WHY CONSIDER INVERTED BOWS ON MILITARY SHIPS? OR WHY NOT ?

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SOMMAIRE

La forme des étraves des navires a connu de nombreuses évolutions au cours de l’histoire de la construction navale. Ces évolutions suivent en général l’avènement de nouveaux besoins ou de nouvelles connaissances. L’industrie navale est cependant très conservatrice, ce qui tend à ralentir des évolutions significatives. Ceci s’applique en particulier au cas des étraves discutées dans ce papier.

Dans les dernières 50 -70 ans, ce qui est assez court dans l’échelle de l’histoire, les étraves des navires ont évolué pour intégrer un dévers assez important afin de mieux surmonter les vagues lors d’opérations sur mer forte. L’action de ces étraves tend à disperser les embruns sur les côtés et produire des forces de rappel afin d’éviter l’enfournement de l’avant sous la vague. Cela a marqué une amélioration par rapport aux étraves assez droites des navires avant cette période.

On assiste cependant depuis le début des années 90 à une recrudescence des designs de navires avec des étraves droites ou inversées. Il est légitime de se demander ce que cela apporte et quel risque prend on le cas échéant en adoptant ce changement. Naval Group s’est lancé depuis une dizaine d’année dans un programme complet d’études et d’essais afin de déterminer l’intérêt et les conditions de succès d’un design avec une étrave inversée. Les principaux résultats de ces études sont rapportés dans ce papier, incluant leur application au design des nouvelles frégates Belh@rra®.

SUMMARY

The bow shapes of ships have evolved throughout history of Naval Construction. Such evolution generally follows the emergence of new requirements and new knowledge. Nevertheless, evolution is often slowed by conservatism and takes time to find its way through the naval industry. This is also true of the bow shapes as we are going to discuss in this paper

In the past 50 to 70 years, which is not a very long time span in the scale of history of the naval construction, the bows of ships have tended towards flared shapes enabling the ship to go through rough weather by spreading the spray on both sides of the ship and attempt to maintain the bow above the level of the waves encountered. This has proven more effective than the rather straight bow shapes seen in most ships around the first part of the 20th century.

However a new trend has emerged since the 1990’s, with a tendency to try again inverted bows. One can ask why change the bow shapes and take a renewed risk? Naval Group has launched into a comprehensive analysis and test program in the past ten years in order to identify all the effects of a

new design involving an inverted bow. This project has enabled identifying not only the benefits and drawbacks possible with an inverted bow, but also to determine critical design parameters which can make such a design successful. Main results of this program are presented in this paper, including its application to the latest generation of Frigate, the Belh@rra®.

1. INTRODUCTION

Recent trend in ship design has shown a renewed interest in straight or inverted bows, as opposed to the flared shapes most commonly seen in ship design in the past 50 to 70 years.

The purpose of this paper is to examine the interest of such bow shapes as well as identify possible drawbacks and guide the designers into the right choices of design parameters. It is based upon about 10 years of research, analysis and testing undertaken by Naval Group (Ref [1] and [2])

2. STATE OF THE ART

2.1. A little bit of history of naval shipbuilding

Across the history of naval shipbuilding the shapes of the bows have evolved many times depending upon the civilisations and their background, but also according to the use that was made of those ships.

Going back to antiquity, when war ships were essentially powered by rows, there was a time when the bow could be used to ram into enemy vessels so as to sink them.

Figure 1: Naval Combat in antiquity

This trend disappeared with the progress made by sailing ships which required bow extension to rig sails. It came back for the same reasons (ramming into enemy ships) with the advent of steam power which enabled again this war tactic. This trend disappeared again with the increase power of naval guns (which made unlikely two ships would come in contact in battle) and the use of steel in the construction of those ships.

Around the turn of the 19th century, when this last trend started to taper off, most ships had either inverted or straight bows. Naval architects gad perceived at that time the importance of waterline length in maximizing the ship speed and the bow extensions above the waterline were kept minimal.

