BOW WAVES MITIGATION THROUGH BUBBLE INJECTION – APPLICATION TO RIVER TRANSPORT TO PROTECT THE NATURAL BANKS OF INLAND WATERWAYS

Atténuation des vagues d'étrave par injection de bulles. Application au transport fluvial pour protéger les berges des voies d'eau

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ABSTRACT

This paper presents an innovative mechanism designed to attenuate the formation of bow waves thanks to a pneumatic breakwater system (bubbles injection) embedded on river boats and barges. The device is folded onboard when the barge is along a quay or in a lock. Then, it can be deployed from the cockpit and thus, it can be immersed in order to operate when the barge navigates in the waterway network along sensitive banks. Thanks to the bubble injection before the formation of bow waves, this device protects the banks of inland waterways against wave action. Preliminary tests carried out with model scale 1/50 are presented in the present paper. An extrapolation to real barges is proposed, then a prototype scale 1/1 could be designed soon. An approximation of the carbon footprint is estimated by comparing the tentative overconsumption of the boat (to produce air bubbles) to the costs of maintenance works and dredging of inland waterways.

KEY WORDS

Bow waves, bubble injection, banks protection, inland waterways

RESUME

Cet article présente une innovation pour atténuer les vagues d'étrave des bateaux fluviaux et barges, grâce à un brise-lames pneumatique embarqué (injection de bulles). Le dispositif est replié à bord lorsque la barge est amarrée le long d'un quai ou dans une écluse. Le dispositif peut être déployé et immergé depuis le poste de pilotage afin d'entrer en action lorsque le bateau navigue sur le réseau des voies d'eau, le long de berges sensibles. Grâce à l'injection de bulles avant la naissance des vagues d'étrave, ce système protège les berges des voies d'eau intérieures contre le batillage. Des essais préliminaires réalisés sur un modèle réduit à l'échelle 1/50 sont présentés dans l'article. Une extrapolation à des barges réelles est proposée et un prototype échelle 1/1 pourrait être réalisé prochainement. Une approche de l'empreinte carbone est estimée en comparant la surconsommation de carburant du bateau (pour produire les bulles), aux coûts de travaux de maintenance et dragages du réseau des voies d'eau intérieures.

MOTS-CLES

Vagues d'étrave, injection bulles, protection berges, voies d'eau intérieures

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1- INTRODUCTION

It is well known that a fine bubble curtain can limit the swell, in particular short waves such as wind waves. Such a possibility was quoted for the first time by Brasher [1], then by many more authors notably Lord Taylor [2], then Evans [3] and Bulson [4]. But to date, swell mitigation by a pneumatic breakwater has not been demonstrated through large-scale real-life applications. Indeed, because of the energy needed to produce the compressed air, it is not possible to protect an entire harbour during a long lasting period.

Nevertheless, in recent years, some very specific applications for short-term uses (passenger transfer) and/or on sensitive sites (presence of posidoniae in the Mediterranean Sea, for instance) were proposed: ATAP[1], DAHET[2]. Such devices have already been presented in some publications [5], [6] and [7].

Civil engineering firms, such as submarine mining companies, use the bubble curtain to limit the shock wave of shootings of explosives under the water and therefore to protect the marine species and the surrounding works. The driving of deep foundations for offshore wind turbines can also produce nuisances on the fauna. In the North Sea, bubble curtains are used to damp the noises of the driving of foundations for offshore wind turbines to protect porpoises hearing. Air bubbles slow down the distribution of the underwater noise and reduce its intensity, so that the bubble curtains created around the embedment zone of mono-piles assure an effective protection.

In all the applications evoked above, the bubble curtain is still. Tests in laboratory swell-canal highlighted the fact that the fine bubbles create a density current and drag water particles away when rising up. By arriving near the surface, the density current changes direction and becomes substantially horizontal, so creating a current against the swell, which makes it break out and thus allows to mitigate it.

The process presented in this paper is rather different because it consists in limiting the waves of a river barge by injecting bubbles at the bow, thanks to a system embedded on the barge, which progresses at the same speed. Thus the fine bubble plume is not stationary because it is released under water at a horizontal speed (cruising speed of the barge). The device in question is called BULBAT[3] and it is presented in the following pages.

2- PRESENTATION OF THE INNOVATION BULBAT

The innovation BULBAT is a device intended to limit the formation of the bow wave of a boat or a river convoy, thanks to a system of pneumatic breakwater embedded on board. It finds applications mainly for the navigation on inland waterways (natural rivers, channelled rivers, lakes, canals, etc.). Thanks to this device, the height of ship-generated waves is strongly decreased, thus reducing considerably the impacts on banks.

The banks of inland waterways are often degraded by the ship-generated waves. To address this degradation, banks must be protected by a range of huge and often expensive devices (rip-rap, sheet-piles, transversal groynes, etc.).

