Forensic Study of *BOUVET* Capsizing

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Abstract: The paper deals with the capsizing of the French pre-dreadnought *Bouvet* during World War One (WWI). If the circumstances of the drama were clear, the reasons for the capsizing -- both concerning the stability of the ship and the nature of the device -- were not, and few hypotheses can be found in the literature. The aim of this work is to clarify those hypotheses and to test modern tools against this rather well documented event. For that purpose both numerical computations and experiments have been planned. Part of them have been performed and reported in the present paper.

Key words: Damaged stability, History of naval architecture, stability criteria, experiments

1. Introduction

Bouvet was a French ironclad launched in 1896, she had been chosen with other ships of a similar design to fight an important battle in the Dardanelles Strait. She sunk after an explosion caused either by a mine or an artillery shell on the 18th of March 1915. According to all the testimonies she sunk in less than a minute. The rapidity of the drama revealed her very poor stability. During World War One many other ironclads shared the same fate. These problems had been considered as a proof that warships built prior to HMS *Dreadnought* were dangerous, because they were not able to survive damage to their intact stability, annulling their military value. With these ships, it was argued, all-out naval warfare in the Mahanian style was impossible.

A deep silence surrounding the utility of pre-dreadnoughts even after the war shrouded the sinking of ironclads. Many historians have described ironclad of the late XIXth century [1-3] but very few have tried to put them back into the context of the war they had to fought, questioning how their military value was perceived by strategists and headquarters.

2. Historical information

2.1 The ship

As shown on figure 1, *Bouvet's* hull form is characterized by considerable tumblehome and with a counter stern, seen today in the US destroyer DDG 1000 *Admiral Zumwalt*.

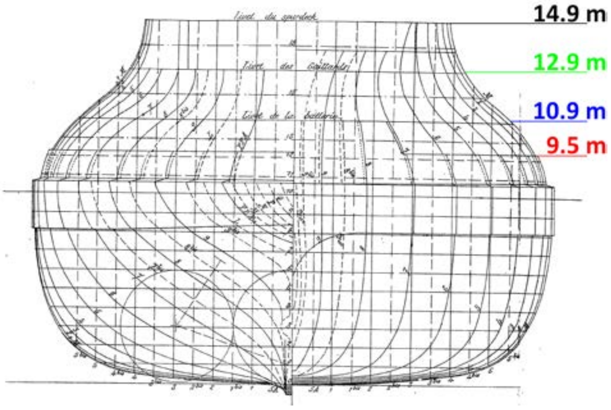


Fig.1: battleship Bouvet hull form.

Thanks to the SHD (Service Historique de la Défense, the historical service of the French ministry of defense) most of the plans are available and historical bibliography gives access to some hydrostatics calculation [4]. The main particulars of the ship are given in table 1.

Table 1 Battleship *Bouvet*, main particulars

Length over all (m)	122.6
Full displacement (t)	12, 220
Beam over all (m)	21.4
Mean draft (m)	8.0

2.2 The dramatic battle

In fighting operations against Turkish coastal artillery the ship was struck either by a floating mine or an artillery shell, below the starboard 274 mm turret. According to the testimonies the ship capsized to starboard in 55 seconds with an initial forward speed of about 12 kts. Out of a total crew of 668 men, only 64 survived.

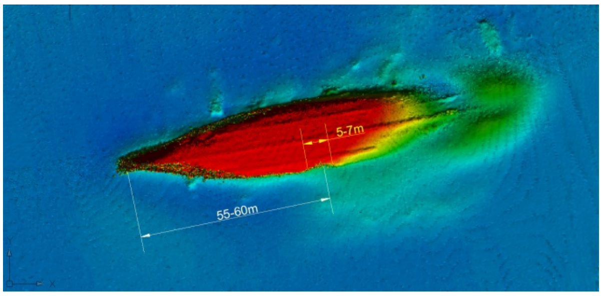


Fig. 2: Sonar image of the wreck from Turkish salvage team

This case study is very interesting because the ship sank in well-known conditions (there are even pictures of the disaster, see figure 3). Also, this case was among those of several other warships whose rapid capsize was to prove the necessity of developing damaged stability rules for warships.

