Rahola criterion revisited: an overview of Jaakko Rahola's research and career

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ABSTRACT

Jaakko Rahola's doctoral thesis, entitled "The Judging of the Stability of Ships and the Determination of the Minimum Amount of Stability – Especially Considering the Vessels Navigating Finnish Waters", has had an enormous influence on the development of international regulations for intact stability. This paper presents the background for Rahola's research, along with the key findings of the thesis. Finally, a brief summary of Rahola's career and contribution to education of naval architecture and shipbuilding industry in Finland is provided.

Keywords: *Jaakko Rahola, ship stability criteria, history*

1. INTRODUCTION

Jaakko Rahola's thesis for the degree of Doctor of Technology was accepted on May 26th, 1939, by the Technical University of Finland, later known as Helsinki University of Technology (HUT, or TKK in Finnish), and finally merged to Aalto University, since 2010.

This thesis, entitled "The Judging of the Stability of Ships and the Determination of the Minimum Amount of Stability – Especially Considering the Vessels Navigating Finnish Waters", has had an enormous influence on the development of international regulations for intact stability, and even after 80 years, the "Rahola criterion" it is still often cited in various related literature.

Over the years, Rahola's research has been summarized and discussed, and for example, Herd (1979) has presented an extensive study on the Rahola criterion in respect to previous work on ship stability. In addition, a short biography, Arjava (2015), has recently been published also in English. This book provides a more detailed description of both Rahola's career and his character.

This paper presents a short overview of the key elements of Rahola's thesis, the so-called "Rahola Criterion" that is considered as the foundation for today's intact stability regulations. In addition, the essential parts of his professional career are briefly summarized.

2. BACKGROUND TO RAHOLA'S RESEARCH WORK

Jaakko Rahola was born in Mänttä on June 1st 1902. He graduated as a naval architect in 1925. His Master's thesis was "Designing a Gunboat". After this he was occupied as a shipbuilding engineer at the naval base, and eventually appointed head of the Construction Office at Navy Headquarters in 1933. During those years, he spent a lot of time designing and supervising the construction of submarines and gunboats, Arjava (2015).

During 1920s and early 1930s, several Finnish ships capsized and sank, with notable loss of life, both in the Baltic Sea and in the Finnish lakes. Two of them are briefly described.

One such incident was the capsizing of the Finnish torpedo boat *S2* in heavy weather in the Gulf of Bothnia in 1925. The whole crew of 53 were lost in the disaster. The ship had fairly good stability but apparently there was some leakage. Rahola was working for the Finnish Navy at the time.

Another disaster took place in the Lake Näsijärvi in 1929. The sinking of the steamship *Kuru* led to the loss of 136 lives. According to Arjava (2015), some of the casualties were relatives of Rahola. The deckhouse of the *Kuru* had been extended in 1927, thus raising the centre of gravity. At the same refit, the bulwark in the bow had been closed without scuppers. Accumulation of water on deck in the heavy weather was considered as the primary reason for the accident.

These two disasters, and a couple of smaller accidents, were the primary reason why Rahola became interested in development of a method for judging the stability of ships and determination of the minimum amount of stability, especially for ships navigating in Finnish waters. Rahola had been involved in analysing some of the capsizing accidents. He had managed to gather material on various capsized vessels, and he was planning to write his doctoral dissertation on this subject.

In autumn 1937, the shipbuilding professorship fell vacant at the University of Technology. Rahola applied for this position, and he was given 18 months to qualify for this post. He obtained a grant and leave of absence from the navy for this period.

Rahola managed to finalize his doctoral thesis within the given time frame. A notable contribution was provided by Mr. Tauno Kaartti from Naval Headquarters, who helped Rahola, for example by drawing various figures and graphs, Arjava (2015).

3. RAHOLA'S RESEARCH WORK

Methodology

Rahola started his thesis with an extensive review on methods for judging stability of ships, considering initial metacentric height, main dimensions of the ship and finally the righting lever curve. He noted that: "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."