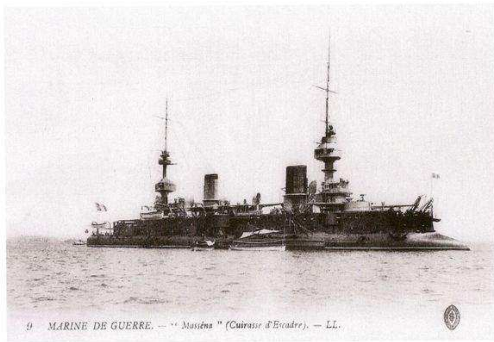

Figure 2: Example of WW I cruiser

It is of interest to note that warships of that period were known to have stability problems. These problems can easily be traced to two main reasons

- The tendency to integrate inward flare to the sides of the ship (inherited from sailing ships and from a time when bullets could rebound on such scanted side shell), which reduced drastically the damage stability of those ships
- The hull segmentation which was insufficient to guarantee sufficient stability after damage as well – this was before the accident of the Titanic – and the consequences it had on defining proper rules for compartments of ships

Inverted bows which were used in the design of warships of that time were often blamed wrongly for the rapid loss of such vessels in combat. The effect of bow shape on the stability curves can easily be shown to be negligible and thus it is important to clear that point.

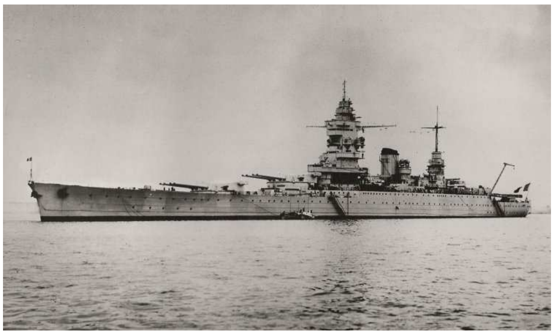

Figure 3: Example of WW II cruiser

In the years following World War II, the bow shapes started evolving to integrate more bow slope and flare to the sides. This was considered to provide better protection for the equipment installed on the foredeck (mooring installation and gunnery for warships). The speed of ships was increasing at that time and ships were subject to bow submergence, due in part also to the relatively low freeboard they had at that time. This trend has continued and most ships today are fitted with flared bows.

Figure 4: Example of post WW II warship

2.2. Recent developments with bow shapes

The past 25 years have seen a renewed activity from ship designers around the world with regard to bow shapes. The reasons for this renewed change can be tied to a research of better seakeeping characteristics, along with solving the newly arisen problem of bow flare slamming, and trying to save some structural weight in a part of the ship that carries little useful function (no payload for commercial vessels and no installation of mission related equipment for military vessels)

Some of the research was carried out in the framework of European Projects back in the 1990's and found their way in the design of commercial vessels mostly, as illustrated by the success of the X-Bow design for supply ships and other commercial vessels. The main reason for pursuing inverted bow designs on commercial vessels was clearly an improvement in seakeeping behaviour.

The X-bow design (figure 5) is claimed to offer smoother passage in heavy seas, with less bow impacts and a thus permitting to sustain a higher speed in a seaway.

Figure 5 Xbow supply ship

With regard to the naval community, there has been several designs developed in recent years with inverted bows but the most significant achievement is, by enlarge, the Zumvalt class of destroyers built for the US Navy.

Figure 6: Zumvalt Destroyer

The Zumvalt has now been at sea for a while and seems to give satisfaction as regard to its hydrodynamic behaviour and its inverted bow. However it is a very big ship and cannot be considered as a general validation of the inverted bow concept by itself.

3. RESEARCH PROGRAM BY NAVAL GROUP

This paper develops the Research made in the past 10 to 12 years by Naval Group in order to identify the interest and shortcomings that inverted bows could present, as well as the keys to a successful design with such a bow shape.

Naval Group has looked into inverted bow design since the mid 2000's and has developed several conceptual designs and tested them in tow tank and hydrodynamic modelling as well as RCS signature evaluation.

Naval Group has identified three main reasons for pursuing inverted bow in military ship design:

- Improved seagoing capability with e smoother passage through the waves
- Reduced RCS signature around the bow
- Increased waterline length at equal exposed deck length

3.1. Hydrodynamic Performance

3.1.1. Swordhip Project

The concept ship SWORDSHIP (ref [3]) was developed with an inverted bow and tested in model basin with satisfactory seakeeping behaviour (fig 7)

Figure 7 Model testing of the Swordship

However more extensive model testing has been carried out on two frigate development designs: FM400 and Belh@rra® as described in the following.