The impact of bow waves - and particularly the erosion of banks - have been the subject of numerous studies – some of them are quoted in the bibliography [8] to [12].

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1 ATAP means in French : Appontement Temporairement Auto-Protégé

2 DAHET means in French : Dispositif Atténuateur de Houle Embarqué pour sécuriser les Transferts de passagers

3 BULBAT means in French : BULles pour limiter le BATillage

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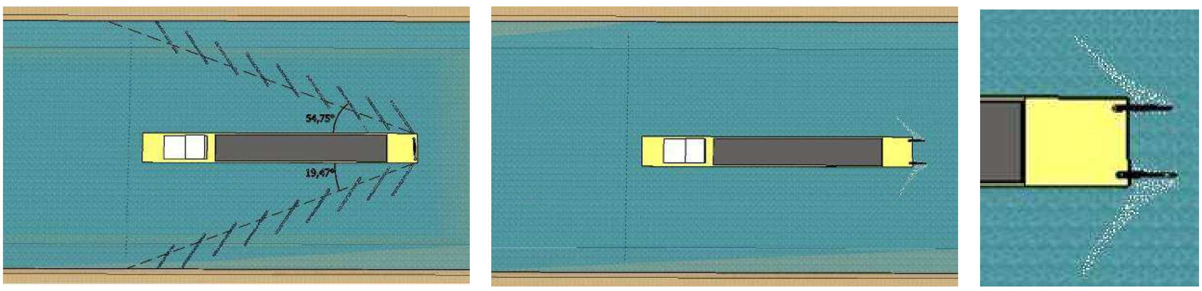
Figure 1 : Barge going back the Rhône to Serrières (photo JM. Beynet, in March 16th, 2015)

Figures 2 et 3 : River sea cargo vessel on the Rhône to Villeneuve-lès-Avignon. Waves impacting on banks after the passage of the boat (photos JM. Beynet, in April 3rd, 2015)

The three sketches below (Figures 4, 5 & 6) present this device by showing - on the left side view (Figure 4) - a standard river barge and the wave field generated. When waves reach the banks, the repeated impacts degrade banks (erosion, leak by fast draining, etc.). The central view (Figure 5) shows the same barge, on which devices BULBAT have been implemented on the two parts of the bow. The injection of bubbles before the formation of bow waves limits and deletes almost totally the wave field. The right side view (Figure 6) shows an enlargement of the central view in the zone of the bow.



Figures 4, 5 et 6 : Top view of a boat navigating in an inland waterway

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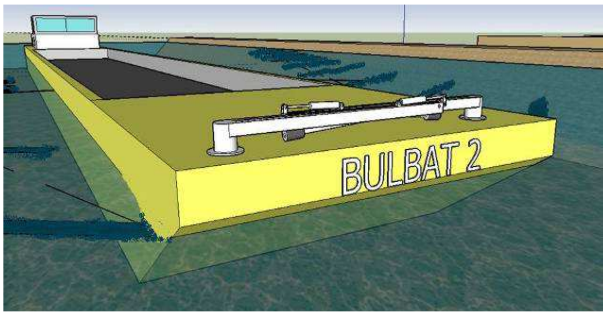
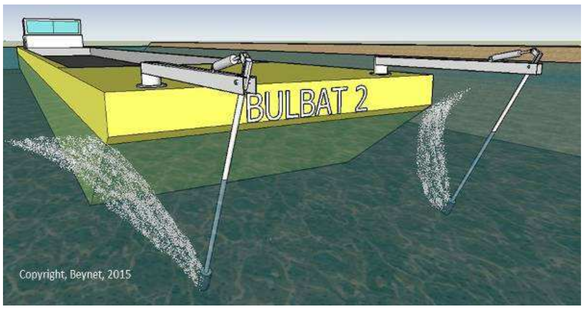
In practice, the device could be implemented on two hydraulic articulated beams and could be deployed at the forward part of a barge as shown on the two figures 7 & 8 below:





Figures 7 et 8 : Implementation of the device BULBAT on a river boat

On the left side view (Figure 7), articulated beams are folded up on board. They are therefore not annoying for the exploitation when the barge is alongside the quay or in a lock. In navigation, articulated beams can be deployed (Figure 8) and then they can be immersed from the cockpit, so as to inject the fine bubbles; this will limit bow waves so that the passage of the barge does not degrade the sensitive banks on both sides of the inland waterway. A GPS storing data about the mapping of the sensitive banks of waterways can help by recommending to the pilot the use of the devices BULBAT on the two parts or on a single part of the barge if only one of the two banks is vulnerable.

To demonstrate the legitimacy of this device, a 1:50 scale model was designed and tested on a canal[4] near Nîmes.

