ELEMENTS OF YACHT STABILITY

The study of stability in general, and of yachts in particular, is one of the aspects of naval architecture and safety that has been misunderstood and all too often overlooked because it requires lengthy and tedious calculations and testing. In the past, many yachts have been designed and built without having undergone the slightest evaluation of their stability. New European regulations stipulate that the stability of all yachts must be assessed by calculations and/or by testing. In recent years, the development of personal computers and specialized software packages has simplified the task of attaining these calculations. Nonetheless, the notion of stability often remains unclear and poorly understood even by professionals and experienced operators. For a number of yachtsmen, a yacht is stable if she doesn't heel over under their weight when they step on board or if she doesn't roll excessively at anchor. This initial stability, while important, is not sufficient to confirm whether or not a boat is stable.

by Eric Ogden

STABILITY OR STABILITIES

As a general rule, stability is defined as a vessel's ability to return to its initial upright position after having been inclined by an exterior force. This phenomenon is largely controlled by the relationship between the center of buoyancy, whose location is influenced by the geometry of the hull, and the center of gravity, which varies as a function of the vertical and longitudinal distribution of the weights onboard the vessel. The main external forces that can incline a vessel are wind pressure, waves, heeling during a high speed turn, the crowding of the passengers on one side, the accidental shift of a poorly secured ballast or cargo, and the free surface effects associated with large tanks or the accidental flooding of one or several hull compartments.
There are, however, different kinds of stability. The aforementioned initial stability, is offset when there is a sudden solicitation, such as that caused by the weight of one or more people boarding or moving suddenly to one side of the boat. Variations in this type of stability depend essentially on the geometry of the waterplane and the position of the metacenter. More simply, a vessel with a large waterline beam, such as a multihull, will have a higher initial stability than a monohull with a narrow waterline. While statical stability at small angles of heel may give an indication of a yacht's stability, it is insufficient when it comes to evaluating the reserve of stability. A vessel's ability to react to wind gusts and waves is known as dynamic stability. Indeed, the lift generated by a planing hull has a strong effect on the dynamic stability of this type of hull. Intact stability, as its name suggests, is the stability of an undamaged hull.
By contrast, stability after damage refers to a vessel with hull damage causing the flooding of one or several compartments. For the sake of simplicity, this article will be limited to the description of the statical stability of an undamaged hull.

Certified weights are to be used for official inclining experiments.

Inclining weights around 6 tons are required to incline a large yacht (175ft).

The angle of inclination is accurately measured with a long pendulum (plumb line).

Tenders and other craft stowed on the upper deck affect the stability of a yacht.

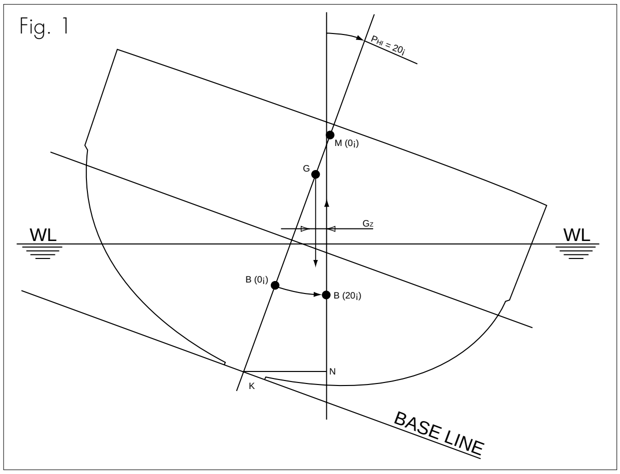
THE BASIC ELEMENTS OF STABILITY

For a vessel anchored in calm waters, Archimede's Principle states that a body is wholly or partially immersed in a fluid loses weight equal in amount to the weight of the fluid it displaces. At rest in still water, the following points are on the centerline: the center of buoyancy (CB) where the hydrostatic forces apply, the center of gravity (CG) through which the total weight of a vessel acts, and thirdly, the metacenter (M). The metacenter is the theoretical point around which the hull swings like a pendulum at small angles. The distance between the center of gravity and the metacenter is known as the initial metacentric radius or height (GM). The center of gravity (CG) must stay under the metacenter for the vessel to return to its initial upright position. This parameter is the fundamental element of initial stability.