3.1.2. FM400 Frigate project

The first of these designs is the FM400 project for which comparative model testing was carried out in seas states ranging from SS5 to SS7 (ref [1]).

This first series of model testing demonstrated some of the features claimed with regard to inverted bows. The behaviour in the most extreme seas was found to be improved with regard to the following considerations

- Passage in high waves smoother, with a tendency recover quicker from bow submergence as the weight of water on the foredeck has less impact on the inverted bow consideration
- Less deck wetness measured at different locations such as the gun or the superstructure forefoot.
- Absence of flare slamming as the inverted bow does not exhibit any significant flare exposed to the waves

It should be noted that these model test comparisons were made on two hulls with the same waterline length and a higher freeboard deck for the inverted bow than the flared bow (as illustrated by figure 8). The global volume offered by the two bow designs was thus roughly equal.

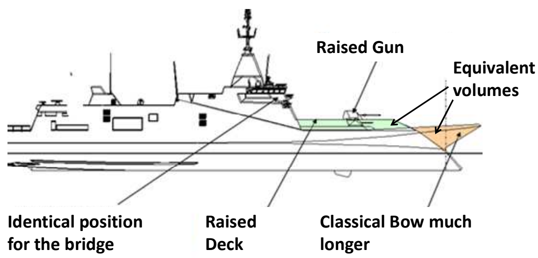

Figure 8 Bow configurations tested in model basin

This increased freeboard does contribute to the lower level of deck wetness however it was deemed a proper way of comparing the two designs as they were offering the same level of hydrostatic volume to recover from bow submergence.

These model tests are illustrated in figure 9 and 10 below.