3- PRESENTATION OF THE TESTS ON 1:50 SCALE MODEL

The characteristics of the model are:

Length :	130 cm
Width :	22 cm
Draught :	6 cm
Weight :	17 kg

Figure 9: 1:50 Scale Model (Photo JM. Beynet)

Such a model represents – 1:50 scale - a real barge size of 11 m of wide, 3 m of draught and 2150 tons of total weight. An aquarium compressor was embedded on this model. This 20 Watt-compressor produces a discharge of 840 l/hour. This air flow was used to feed porous stones of aquarium. To be able to assess the impact of air bubbles on bow waves, tests of towing in an average speed of 0.50 m/s were made first of all without sending compressed air and in order to well visualize the symmetric bow waves on both sides of the barge (Figures 10 & 11)

Figures 10 et 11 : Tests with no bubble injection (Photos JM. Beynet, March 2014)

[4] Thanks to the Company BRL to have authorized these tests on the Canal des Costières in the first quarter 2014.

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The same towing tests were then repeated again by feeding with compressed air only the device BULBAT located at the left forward part of the barge (thus on the right on photos, Figures 12 & 13).

Figures 12 et 13 : Tests with bubble injection on left board (Photos JM. Beynet, March 2014)

It appears clearly on the previous photos that the bow wave is completely limited by the side fed with compressed air. The bank located on that side thus undergoes no degradation in spite of the passage of the barge launched at its cruising speed. The video of the tests of the scale model is available online via the following link: https://www.youtube.com/watch?v=y0j2pNg8lNo

4- PROJECT OF IMPLEMENTATION OF A 1:1 SCALE PROTOTYPE

The implementation of a prototype on an existing barge will allow to optimize the air flow and thus the power and the consumption of the compressor. In particular, we shall look for the best position of the tube to produce bubbles with regard to the forward part of the bow as well as its depth of dumping and the sharpness of bubbles.

For a river boat moving on average at 10 kph (2,8 m/s), the wavelength and the period of bow waves can be calculated by the application of the formulae below (U = boat speed):

$$\lambda = \frac{2\pi}{g} U^2 \qquad\qquad T = \frac{2\pi}{g} U \qquad\qquad \text{(1) and (2)}$$

That is to say 5 m for the wavelength and 1.8 second for the period.

Tests in laboratory swell canal for the development of a previous innovation [6] have been carried out in 2006 with a curtain that was stationary with regard to the bottom. Considering, (1) a 2.50m immersion depth for the tube producing bubbles (which approximately corresponds to the average draught of large-gauge boats), (2) a 2.8 m-long release of bubbles for a 1-second long movement of the boat (i.e.boat speed), and (3) a transmission factor Ct = 0.25 (ratio between the height of acceptable waves after breakwater and the height of incident waves before breakwater), a flow of 0.075 m^3/s for one tube (on a single board) would be necessary, i.e. 75 l/s, or 4500 l/mn or 270 m^3/hour. This value is only a first approach given for information purposes, because in the tests carried out in 2006, the bubble curtain was injected by tubes that are stationary with regard to the bottom, which is not the case of the present application, because bubbles are released at a horizontal speed equal to the speed of the river boat.

Such a flow would approximately correspond to a 50 kW compressor. It has to be noted that because of the low necessary pressure, the production of compressed air could come not from a compressor, but from a blower, which is cheaper and more energy-efficient. For information purposes, a blower (turbine) able to feed tubes to produce bubbles on the two forward parts the boat - to supply 300 to 500 m^3/hour at 450 mbars - would consume from 12 to 15 kW, which is almost negligible compared to the motorization of propulsion of the river boat. Indeed, if we consider a 1300 kW-motorized Class V boat (110 m x 11.40 m), the overconsumption in energy to produce the compressed air will be of about only 1% in the case of a blower.

Furthermore, it could be possible that the overconsumption is non-existent or almost negligible because, on the one hand – as it can be seen on the video of the first 1:50 scale tests - a part of the bubbles passes under the hull, thus probably decreasing the friction of the hull in the water and, on the

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other hand, the boat does not have to fight any more in principle against the bow wave it generates because the wave is limited before its formation thanks to the bubbles.

Before the implementation of a 1:1 prototype, new tests on physical model in the 1:25 scale realized in a canal with a current, would allow to measure the traction of the boat to check if the injection of bubbles at the forward part decreases this tractive force or not.

For future river boats, this innovative system of injection of bubbles at the forward part of the bow could be combined with the recent innovations of air injection in cavities under the hull to decrease the friction in the water and to reduce fuel or NGL consumption. In recent research [13] and [14], fuel savings are said to be of about 15%.

If, in spite of such 1:1 scale tests of optimization, the necessary power to produce bubbles turned out to be penalizing compared to the consumption of the boat, the solution of the power supply by an embedded fuel cell could be envisaged.

