a freeboard, and the deck may submerge with even a light heel.

Equally important to the overall weight of the loaded vessel is how that weight is distributed. The center of gravity is the point at which the vector of the whole weight of the vessel can be said to act vertically downward. As a general rule, a lower center of gravity means a more stable vessel. A vessel with a high center of gravity is said to be "top heavy." When a vessel lists or heels to one side, the center of gravity pushes down in the direction of the list.

The designer also has a great deal of control of a vessel's weight characteristics during the design phase. A detailed weight estimate is an essential part of any design package. The equipment selection and arrangements must be constantly monitored to ensure that the vessel stays close to its target weight and center of gravity. Margins on weight and center of gravity should also be included in the calculations to account for the inevitable overlooked objects or estimating errors.

Unlike the buoyant volume of the hull, the vessel weight and center of gravity change constantly as vessel loading changes. For example, a heavy object placed high on a deck will produce a higher center of gravity - and less stability - than a load stored below deck. Similarly, removing a load from low in the vessel, such as burning fuel oil, will cause an increase in the vessel's center of gravity, thus reducing stability.

Additionally, vessels gain weight over their lifetimes as equipment is added or other changes are made to the arrangements. A good design will allow for some weight growth, but careful attention must be paid to modifications to the vessel to ensure that it continues to meet the applicable stability requirements.

Stability

Stability is one of the more quantitative aspects of how a floating object behaves in water. There are a number of calculated values that together determine the stability of a vessel.

Initial stability concerns a vessel's initial resistance to being pushed over. The GM, or metacentric height, is the term used to measure initial stability. GM is measured in meters or feet; a larger value indicates greater stability. A "stiff boat" has a higher GM than a "slow roller." Too little GM results in a vessel with a long, slow roll that, while comfortable, could lead to capsizing. Excessive GM, however, results in a vessel with uncomfortable, snappy, motions in heavy seas that contributes to seasickness and can actually damage equipment as it "whips" the vessel upright after being pushed over by a wave.

Righting energy is the term used to describe a vessel's ability to right itself after being heeled over. As the vessel heels, the vertical vector of the center of buoyancy moves away from that of the center of gravity. The distance between vectors, called the righting arm or GZ, varies as the vessel heels and is measured in meters or feet. Typically, righting arms are plotted on the vertical axis of a graph with the heel angle on the horizontal axis. The area under the curve so generated represents the amount of righting energy. A properly-loaded vessel should have positive righting energy to a heel of at least 50 degrees. The magnitude of the largest righting arm is also an indication of a vessel's stability.

Because of the relationship between weight and buoyancy of a given hull shape, both GM and righting energy vary significantly with the weight and center of gravity of the loaded vessel. This means that how a vessel is loaded has the largest impact on the stability of the vessel.

The previous paragraphs have discussed vessel stability characteristics in the intact state. They also apply to a damaged vessel. However, the buoyant force and center of buoyancy of the damaged hull will differ significantly from that of the intact hull, depending on hull compartmentation as well as the location and extent of damage.

Stability Regulations

A variety of stability criteria have been developed to answer the question "how much stability is enough?" Which criteria apply depends upon the regulatory environment of the vessel - there are different criteria for passenger vessels, tugs, barges, and tankers, to name a few. Research vessels also have their own regulations. The applicable stability criteria are also dependent on the vessel size and location of operations. It is common for a vessel to have to meet separate criteria for rough seas, high winds, towing a trawl or other submerged object, and for crane lifting operations.

Effects of Operations on Stability

Many of the daily operations of a vessel have significant impacts on its stability.

An area of particular concern in operations is the free surface effect. When a vessel with full tanks heels over, the contents of the tank do not shift. The tank's center of gravity does not change, so it does not affect the vessel's stability. In a partially filled tank or fish hold, the contents will shift with the movement of the boat. The center of gravity moves over to the side, making the vessel less stable. This "free surface effect" reduces stability and increases the danger of capsizing. Good initial vessel design can minimize this effect by avoiding large, wide tanks. Good operational practice can minimize this effect by keeping the number of slack tanks and holds to an absolute minimum.

Loading and unloading operations have a dramatic effect on stability. For example, when a heavy load is lifted clear of the water it has the same effect on the vessel's center of gravity as if the weight were located at the tip of the boom. The vessel will also heel. Good design and operational guidance should include crane or boom load limits.

Heavy icing due to weather will also seriously affect stability by adding weight high on the vessel superstructure and masts. In severe conditions, it is very dangerous and it may be necessary to either remove the ice or head downwind to reduce the accumulation.