Most of these previous studies considered ships operating in high seas. Rahola focused on ships operating in Finnish waters, and he divided these fairways into two separate categories:

- Baltic Sea and Lake Laatokka (part of Finland at the time, now known as Ladoga)
- lakes, rivers and inner waters

The vessels and the operating conditions in these two areas were considered to be very different, and consequently, Rahola decided that different judging methods were needed.

During his studies, Rahola had spent over one month abroad, in Vienna, Berlin, Hamburg and London, Arjava (2015). The main objective of this travel was to gather detailed information on several capsizing accidents.

Rahola noted that for judging stability arm curves, he first needed to examine such cases, where a poor stability has evidently, or very likely, been the reason for the accident. During his travels, he had managed to gather a large number of stability curves for vessels having suffered accidents abroad (outside Finland).

In the appendix, Rahola describes 34 accidents that occurred outside Finland. However, he presents detailed stability analysis only for 13 ships, where reliable righting lever curves from various sources were available. Since the objective of the research was focused on ships operating in Finnish waters, most of these sample ships were quite small, representing typical coastal vessels. Rahola then divided these ships into three categories:

- adequate/sufficient stability
- critical stability
- insufficient stability

For this categorization, he used the available accident investigation reports, and especially comments on the stability characteristics of the ship and their influence on the casualty. Some of these ships were actually included in more than just one category since different loading conditions were considered separately, Table 1. For example, the whaler *Rau III* that capsized during sea trials in 1937 is included in all three groups. The actual loading condition clearly had insufficient stability, but the planned condition was judged as critical, and with full cargo the ship would have had adequate stability.

Table 1: Summary of the sample ships, and number of loading conditions in each category.

Name	Insufficient	Critical	Adequate
Torp. Boat no 10	1		
Margarethe Russ	1		1
Cargo ship	1	1	1
840 t cargo ship	2		
Negros	1	1	1
Flottbek	1		1
Rau III	1	1	1
Monica	1	1	
Kreuzsee	1	1	
Galleon		1	
Elbe I		1	1
Narvik			1
Calder	1		1
Total	**10**	**7**	**8**

It is worth noting that Rahola used symbols from the German Society of Naval Architects, and hence e.g. the initial metacentric height is marked with M_0G instead of the currently preferred GM_0. In this overview paper, all symbols and terminology are the same as in Rahola's thesis.

Stability Arm Characteristics

In 1930s the initial metacentric height was in practice the only measure of stability that was considered in Finland. Rahola noted that stability at large heel angles were more suitable for judging. He selected the following characteristic parameters for detailed comparison:

- righting arm values at 15°, 20°, 30° and 40° heel angles
- heel angle, where the maximum righting arm occurs, denoted as the "critical statical heeling angle", φ_m
- capsizing angle (i.e. vanishing stability), φ_k

The righting arms at the studied heel angles for the sample ships were plotted, based on the categorization for sufficient stability, Figure 1. The righting arms that were judged as sufficient were plotted on the right hand side, whereas the insufficient and critical cases were placed on the left hand side of each respective heel angle. The adopted plotting technique allowed drawing of a demarcation line between sufficient and critical stability.

Rahola also examined the literature and the various previous proposals for the critical capsizing angle φ_k and the heel angle φ_m, where the maximum righting arm is achieved. Based on this review and detailed analysis of the sample ships, he noted that with all probability, sufficient limits for the statical critical heeling angle and capsizing angle of small seagoing vessels are $\varphi_m \geq 35°$ and $\varphi_k \geq 60°$, respectively.

Rahola further noted that determination of the minimum righting arm at 40° heel is futile, because once the conditions of the smaller heel angles are complied with, also the stability at this large heel angle is sufficient.