When a vessel heels due to an external force, the geometry of the underwater volume changes and the center of buoyancy moves out in relation to the vessel's centerline. The center of gravity, providing that no onboard weight has been moved, remains on the centerline. The combined action of upward forces acting up through the center of buoyancy and the weight of the vessel acting down through the center of gravity creates a righting moment. The perpendicular distance between the center of gravity and the vertical through the center of buoyancy is referred to as the righting lever or GZ, and varies for each angle of inclination. A statical stability curve is then constructed once the righting lever has been calculated for each angle of inclination, it has the general form shown in Fig. 2.

THE ROCKING-CHAIR ANALOGY

To better visualize or understand the concept of metacentric radius it may help to compare it to a rocking chair (Fig 3). G is the combined center of gravity of the chair and its occupant, B is the point of contact with the floor and M is the center of curvature of the rocker and is the "metacenter" of the chair or the point under which G must remain for the chair to return to its initial position. If the seated person stands up on the chair and holds on to its backrest, the center of gravity G will be above the metacenter M and the chair will "capsize". It should be noted that the back of the rocking chair skids are normally flatter than the front in order to push up the metacenter and limit the risk of the chair tipping over. This analogy also demonstrates the incidence



Position of the various centers of an inclined hull.

of the metacentric radius GM on the roll period of a vessel. An unoccupied rocking chair has a lower center of gravity hence a higher GM and therefore a shorter roll period. If the person sitting on the chair progressively stands up, the rocking motion will slow down. On a vessel this phenomenon is similar, a higher GM produces a quicker and more uncomfortable period of roll.

FACTORS INFLUENCING STABILITY

As previously outlined, the main factors affecting vessel stability are the geometry of its waterplane area and the height of its vertical center of gravity. The incidence of the waterline beam is critical as the distance between the center of buoyancy B and the metacenter M, (BM), varies as a function of the cube of this beam. It is therefore crucial to design this beam not only to optimize the hull resistance but also to achieve the required stability. In optimizing both the height and the overall weight of superstructures, the designer aims at reducing the weights above the deck. This is why many motor yachts with a steel hull have been fitted with aluminum alloy superstructure to lower the vessel's center of gravity.

Since their original launch, dozens of yachts have become “top heavy” by the addition of new superstructures, cranes, tenders and radio/satellite communication antennas. These alterations and additions have been carried out by successive owners and captains during refits, often without any verification of stability. Inclining experiments, carried out at the request of officials for yachts changing flags or intended usage, often reveal serious stability deficiencies.

Onboard larger yachts, the loading conditions have a significant impact on their stability. Take the example of a displacement yacht over 130 feet in length, with a total fuel capacity of more than 100 tons and a lightship displacement of around 300 tons: the center of gravity rises by about 40 inches between the departure condition, with pressed-up fuel and water tanks, and the arrival condition, when only 10% of consumables left on board after a long distance crossing.

For this reason, it is not unusual for a captain to recommend that his successor only go at sea with a certain quantity of fuel on board, indicating the very real existence of stability problems beyond a minimum seagoing loading condition.

INCLINING EXPERIMENTS & STABILITY CALCULATIONS

The introduction of desktop computers has allowed for the development of powerful and relatively low-cost stability software packages for naval architects and design offices. Based on line plans, these programs compute not only the hydrostatics for an upright hull but also the righting levers for the vari-

Typical curve of the righting levers of a yacht.

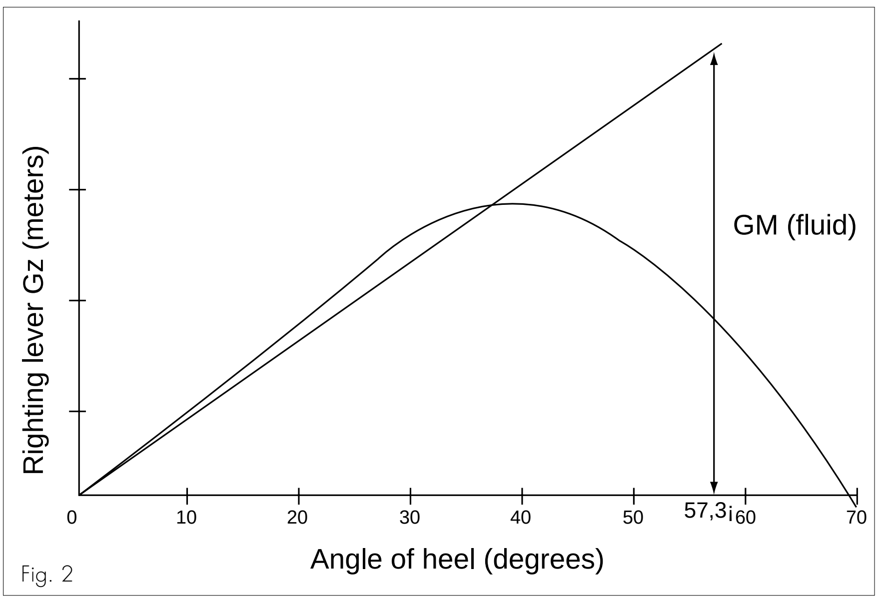
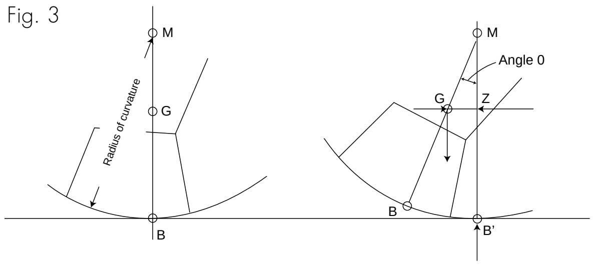


