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Intact stability criteria of ships – Past, present and future

Alberto Francescutto

University of Trieste, Italy

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ABSTRACT

This paper contains a brief excursus of the developments of intact stability of ships through the time from stone age, through historical period, modern age, renaissance, completion of the first intact stability code, beginning of development of 2nd generation intact stability criteria, present status and the foreseeable future developments.

1. Introduction

Sinking due to insufficient buoyancy and capsizing because of insufficient stability are two of the major threats to ship survivability at sea. The safety from sinking and capsizing is thus an important part of the safety of navigation with the entailed safety of life and protection of the environment in waterborne transportation. The two aspects had an extremely different development through history. As we will see, this is substantially due to the different perception of the immediacy of danger and to the very different entailment of physical and mathematical aspects in the two aspects. An important change in the perception was given by the change in propulsion, in particular the passage from sail ships to mechanical propulsion.

This paper does not deal in detail with the history of the theory of ship stability (King, 1998) nor with the developments of dynamic stability, which are contained in the companion paper by Neves (2015). The main focus is in the origins and developments of rules and regulations for ship stability, i.e. on the applications to ship safety from capsizing. The paper aims, indeed, to trace the timeline leading to the formulation and development of intact stability criteria as we know today and beyond. The adopted nomenclature for historical periods does not conform to the standard use. It has been adapted by the author (Francescutto, 1993, 2004, 2007; Francescutto and Papanikolaou, 2011) to the slow development of ship stability as a science.

Apart a single mention, the paper does not deal with the history and developments of intact stability for Navies. This subject was extensively treated in Reed (2009), while a review of more recent developments is given in Bačkalov et al. (2015).

E-mail address: francesc@units.it

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2. From the stone age to the beginning of history

Man has traveled for thousands of years throughout the oceans without knowing how and why this was possible. Although the basic concepts of floatability and stability will have been known before, the basic laws of hydrostatics of floating bodies were introduced by Archimedes in 300 B.C. It is well established that he was the first to formulate the basic law of buoyancy and eventually floatability. He had also set the foundations of stability of floating bodies by introducing the concept of the balance of couples of forces or moments.

The part of naval architecture known as buoyancy and stability has been directly founded on the roots of Archimedes' principle, but it is not clear whether his early findings about the stability of floating paraboloids were generalized by himself to actual ship forms or not. What is certain is the fact that, after some great scientific achievements in the Hellenistic era, there was a long silence (Russo, 2004). Gained knowledge remained unexploited for centuries (or was simply ignored and not referenced) and it is not known what its impact on later developments of ship stability actually was. The development of ship stability as a science, indeed, occurred very late in the 18th century with two different approaches based on the introduction of the metacentre and the righting moment notions respectively. These approaches were developed respectively by Bouguer and Eulero.

3. The beginning of history

Additional details on the similarities and differences between Bouguer and Eulero are contained in Nowacki (2001), Nowacki and Ferreiro (2003), Francescutto and Papanikolaou (2011). What is important to remark here is that, after the bright but isolated spot of Archimedes, the decisive progress of ship stability, as we know it now, came from the (mostly) geographer Bouguer while he was strolling up-and-down the Andes in search of a proof that Earth shape was following Descartes theories against Newton's theories. The result was the notion of metacentre, i.e. the upper limitation of the position of center of gravity that guarantees the stability-in-the-small or initial stability.

It is important to note the observation made by Bouguer in the Preface to his book (Bouguer, 1746): “Il n'était guére possible que l'Architecture navale, compliquée comme l'est par la multitude des diverses connaissances qu'elle suppose, fit des progrès aussi rapides que les autres parties de la Marine qui sont incomparablement plus simples. Il fallait non-seulement que les diverse Théories sur le mouvement dont elle dépend, & dont l'époque est assez recente, fussent portées plus loin, il était encore nécessaire que l'Analyse même & les methods géométriques qui devoient servir à résoudre les grandes difficultés qui lui sont propres, parvinnent elles-mêmes à un degré de perfection qu'il ni a pas longtemps qu'elles ont acquis.”

This witnesses the intrinsic physical and mathematical difficulties connected with the development of the subject. It is not casual that previous development was due to the best mechanical-mathematician of the ancient Greece (although he flourished in Magna-Grecia, present Italy…).

The first part of the work was completed by the Rev. Moseley (1850) introducing the concept of dynamic stability in 1850: “Whence it follows that the work necessary to incline a floating body through any given angle is equal to that necessary to raise it bodily through a height equal to the difference of the vertical displacements of its center of gravity and that of its immersed part, so that other things being the same, that ship is the most stable the product of whose weight by this difference is the greatest.”