When considering the capsizing angle, Rahola noted that it is not as important as the statical critical heel angle. Consequently, he concluded that the stability of a seagoing ship can be judged as sufficient if the following is satisfied:

- righting lever for 20° heel, $h_{20°} \geq 0.14$m
- righting lever for 30° heel, $h_{30°} \geq 0.20$m
- heeling angle of maximum righting arm $\varphi_m \geq 35°$

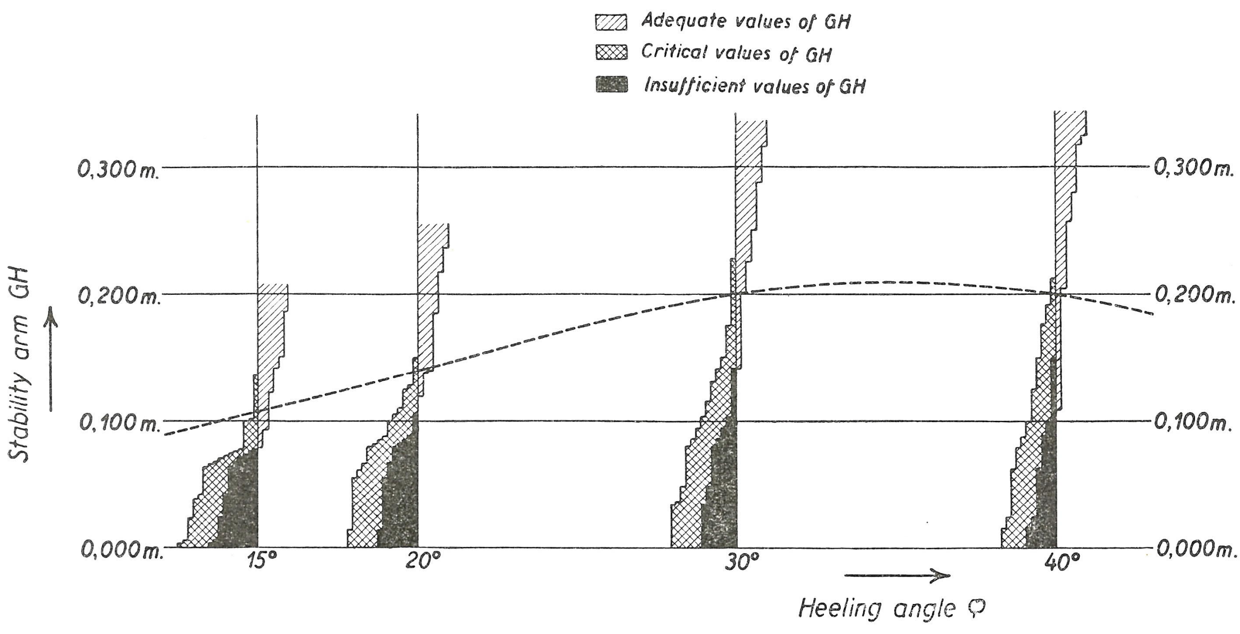

Figure 1: Critical righting arm values based on the sample ship data, adopted from Rahola (1939)

Rahola referred these requirements as the “minimum rule for the statical stability”. In the subsequent text, he emphasized that this rule was not intended for general use, because the examined lost ships were mainly small ones, and the applicability of the same standard righting arm curve for ships with different size was considered unsuitable. In addition, he noted that for large ships a small initial stability may be compensated by means of greater righting arm values at large heel angles, mainly due to higher freeboard.

Limit Heel Angle for Dynamical Stability

Rahola noted that the dynamical stability of a vessel has a greater importance than the statical stability. He first raised the question on the limit angle, up to which the dynamical stability arm should be calculated.

For the limit angle of the range of stability φ_r, Rahola suggested the minimum of the following:

- critical statical heeling angle φ_m
- immersion angle of non-watertight hatches (i.e. down-flooding angle)
- estimated dynamical angle of repose of unsecured cargo (based on simplified method accounting for the roll period and the cargo hold)
- absolute maximum of 40°

Since full details of the sample ships were not available, the immersion angle and dynamical angle of repose were not applied by Rahola in the analysis of the sample ships.