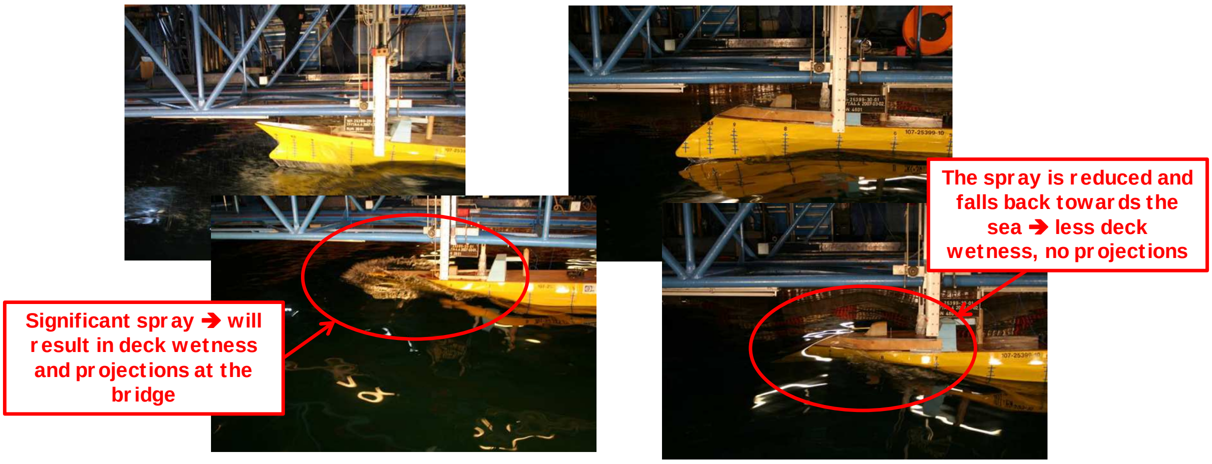

Figure 9: Comparison of flared (left) and inverted (right) bow in SS6

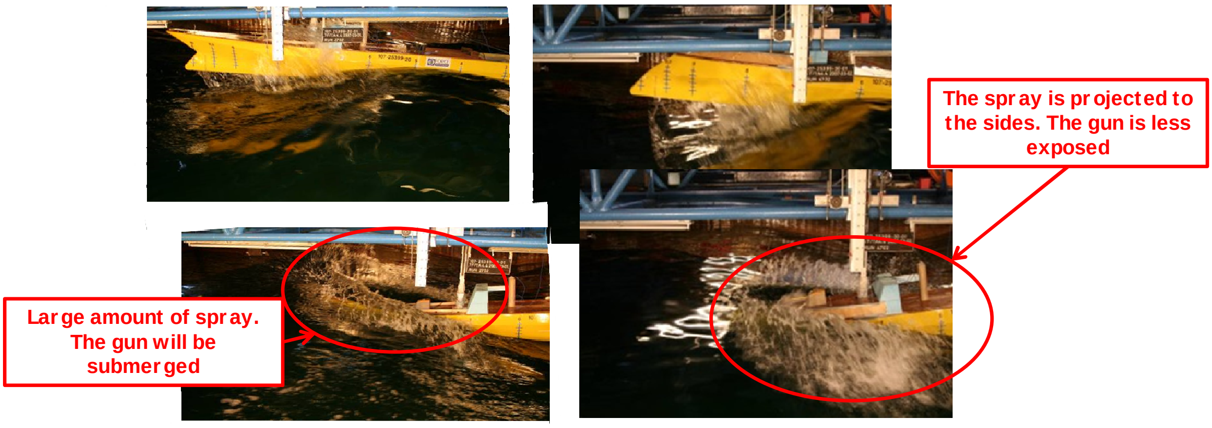

Figure 10: Comparison of flared (left) and inverted (right) bow in SS7

Results of these tests are illustrated in figure 11 with the comparison of the occurrence of deck wetness measured during these tests.

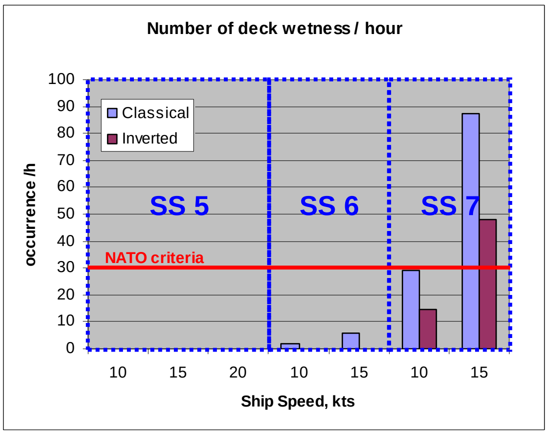

Figure 11 Occurrence of deck wetness for various sea states and speeds

This shows a real advantage to the inverted bow. However, as was stated earlier the raised deck contributes a great part to this result.

Another interesting comparison is the hull resistance in heavy seas, illustrated by figure 12 below. It shows a small, but measurable advantage to the inverted bow.

It is believed to be due to the lesser impacts of the bow cutting through the waves, as the inverted bow tends to deflect the spray sideway and the flared bow tends to project the spray forward.

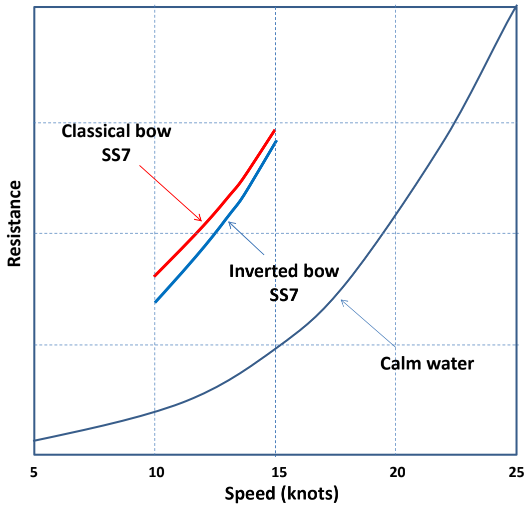

Figure 12 Comparison of added resistance in heavy seas

3.1.3. Belh@rra® Frigate project

More recent work was carried out as part of the development of the Belh@rra ® (figure 13) frigate design.

Figure 13 Belh@rra ® frigate

This ship design was developed as part of a French Navy contract for its new FTI program. It was presented to the public in 2016 and is now under development at Naval Group.

Comparative model testing was again done in this program to verify the overall behaviour of the inverted bow in heavy seas, with regard to the seakeeping requirements for this project and in a comparative way as well with a conventional flared bow configuration.