5- COMPARATIVE APPROACH OF THE CARBON FOOTPRINT AND SOCIAL ACCEPTANCE OF THE INNOVATION

In 2006, the Regional Office of VNF in Lille (France) performed a study for the rehabilitation of the banks of the inland waterway network in the Région Nord-Pas-de-Calais [15]. Conclusions drawn by this study show that "*the systematic field surveys on all the banks and the dikes allowed to draw up a morphological diagnosis: it seems that 30% of banks are in bad or very bad state. These damages are mainly due to a very high river traffic (more than 40 boats a day), which implies thus very significant constraints linked to the wave action.*" [5]

As estimated in the previous paragraph, the overconsumption of a boat equipped with the device BULBAT could be of about 1% or even less than it if the boat does not have to fight against its bow wave. Besides, if we consider that the device will not have to work continuously, but that it will have to be deployed and immersed when the boat navigates along sensitive, vulnerable or already degraded banks, the percentage of overconsumption would then be still decreased.

To help the pilot decide whether to deploy the device BULBAT or not, a GPS storing the location data of sensitive banks (or high risk areas) is embedded. If only one of the two banks followed by the barge is sensitive, the GPS indicates it and in this case, the pilot can deploy the BULBAT system on this board only, thus dividing by two the consumption needed for the production of the fine bubbles.

In the example quoted above, for the inland waterways of the North of France, there are 30% of sensitive banks on the overall route of the boat. In these conditions, the overconsumption would be at the most 0.3%, which would have a negligible or non-existent impact for the carbon footprint.

On the other hand, thanks to the implementation of the device BULBAT, the dredging and maintenance works of banks could be reduced, thus further improving the carbon footprint of such works. As an example, in the "Memento du fluvial 2010-2011", VNF quotes some financial estimations for the costs for operating and securing the network and announces the figures of 55.8 M€ for the restoration of the large-gauge network, 12.7 M€ for the restoration of the main small-gauge network and 12.4 M€ for the small-gauge regional network.

In the same document, VNF specifies that the average cost for the stabilization and the protection of banks is of about 1 M€/km to 1.5 M€/km and it adds that the cost of protection of banks through revegetation techniques oscillates between 100 k€/km and 300 k€/km (except stability of dike).

[5] Original text in French : translation into English has been made for the present article.

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Another example of the cost of works is provided in Wallonia (Belgium). In a synthesis document [16], the Direction Générale Opérationnelle de la Mobilité et des Voies Hydrauliques (DG02 du Service Public de la Région Wallonne) details the budgets spent in 2013 for the maintenance of waterways. It explains that maintenance works amounted to more than 20 M€ (among which about 10 M€ for dredging works) for 450 km of waterways. Among volumes to be dredged, a part comes from the destructuration of banks due to the wave action and the carriage of fines by the current. The sediments – pulled up from the banks – settle then at the bottom, a short distance downstream, thus reducing the depth of the waterways over the years, which requires dredging works to restore this depth.

Whether it be in France or in Wallonia, and as far as earthmoving works, maintenance dredging works or even the supply of protection materials are concerned, these activities generates significant CO_2 emissions. In a recent study, VNF provides some figures for its own network [17] : *« construction materials used for the restoration of banks and river structures (except sheet-piles) generate 42 820 t CO_2 e (ton CO_2 equivalent). Sheet-piles are the second source of emission, with 29 650 t CO_2 e*[6] *».*

Finally, by adopting and by equipping river boats and barges of the device BULBAT, all the stakeholders of the inland waterways would gain the following:

- The no-degradation of banks and thus the decrease of the maintenance works should interest the European Inland Waterways Authorities;
- The possibility of increasing the speed (or not to reduce it in the zones of sensitive banks) with a negligible impact on the consumption should interest the water carriers;
- The local residents and other users of the inland waterways (fishermen, for example) will appreciate too the no-degradation of banks and the reoxygenation of the environment through the injection of fine bubbles.

It is widely recognized that waterway transport is the most ecological transport mode compared to road or even rail transport [18]. Waterway transport releases less CO_2 per tonne moved, especially in the case of wide-gauge navigation (Class V). The waterway ecocalculator made available online by VNF enables to easily check it with specific simulations.

But so far, there was nevertheless a negative impact on banks and on waterside activities. This negative impact will not exist any more when river boats and barges will be equipped with a device such as BULBAT.

To conclude, the innovation BULBAT shows a high potential for the protection of the environment and the reduction of CO_2 emissions. By resorting to this device, river transport will be even more ecological than it is at present, compared to other modes of transport.

Thanks to the savings expected on the maintenance works on banks and dredging, it would be interesting that the European Commission and the Inland Waterways Authorities induce river transport companies to gradually equip their existing and future fleets – and that they help them finance the implementation of the device.

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