It is also noteworthy, that the statical critical heeling angle is not considered as a range limit in the current intact stability regulations.

Minimum Dynamical Stability

After having determined the limit heel angle φ_r for calculation of the dynamic stability arm, i.e. the area under the righting lever curve, Rahola focused on defining the threshold value, using the same set of sample ships and loading conditions.

In order to obtain a precise picture, Rahola plotted the dynamical stability levers at the limit heel angle for the sample ships, Figure 2. He used the same drawing method as for the statical righting arm. Based on this result, he concluded that the dynamical stability is sufficient, if:

$$e_r = \int_0^{\varphi_r} h(\varphi)d\varphi \geq 0.08\text{mrad} \qquad (1)$$

Rahola called this “the new minimum rule for dynamical stability of seagoing vessels”.

It is noteworthy that for some sample ships with adequate stability, the dynamical stability was limited to the heeling angle with maximum righting arm φ_m notably smaller than the absolute maximum of 40°.

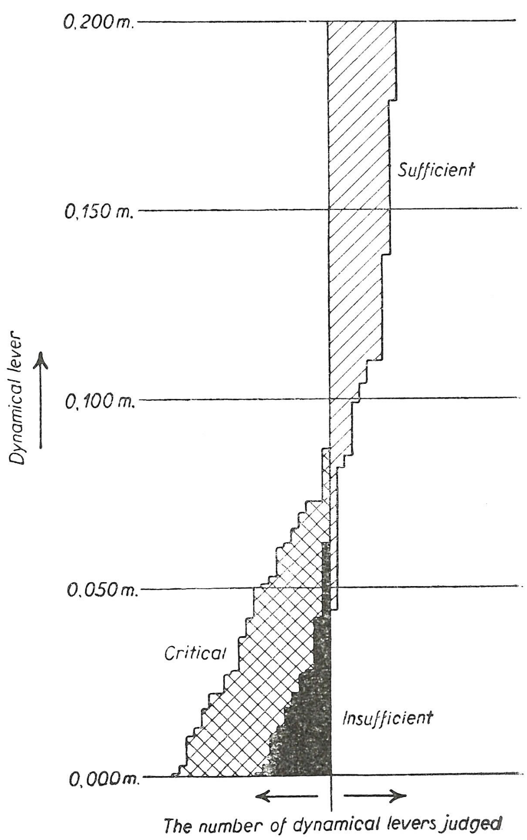

Figure 2: Critical dynamical righting lever value based on the sample ship data, adopted from Rahola (1939)

Rahola Criterion for Seagoing Vessels

The principles for judgment of stability of seagoing vessels are summarized in Figure 3. Although, Rahola considered both statical and dynamical stability, these requirements are usually simply known as the “Rahola criterion”.

Rahola also briefly compared the statical and dynamical methods for judging sufficient stability, and concluded that they are in good agreement.

However, he noted that the dynamical one is more favourable to a ship designer, since it does not impose requirements for initial stability (metacentric height), even indirectly.

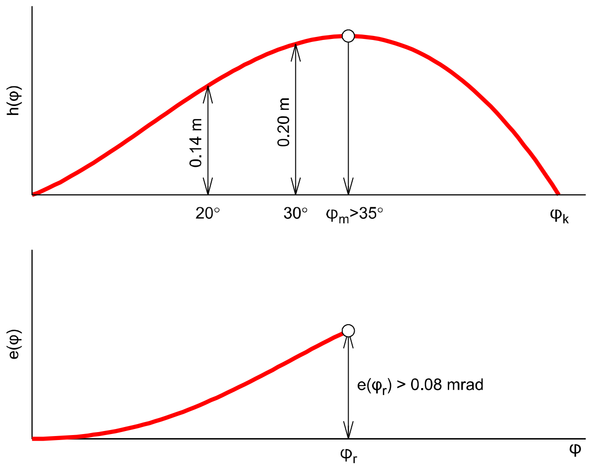

Figure 3: Visualization of the Rahola criterion for seagoing vessels, considering both statical and dynamical stability

Judging Method for Inner Waters

In addition to the well-known judging methods for stability of seagoing vessels, Rahola dedicated a full chapter for consideration of stability of vessels operating on the Finnish lakes.