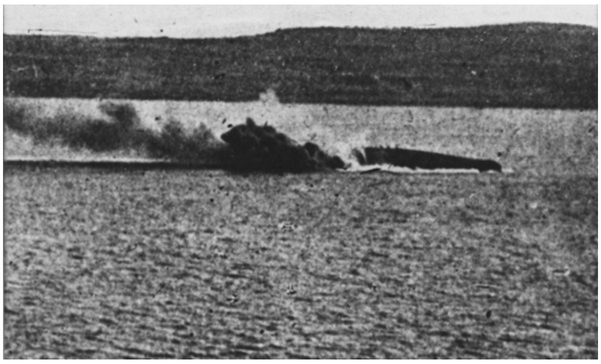


Fig. 3: Picture of the capsizing of Bouvet the 18th Mars 1915 taken from HMS Agamemnon.

2.3 The theory of stability in a military environment. The contribution of French engineers at the beginning of the XXth Century

At the verge of WW1 the Service de Construction Navale (SCN) of the French navy was divided over the use of models and theories to represent warships [5]. The first group, primarily older and experienced engineers, was still following empirical methods and doubted that the calculation of dynamic stability made with wooden models could be used to qualify a ship as stable or not. The second group of younger but capable engineers were developing new methods and were aware that dynamic stability was as much as determinant for safety as was intact stability. Chief among these engineers was Louis-Emile Bertin (fig. 4), who had defended and popularized this idea among the public and denounced the general design of warship built at the end of the XIXth Century, which he said had “feeble stability” [6]. He stated the theory that the military value of a warship depends on survivability, meaning stability after damage. Louis-Emile Bertin was the initiator of the first French towing tank, the *Bassin d’essais des carènes* build in 1906 in Paris (now named DGA Techniques Hydrodynamiques located in Val de Reuil). He had greatly contributed to ship construction. He developed the method of experiment on wooden model. The model is provided with a movable disc displaced transversely by a fixed screw in order to precisely measure the motion of a calibrated weight. There is also a long vertical arm pendulum in order to measure the angle of heel. To study the damaged case, as wooden model is constructed with floodable compartments. Unfortunately we have not yet found examples or pictures of these models.

In 1894, Bertin knew already that more mathematical methods existed, for example mechanical integrators, but he found his method of using models easier, more flexible, less expensive, no more time consuming (he expected 2 months to study a new design as with others methods) and more adapted to damaged stability.

Fig. 4: Louis-Emile BERTIN (1840-1924).

2.4 The drama of the *Bouvet* had been anticipated

The case of the *Bouvet* is interesting also because this is a good example to describe and understand how safety progresses in a military environment. The situation is different than the one that occurs in merchant navy where the market and the recommendation of insurance companies exert pressure on shipping. In the Navy the process of technical change in safety is rather different; in this case a dramatic event had been necessary to make decision-makers realize what the uselessness of the pre-dreadnought fleet. The loss of the *Bouvet* showed clearly the way but many hints could have been analyzed before the drama.

Before the war several commanding officers of the *Bouvet* had the intuition that the flooding of some compartments would endanger her. The longitudinal bulkheads had been pointed out as a particular hazard that would cause off-center flooding. In order to reduce the risk, transverse cross-flooding connection had been built to avoid heel angle after damage in the engine room. The crew made strong efforts to increase maximum initial stability by placing coal and heavy tackle low in the ship. Initial stability that was judged too small at the time would be seen as good enough from our modern eyes (GM greater than a meter). It seems that for them initial stability was more a matter of steadying the ship platform during gunfire than avoiding capsize. Moreover, the damaged stability of a ship compartmented as the *Bouvet* had been studied completely in 1899. The prescient conclusion of the engineer Maugas [7] was that the ship might sink if the hull suffered any damage.

During the Dardanelles fight, others warships had been damaged. One of them was the *Gaulois*, which had been hit by shellfire and repaired at Toulon. While in the shipyard, it was fitted with an above-water wooden caisson to improve the stability after damage, the direct result of the Navy’s learning from the experience of the *Bouvet.* This happened just in time, as the *Gaulois* was torpedoed several months later on the 26th December 1916, and the caissons were credited with keeping the ship upright and afloat long enough to evacuate the crew [8].

3. The project

Main issues

From a technical point of view it was important to performed experiments to use the sinking of the *Bouvet* as a validation case for up-to-date damaged stability software codes. Moreover the example of the *Bouvet* is relevant for others reasons. It has brought to light how to study how military staff perceived the military value of the ships they had to engage in the Great War. The Dardanelles fight is for the French Navy the moment officers realized that pre-dreadnoughts had no military value and the strategy had had to be totally revised. Finally, the example of the *Bouvet* is very relevant to model the process of technical change in safety procedures in a military environment especially at a time when market and insurance input were inexistent. It is clear that the dramatic fate of pre-dreadnought ships had been taken in account by engineers to create rules and norms for warship stability.