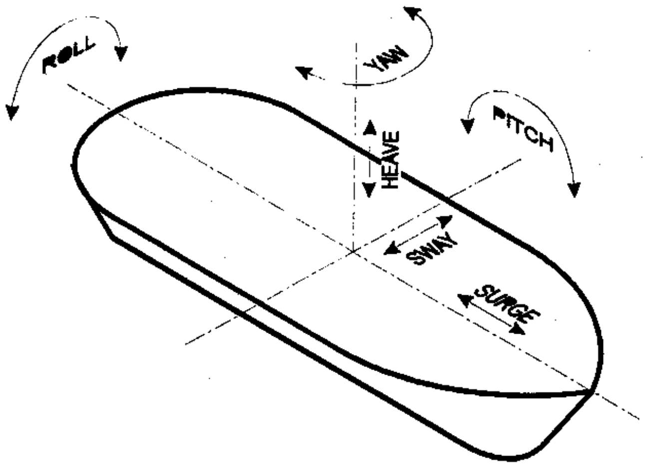
Stability Guidance

Proper operational guidance to the Master is critical to ensure the vessel maintains adequate stability. This guidance can take several forms. A Stability Letter listing the basic operational limits and guidance in a few pages is common for smaller vessels and is typically posted in the wheelhouse. A Trim and Stability Booklet contains more detailed instructions and includes forms for the Master to actually calculate the weight and center of gravity of the vessel. Curves of the maximum allowable center of gravity are then used to determine if the loaded condition meets the required criteria.

Conclusions

Proper application of both weight and buoyancy margins throughout the design phase, coupled with close monitoring of weight growth once the vessel is in operation, will help a vessel maintain adequate stability throughout its life. Ensuring adequate stability in a vessel is a combination of many factors including recognizing the loading limits of a given hull form and operating within those limits at all times. Stability considerations must always take precedence over operational requirements to ensure the safety of the crew and passengers and to prevent the loss of the vessel and cargo.

Figure 1.



Vessel Motions

Figure 2.

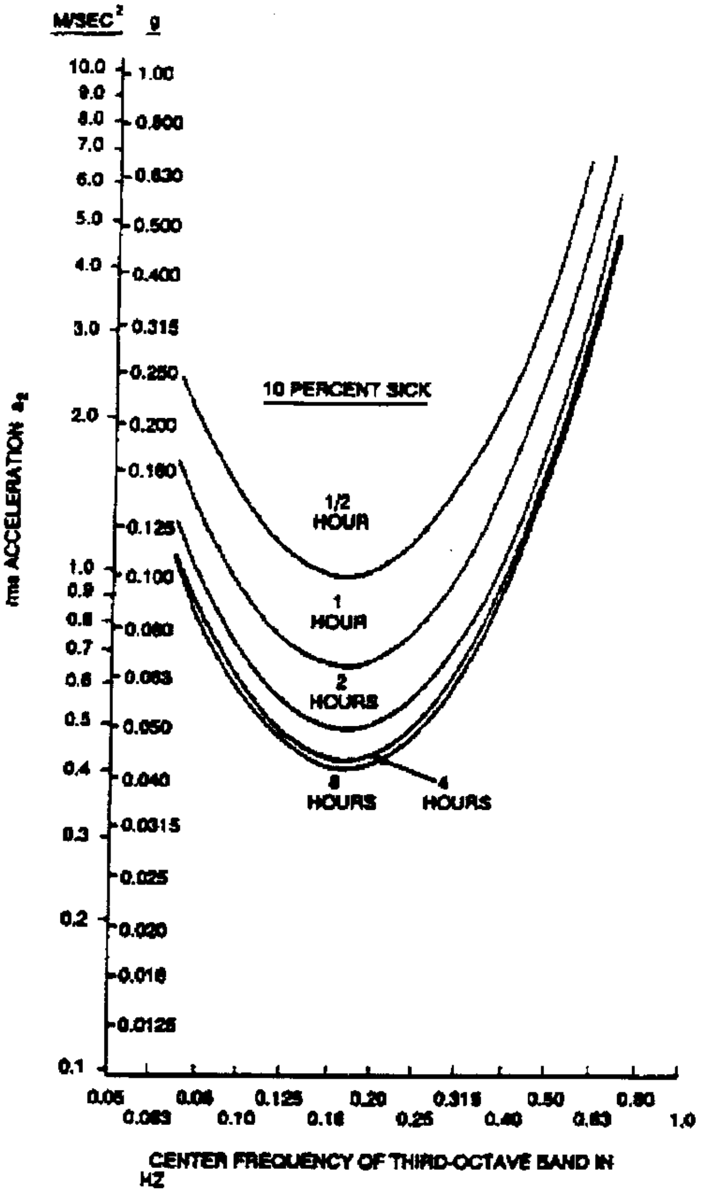


FIG. 98 **The 90 % Motion Sickness Protection Limits for Human Exposure to Very Low Frequency Vibration**

Figure 3.