Rahola considered that a separate judging method should be used for these vessels, mainly because they were not governed by the International Load Line Convention from 1930, and the freeboard varied notably between different vessels.

Consequently, Rahola believed that it was futile to establish requirements for critical statical heeling angle of lake vessels, and an alternative approach was needed. First, Rahola examined heeling in steady turning motion, considering both rudder and centrifugal forces. For this purpose, he had organized manoeuvring tests in calm water for several Finnish lake steamers in the summer of 1938.

Rahola continued with the wind and passenger crowding moments. After a careful literature analysis, he recommended to use 20 m/s for steady wind and 28 m/s for a gust in a gale, as suitable values for Finnish inland waters. Finally, he considered also the effects of waves and water on deck.

The final conclusion was that the determination of the minimum stability of a vessel in inland waters must be based on the most unfavourable situation, where heeling moments of turning motion and wind are combined. For this purpose Rahola presented various pre-calculated tables and diagrams for the evaluation of the sufficient dynamical stability.

Compared to the well-known judging method for seagoing vessels, the presented approach for vessels operating in inner waters is much more complex and immature.

Demonstration of the Judging Methods

The final chapter of the thesis contains calculation results and discussion on the stability of various Finnish ships that had capsized. Among them are the torpedo boat *S2* and the lake passenger steamer *Kuru*, the main motivators for Rahola's research work. The developed criteria, both for seagoing and lake vessels, were used, depending on the location of the accident.

4. LATER CAREER

In 1941 Jaakko Rahola was appointed Professor of shipbuilding. However, during the war, he was also a temporary head of the shipbuilding division at Naval Headquarters.

After the war, Rahola was made responsible for organizing the ships to be delivered to the Soviet Union as war reparations. The administration of this task was entrusted to the War Reparations Commission (Soteva). Later he was appointed Soteva's head of the shipbuilding department, and deeply involved in the development of the Finnish shipyards to undergo the enormous task of building 508 new ships in a short time period. These included sail, steam and motor ships, and they were built by several Finnish shipyards. The effort was ended in 1950, and Rahola could again concentrate on teaching at the university.

According to Arjava (2015), it appears that Rahola had some plans to continue his research on ship stability. However, considering his enormous workload during and immediately after the war, it is quite understandable that these plans never materialized.

In 1955 Rahola was appointed Rector of the university, a position that he held for ten years. During this time, the university moved from central

Helsinki to nearby Otaniemi, where the Aalto University campus is still located.

For the final years of his professional career, Rahola was working as Permanent Secretary at the Ministry of Trade and Industry, where he retired in 1969. Professor Jaakko Rahola died on September 10th 1973.

5. CONCLUSIONS

The criteria for sufficient the stability of seagoing vessels that Jaakko Rahola developed in his doctoral thesis were based on personal judging and categorization of quite limited set of sample ship data, Kobylinski and Kastner (2005). However, this pioneering work paved way for establishment of the first proper international regulations for intact stability at IMCO (Inter-Governmental Maritime Consultative Organization, predecessor of IMO) in 1960s, as discussed by Thomson and Tope (1970). A comprehensive overview of the development of the intact stability regulations is given by Kobylinski and Kastner (2005).

In addition to his significant research work in the late 1930s, Rahola's contribution to the war reparations program and teaching of naval architecture have had a notable effect on the subsequent success of the Finnish shipbuilding industry.

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