It should be noted in this case that again the comparison was made at equal waterline length and with strictly the same underwater hullform. This made the comparison easier to carry out in model basin as both bow configurations could be installed on the same model (figure 14).

Figure 14 Bow configurations tested in model basin

However, as the freeboard was identical in this case, the total volume of the bow was in fact greater for the classical bow. This was a potential advantage in terms of seakeeping in heavy seas but would in return penalise the design with a significantly heavier bow structure if it were carried out in the design of the frigate.

Figure 15 shows a comparison of the model tests carried out in SS7. It can be seen again the tendency of the inverted bow to deflect spray along the side where it is projected over the bow with the classical bow.

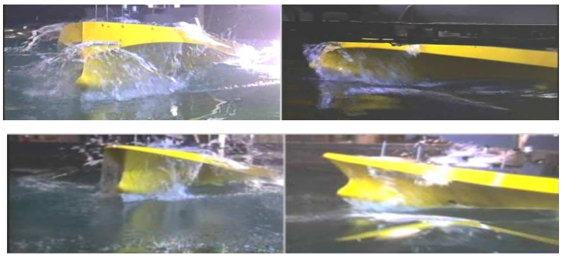

Figure 15 Comparison of model tests in Sea State 7

However, in this case, few cases of higher occurrences of deck wetness were found in the tests but they corresponded mostly to unrealistic speed/sea state conditions. This effect is a logical result of the configuration of the classical bow which is at the same waterline length and freeboard as the inverted bow.

In this case, the comparison of hull resistance in heavy seas did not show any measurable advantage either way.

However some CFD calculations showed a small theoretical advantage to the inverted bow, dependent upon the angle of the stem. This was described in ref [4].

3.2. Radar Cross Section

3.2.1. Swordship project

First assessment of the RCS contribution of inverted bows was made as part of the SWORDSHIP project (ref [3]) and is illustrated by figure 16.

Although this design was entirely dedicated to obtaining very low signature (and not only the bow contribution), it can be seen that the bow contribution itself is very low (no sacrificed sector), thus confirming this aspect which was certainly among the reasons for the selection of an inverted bow on the Zumvalt class for the very same reasons.

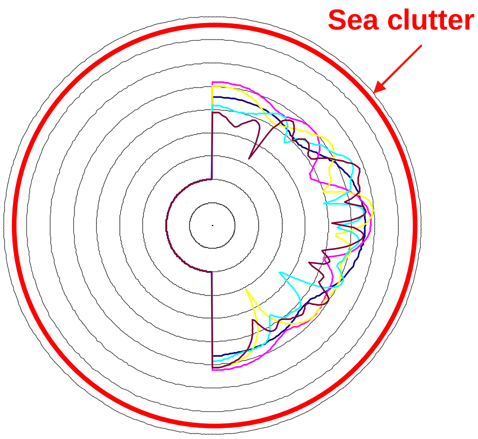

Figure 16 illustration of RCS calculations results on the SWORDSHIP concept

3.2.2. FM400 Frigate project

RCS calculations were also made on the hullforms considered for the FM400 frigate. A comparison was made and is illustrated in figure 17.

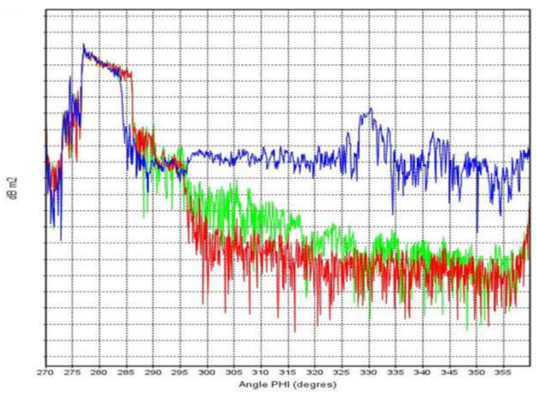

Figure 17 comparison of RCS calculation for three bow hull shape (in blue = flared bow, in red and green = two configurations of inverted bows)

3.2.3. Belh@rra® Frigate project

The same comparison was made with the two bow configuration tested for the Belh@rra® design. The results are illustrated in figure 18 and show again a wide range of headings where a significant advantage is found to the inverted bow configuration.