The initial metacentric height as a measure of stability was an important step forward, but it was time to improve the picture. Quoting Barnes (1861): “The first general theorem for the determination of the measure of a ship's stability was given by M. Bouguer, in his Traité du Navire, about a century ago. This measure of a ship's stability, although only strictly true when the angle of inclination from the upright is extremely small, yet gives the relative stabilities of ships of the usual form for a tolerably large angle of inclination with sufficient exactness for all practical purposes. Bouguer's measure, in consequence of the simplicity of the calculations for obtaining the height of the metacentre and its close approximation to the correct results, is that which is in general use: but a naval architect should also be familiar with the mechanical principles upon which the stability of a ship depends, and be able to determine the exact stability of a ship of any form whatever, at any given finite angle of inclination.”

Unfortunately, the idea of Moseley did not have real practical applications. Notwithstanding fierce debates, mostly in the frame of the Institution of Naval Architects, as a consequence of the sudden sinking of the monitor Captain (designed by Cole) having a greater metacentric height but a smaller freeboard giving a smaller range of positive stability with respect to the Monarch (designed by Reed). White and John (1871) comment: “In 1867 calculations were made at the Admiralty of the stability of two or three low-sided vessels, and the results were embodied in a Paper read by Mr. Reed at the Meetings of this Institution in 1868. With this Paper most of the Members and Associates are doubtless familiar. It showed conclusively that instability would occur in such vessels at a very moderate angle of inclination, and illustrated the contrast, as regards stability and safety, existing between rigged ships with high freeboard and those with low freeboard. … This paper did not succeed, however, in impressing members of the profession with the necessity for more complete calculations of stability, and the subject remained in comparative obscurity until the loss of the Captain forced it into painful prominence.”

The reasons for the absence of transformation of Bouguer intuition in practical (stability) rules are well explained by Rahola (1939) in his doctoral thesis: “Even the most recent of the fundamental laws that determine the amount of stability for a vessel are already about 200 years old. Consequently, it would seem natural that the estimating of a vessel's stability and the determining of its minimum amount should have drawn attention very early. However, that is by no means the case. Only about a hundred years after forming the principles for the theory of stability one began to understand, by reason of a certain accident having occurred, the great importance the stability qualities of a vessel have for its seaworthiness and non-sinking qualities. This earlier under-valuation of the stability circumstances appears at first sight difficult to explain, particularly when one compares the fortunes of this question with those of its parallel question, the development of the problem of preventing the overloading of vessels. … The slight interest roused for the amount of a vessel's stability can in a way is explained very simply. So long as the wind was the propelling force for the ships, one was obliged, without studying the matter theoretically, generally to have a comparatively high freeboard for the hull. This brought about at the same time that the range of stability became great. The master of a sailing ship was also aware at every moment of the approximate amount of the stability, because when sailing he constantly happened to perform some kind of inclining experiment with his vessel, even if it was primitive. It was therefore easy for the master to avoid imperiling the stability of his ship, and whenever he was tempted to load an excessive deck-cargo or otherwise reduce the stability, he probably did so well aware of the risk he was causing his vessel. … The construction of a diverging type of vessel led to a flagrant violation of the building rules for well tested sailing vessels”. Unfortunately, this was not the case of Mr. Cole…

4. The beginning of the modern age

This is situated in the 30s of last century and is substantially based on two papers. First of all, Pierrottet (1935) laid the foundations of what later will be the Weather Criterion. During his presentation in front of the Royal Institution, the following debate, illuminating about the general conception of stability at that time, was recorded: “The CHAIRMAN: I do not wish in the least to detract from the good work that Professor Pierrottet has done. I think the Paper will be very useful to us, but I do hope it will be a long time before it is made the basis for new Board of Trade regulations by the Classification Societies. The number of losses from capsizing is so exceedingly small, even more tiny than he says, that it would be a very stiff to impose these regulations. After all, when you had imposed them, the skipper might upset them all by his loading of the ship. There is the difficulty. I hope Professor Pierrottet will not assume that I am pouring too much cold water on his scheme, for I think you will agree with me that he has devoted his energy, brains and ability to producing an interesting and, I believe, a useful Paper, and that we ought to accord him a very hearty vote of thanks”

PIERROTTET: “To Sir Archibal Denny I would say that I think the problem of stability is rather neglected by ship designers. I can see danger in his recommendations of empirical, rather than scientific methods. If the proportions of bridges across rivers were decided empirically, I am sure that sooner or later there would be many a disaster. The limits of the field over which empirical methods can safely be applied are very vague. It is my opinion, therefore, that no effort should be spared to study scientifically the stability of ships, and to ensure that designers do not neglect its consideration. I am