3.1 Ship configuration

A four-meter long model of the *Bouvet* was built and the static stability fully explored. Experiments have been performed in calm water without forward speed. The progressive flooding represents different configurations and internals arrangements. Experiments and numerical calculations have been performed on different cases. A view of the internal arrangement in the workshop is shown on figure 5 where the two starboard boiler rooms separate by a cofferdam (on axis) and starboard 274 mm ammunition room can be seen.

Fig. 5:Iinternal arrangement.

This arrangement represents the area of the ship shown on the original plan presented on figure 6 where all the compartments experimentally modeled have been underlined and the position of the explosion (mine or shell) positioned.

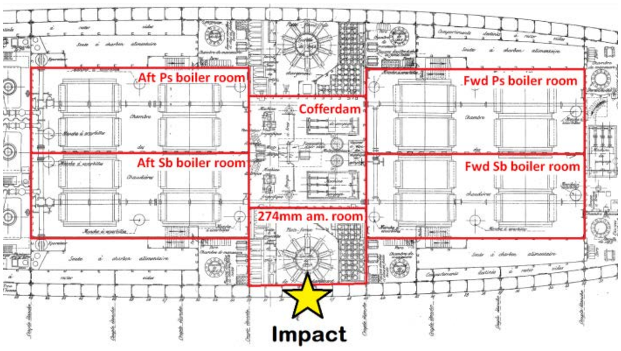


Fig. 6: Detail of the general arrangement in the area of impact.

At the location of the impact, a watertight door seals the ammunition compartment. At the beginning of the experiment the door is opened and the ammunition room open to flooding. Water can then flood a variety of compartments defined by bulkheads. Moreover to determine the movements of the ship, the model has been fitted with 6 reflecting spheres which can be seen in figure 12. We used a tracking system consisting of 4 infrared cameras and software that plots the position of the ship every 1/100 second.

3.2 Numerical computations

As we began the study, we attempted to determine how 19th century engineers defined watertight volume used for the determination of GZ curve. This proved very difficult to determine. Performing hydrostatic calculations it has been found that GZ original curves correspond to the whole closed volume of the ship. The same evidence has been found on other ships of the same period (*Gaulois*, *Charlemagne*), the first one has been hit by a shell during the same operation and went to ground on Rabbit Island and the second faced stability problems during turning experiments in the bay of Brest (about 30° of heel at 12 kts and 15° helm)[9]. To build a curve with the same shape and the same vanishing stability angle we have progressively modified the watertight deck and obtained the result shown in figure 7 when the watertight volume has been limited by the uppermost deck. In these conditions (which seem rather optimistic...), we have obtained very similar curves even if in the range 20-40° the 1913 computations lead to underestimation of results obtained by modern numerical methods.

During this study the bibliography has been explored unsuccessfully to find regulations that applied to that kind of ship. From our computations we deduced that all the closed volume was used to define the GZ curve, even if this volume is far from watertight as determined by the criteria used today to define the watertight deck or the exposed deck.

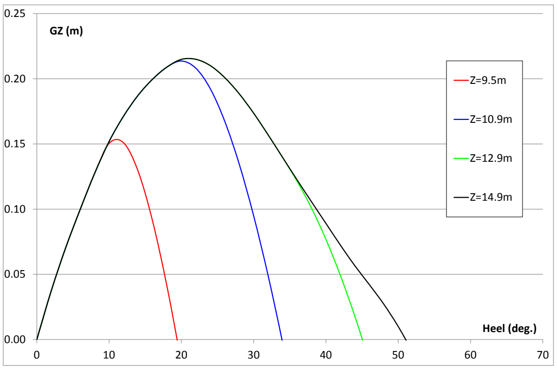


Fig. 7: Effect of watertight deck height on GZ curves.

The full GZ curve shown on figure 8 shows that the intact stability was quite poor, actually better when the ship was upside down! The estimated angle of vanishing stability was about 55° and the initial GM of about 1 m, but the GZmax value is of only 0.2 m. The two first parameters are not so bad but the third is catastrophic.