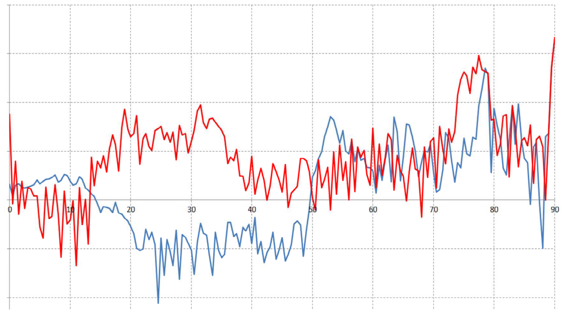

Figure 18 comparison of RCS calculation for two bow hull shape (in red = flared bow, in blue = inverted bow)

This comparison clearly shows a marked advantage over a wide range of headings to the inverted bow configuration as compared to the flared bow configuration.

3.3. Increased Waterline length

One of the main advantage of adopting an inverted bow is the possibility of increasing waterline length when all else is equal.

The design of a warship involves critical considerations early on as to what must fit in its length in terms of weapons, sensors, aviation, boat launch, uptakes, bridge, mooring installation and other consideration.

Once a designer has made the necessary reservations in the topside for these essential features, there is little room for varying the hull length.

Once an overall length has thus been determined and optimized, any increase above that usually results in increased weight and cost. However, considerations must be given to increasing hull length in order to gain hydrodynamic advantage and thus better performance.

One way to increase the waterline length without impacting the overall length is precisely to increase only the waterline length and adopt an inverted bow, as illustrated by figure 19 below

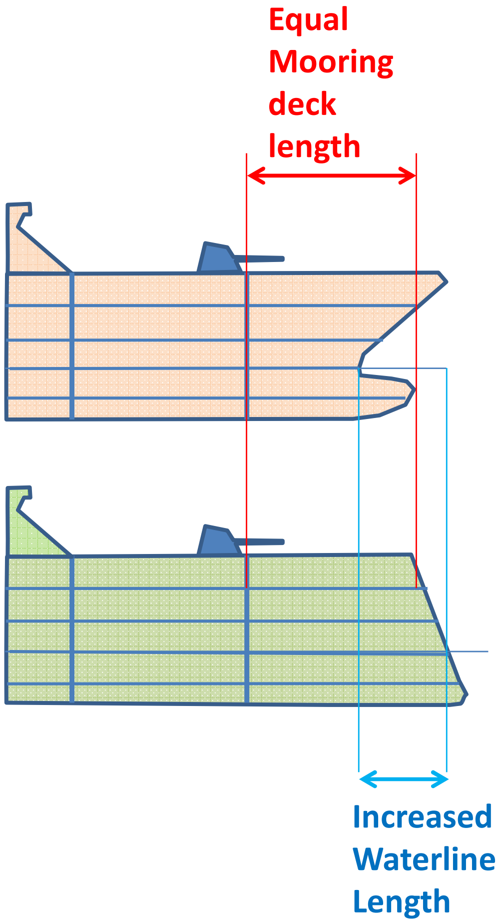

Figure 19 increasing waterline length with an inverted bow.

As shown in figure 19, one must be careful when integrating an inverted bow not to reduce the mooring deck length as it would become a critical issue.

It can be seen also that with such an approach the overall bow volume, identified since the start of Naval Group work on this topic as essential to the success of an inverted bow configuration, can easily be guaranteed as the volume enclosed in both bow is roughly of the same order here.

The resulting increase in waterline length will yield in turn significant improvements in hydrodynamic performance:

- Improved speed/powering performance. In this case a gain of more than 0.5 knots was made possible
- Improved pitch behaviour. As the waterline length is greater, this result in higher water plane longitudinal inertia and shorter pitch period. This is in addition to the improved behaviour in heavy seas discussed earlier. This could not however be shown by the comparative model testing as , for practical purpose, these were carried out on equal waterline length models

At the same time, increasing waterline length by the same amount while keeping a conventional bow shape would result in a significant increase in hull weight and cost and subsequently reduce the advantages gained by such an increase.

3.4. Other considerations

Besides from the three main topics described above, a global comparison of advantages and drawbacks was carefully conducted by Naval Group in order to ensure that there was no “show stopper” with regard to inverted bows.