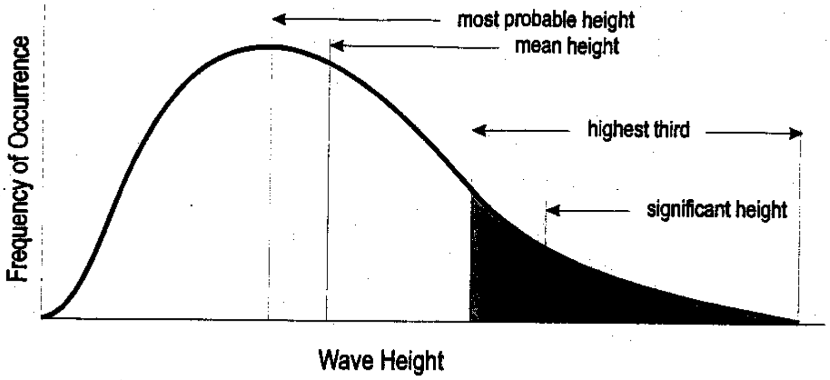
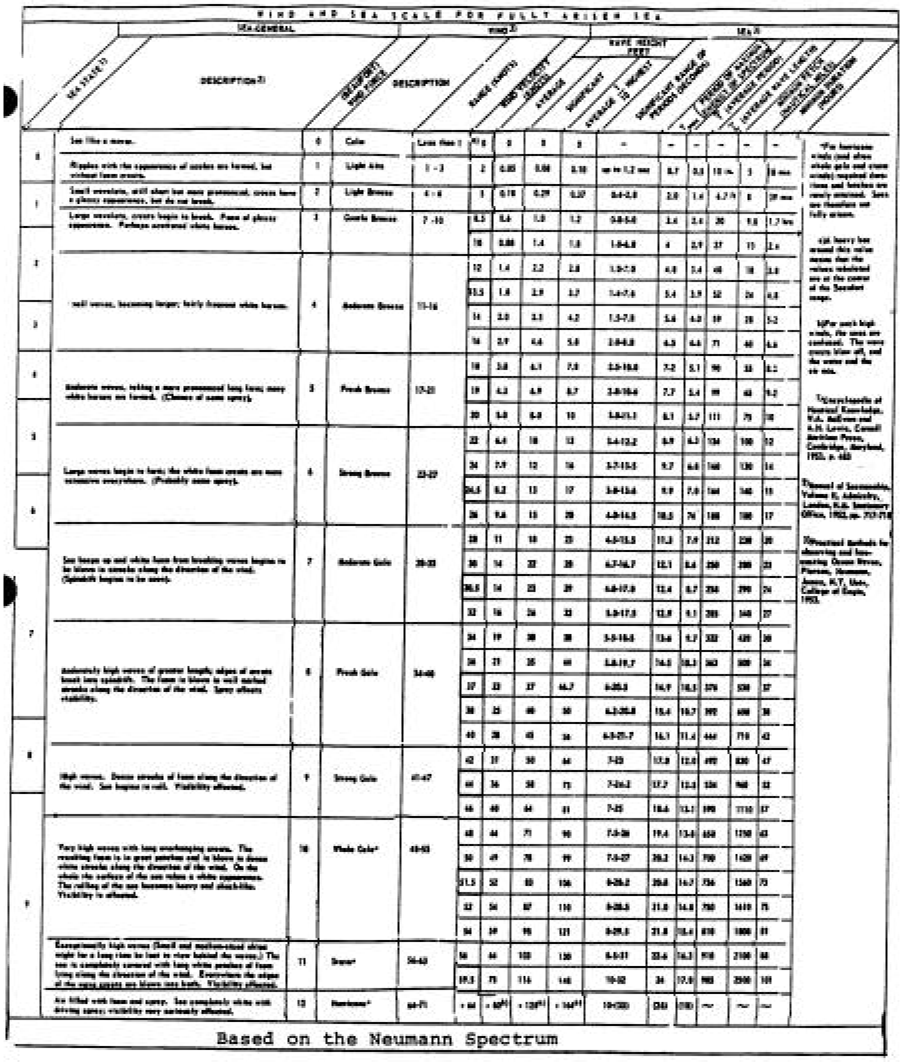

most probable height
mean height
highest third
significant height
Frequency of Occurrence
Wave Height

Figure 4.



Based on the Neumann Spectrum

This table compiled by Wilbur Marks,
David Taylor Model Basin, 1956

Figure 5.