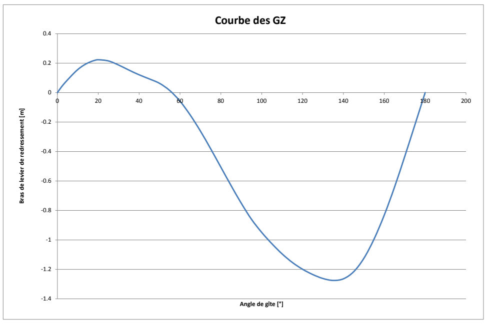
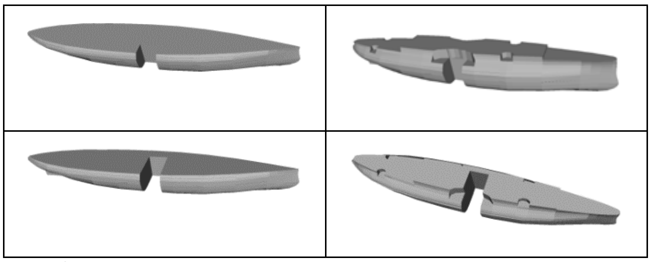


Fig. 8: Full GZ curve watertight deck at 14.9 m.

Stability in damaged conditions has been computed too. As discussed previously, the watertight intact volume is uncertain and the progressive flooding is unknown. Thus computations have been performed using different hypothesis concerning the watertight deck (10.5 m and 14.9 m) and the flooded volume (starboard ammunition room only and starboard ammunition room and cofferdam). The value of 10.5 m is adopted from the height of the armored deck which was fitted with a 1 m height coaming surrounding the deck. This value has been used to build the model. Watertight volumes corresponding to the different hypothesis are given on figure 9.



Left column: Watertight deck 10.5 m
Right column: Watertight deck 14.9 m
First row: Starboard ammunition room flooded
Second row: Starboard ammunition room and cofferdam flooded

Fig. 9: Watertight volumes.

Results are given on figures 10 and 11.

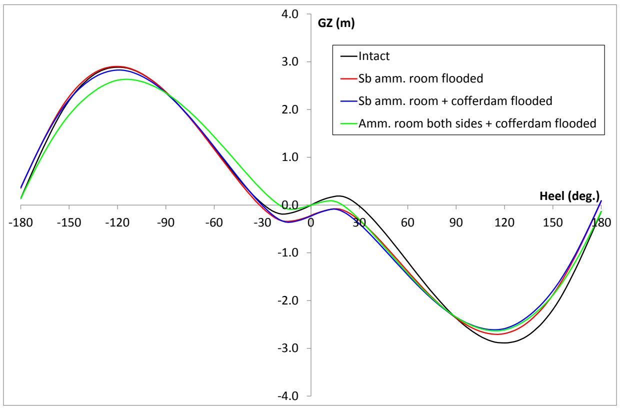


Fig. 10: GZ curves for watertight deck positioned at 10.5 m.

It can be seen that whatever the hypothesis the capsizing was certain; the only equilibrium position corresponds to 175° of heel. The experiments will give an insight, using the time to sink, to define the right hypothesis.

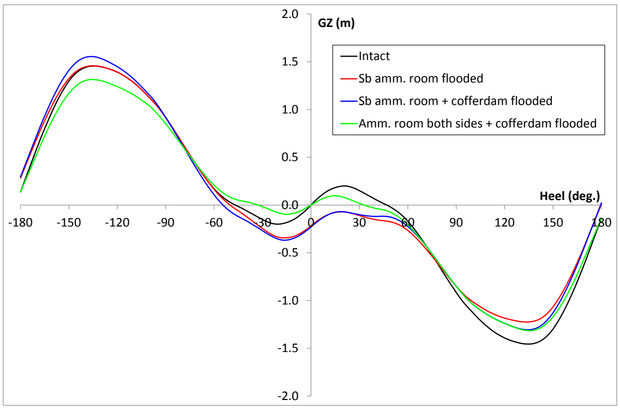


Fig. 11: GZ curves for watertight deck positioned at 14.9 m.

3.3 Experimental investigations

The model allows a modification of the internal arrangement that can lead to different flooding configurations. The model is shown on figure 12.

Fig. 12: Model during tests in the tank.