This analysis included in particular the following aspects:

- Stability
- Mooring and anchoring
- Gun integration
- Visibility from the bridge

3.4.1. Stability

As was mentioned earlier in 2.1, there has been some confusion over the impact of the bow shape on ship stability as warships from the WW 1 era were known to experience stability failures after damage. It was clearly tied to the tumblehome hullform often associated to their inverted bows and to poor compartmentation rules at that time.

The bow itself has very little impact on ship stability as its volume does not get submerged when the ship rolls and thus its contribution to the righting arm curve is minimal. This is illustrated by figure 20 below.

In addition, since the upper bow part on a military ship is used to integrate a covered mooring deck (question again of RCS reduction), it is not considered as reserve for damage stability (the mooring deck is considered a floodable area). Thus there is no advantage either in terms of damage stability to the flared bow configuration.

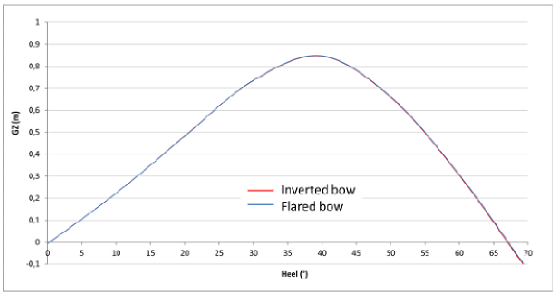

Figure 20 comparison of righting arm curves, inverted and flared bow configurations

The only concerns one may have would be with regard to dynamic stability in following seas, when the ship might use the enlarged bow shape to gain an advantage. The specific hull shape developed by Naval Group around its inverted bow does offer however e significant volume in its upper part, thus the difference here is minimal.

3.4.2. Mooring and anchoring

As mentioned earlier, when designing a ship with an inverted bow, careful considerations must be given to the integration of the mooring and docking capabilities. The mooring deck must be of sufficient dimensions to integrate mooring installations. For this reason, it would be disastrous to reverse the bow starting from a ship design already developed. These aspects must be integrated from the onset of the project.

The interactions of the anchor and anchor chain with the bow must be carefully analysed in order to ensure the mooring will not damage the bow bulb, especially when such bulb oftentimes integrate a bow sonar on a military ship.

However there is one clear drawback to the adoption of an inverted bow: it is not possible to integrate an axial anchor. Axial anchor are often used on military ships as they enable the integration of a bow mounted sonar with lesser risk of interference between the mooring line and the bulbous bow.

It was verified however on Naval Group projects that the lateral anchor would drop in the water clear of the bulbous bow and its sonar. It remains that care must be taken in avoiding the mooring line to get tangled around the bulb and damage the sonar dome. This will require special attention to wind and current conditions in a limited number of cases.

3.4.3. Gun integration

The main gun must be integrated likewise early in the design as for the rest of the components contributing to determine the minimum ship length explained earlier in 3.3.

The downward slopes of the hull sides around the gun mount enable a small but appreciable increase in firing arc at low angles, allowing firing at close distance to the ship. This is interesting for firing police warning shots across the bow and also in keeping track of approaching boats in the context of asymmetric warfare.

3.4.4. Visibility from the bridge

Likewise, the visibility at close range across the bow of the ship is improved with an inverted bow configuration, enabling a better tracking of small boats coming near the bow and of the approaching pier when docking.

One drawback however that has been mentioned is that the captain cannot visualize as well the distance between the pier and the bulb which is the foremost part of the ship. He must therefore use caution when approaching in order to avoid collision of the bulb with the pier.

4. CONCLUSION

This paper presented the experience gained by Naval Group in designing warships fitted with an inverted bow.

It showed the advantages gained by such a novel design in terms of:

- Seakeeping behaviour in heavy seas, with the absence of bow slamming in particular
- Radar Crosse Section reduction over a wide range of headings
- Hydrodynamic performance, through increased waterline length

These advantages were shown to have little counterpart. This prompted Naval Group into adopting this new hull shape on its latest generation of frigates, i.e. the Belh@rra® frigate (fig 21).

Figure 21 Belh@rra® frigate by Naval Group

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