Fig. 3



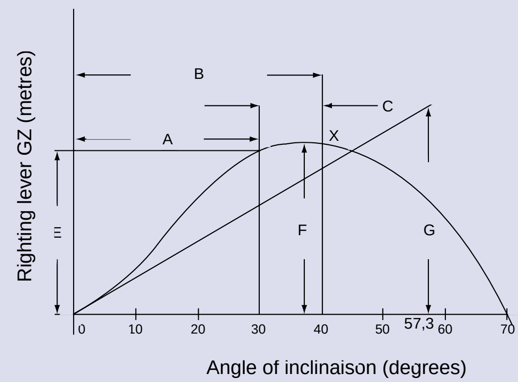
The motion of a rocking-chair helps visualizing the equilibrium of a yacht.

ous heel angles and loading conditions. They do not, however, preclude the designers from carrying out the fundamental task of putting together a detailed weight estimate. Indeed, the Naval Architect must add up, as accurately as possible, the weight and the center of gravity of each individual component of the vessel's structure, systems, and interior to calculate the vertical and longitudinal center of gravity for the various loading conditions. This task remains tedious and methodical, and requires a great adherence to regulation. It is too often overlooked by designers who find out at the official launch that the dream yacht doesn't float according to its designed waterline or that it cannot be certified or approved because of a lack of stability.

It is imperative that the theoretical calculations be validated by an inclining experiment in order to accurately confirm the lightship displacement and center of gravity. An inclining experiment is performed by shifting weights from one side of the vessel to another to create known inclining moments. For each weight shift, the inclination is measured with pendulums (plumb lines) or inclinometres. These angles are relatively small, between 1°- 3° to calculate the initial slope of the stability curve and the metacentric height that is then used to determine the lightship center of gravity. This data is then used to compute the righting levers and cross curves. With these curves the captain can easily plot the righting levers for various loading conditions and check them against the applicable stability criteria.

STABILITY CRITERIA

The criteria are simply minimum allowable values for various elements of the stability curve: the initial metacentric radius, the angles and righting levers, and the areas under the curve. Although these criteria are based on statical stability, they incorporate factors which take into account the vessel's power of recovery in a seaway with various wind strengths and sea states which may affect the safety of a yacht. The introduction of stability criteria for yachts is quite recent. A number of new rules and regulations such as the European Recreational Craft Directive 94/25 for pleasure yachts of less than 24 metres (79ft) and The Codes of Practice for The Safety of Small and Large Commercial Sailing and Motor Vessels applicable to British Registered Commercial Yachts now have their own stability requirements. The criteria for the European Directive are based on the ISO 12217 standards currently being finalized. The UK MCA Codes of Practice for yachts over 15m (49ft.) require that all such yachts carry onboard a stability information booklet and meet the stability criteria of the IMO Resolution A 167.



STABILITY CRITERIA - IMO RESOLUTION A167

A - Area under curve up to 30° to be not less than 0.055 metre.

B - Area under curve up to x degrees to be not less than 0.09
metre-radian.

C - Area under curve up to x degrees to be not less than 0.03
metre-radian.

X - 40° or any lesser angle at which the lower edges of any openings in the hull, superstructure or deckhouses which lead below deck and cannot be closed weather-tight, wouldbe immersed.

E - Teh righting lever GZ to be at least 0.20 metres at an angle of heel equal or greater than 30°.

F - Maximum GZ to occur at an angle of heel preferably exceeding 30° but not less than 25°.

G - After correction for free surface effects, the initial metacentric height GM to be not less than 0.15 metre.