The flooding configurations that will be tested are the following:

Case 1 : Starboard ammunition room only

Case 2 : Starboard ammunition room with cofferdam

Case 3 : Case 2 + Starboard boiler rooms (fore and aft)

Case 4 : Case 2 + Starboard forward boiler room

Case 5 : Case 2 + both forward and aft boiler rooms

At this time, only succinct analysis has been performed. The repeatability of the measurement has been checked and is quite good as shown by figure 13 The heel angle versus time is reported on figure 13.

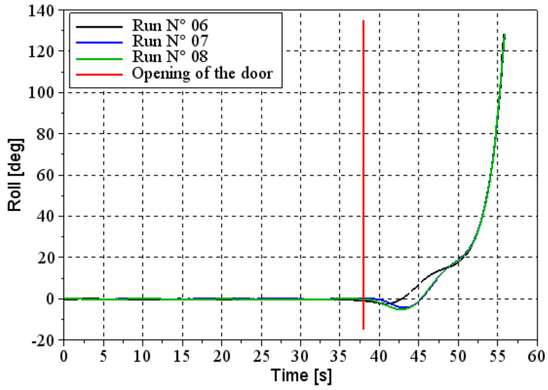
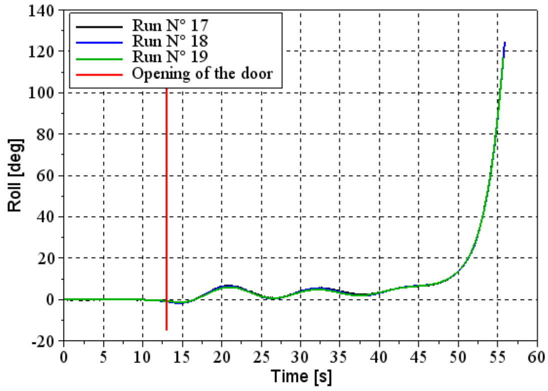


Fig. 13: Time history of the capsizing in case 2.

The roll angle was measured until a heel angle of about 130 degrees after what the markers are underwater. In case 2 the time to reach this angle is about 18s while 55 s have been reported by witnesses. Even if they report the duration of the full reversal – and not only till 130deg – the difference is quite large. As we can see on the figure 13 after beyond 20 degrees heel angle the capsize speed increase a lot. One could expect that after 90 degrees the deckhouse – not represented on our model – enter the water and slow down the motion because of drag effect and air locked in the decks.

If we now look at the results obtained with case 5 – a less favorable case as more compartment are flooded – but with a smaller opening size we can see that the capsizing time is closer from the 55s.



Further test and post-processing will be necessary to fully clarify and verify our hypothesis.

Conclusions

At several times, a few senior Navy officers had pointed to problems of stability, mainly concerning the longitudinal bulkheads which, in case of breach in the compartment, allow off-center flooding to induce a large heel angle. They recommended cross-flooding ducts to prevent this event, though these ducts were never fitted [10]. We have tested this possibility and their intuition was correct. As shown on figure 14, for a quasi-static flooding, an area remains under the GZ curve, whatever the watertight deck.

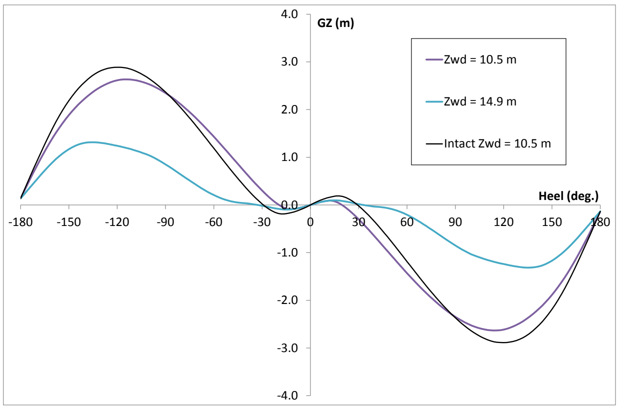


Fig. 14: GZ curves with a cross flooding duct.

Nevertheless the positive area under the curve is so tiny that the dynamic force of the capsizing would have overcome this feeble stability and led to capsize. Moreover, even had the ship been fitted with cross-flooding ducts in the three compartments, the dynamic nature of the flooding would still have led to the capsizing of the *Bouvet*.

This preliminary study has demonstrated that *Bouvet* was a doomed ship from the moment it was built. Further analyses will clarify the exact nature of the damage, including the likely weapon (mine or artillery shell) and the timeline of the capsizing.

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