EXPERIMENTAL STUDY OF THE DIFFERENCE IN SENSITIVITY TO FLOW NOISE OF CLASSICAL AND SURFACE PVDF HYDROPHONES

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1. INTRODUCTION

The flow noise induced by the turbulent boundary layer (T.B.L.) on the acoustic arrays of any ASW sonar (towed arrays, bow and flank arrays of ships and submarines, etc) is becoming a predominant limitation of passive sonars performances, due to the significant reduction of the other self noise contributions (by propeller optimization, ship machinery quieting etc.)

This flow noise depends on many parameters :

- for hydrophones mounted directly on the hull, any pressure fluctuation of the T.B.L. creates a "pseudo-acoustic" response of the hydrophone. Most of the energy of the T.B.L. is unable to create an acoustic radiation (the associated wave numbers differ from the acoustic wave numbers, cf. fig. 1) but exerts forces on the transducing element and induces an electric response similar to the acoustic one.
  There is only one filtering effect : when the extent of the sensitive area exceeds the pressure fluctuations wavelength, a fraction of its instantaneous strengths vanishes by the spatial integration effect (cf. fig. 2).

- when an elastic layer is added between the flow and the sensitive face of the hydrophone, an additional filtering of the T.B.L. excitation is obtained. That means that the excitation content close to the acoustic wavelength in the elastic layer is fully transmitted, and the other components decay exponentially. If the layer is "acoustically transparent" (i.e. its acoustic wavelength very close to the surrounding acoustic medium), we may obtain an interesting compromise between the acoustic sensitivity of the hydrophone and its flow noise insensitivity (cf. fig. 3).

- most of the time, the hydrophone is installed in an "acoustic cavity" filled with water or oil, and separated from the flow by an "acoustic window". The flow noise induced by the T.B.L. becomes now the result of several mecano-acoustic energy transfers (cf. fig. 4):

  * as a result of the high "acoustic transparencies" of the acoustic window, the acoustically coincident fraction of the T.B.L. energy propagates without attenuation to the hydrophones but it is most of the time a low fraction of the total T.B.L. energy.

  * the T.B.L. excitation induces vibrations of the acoustic window. These vibrations propagate to the stiffeners, sides and corners of the window, and it results, due to the plate-like structure acoustic radiation mechanisms, in a significant inhancement of their "acoustic efficiency" : the window vibrations convert to the T.B.L. non-acoustic contents into acoustic radiations in the acoustic cavity.

  * the T.B.L. excitation induces vibrations of the surrounding structures (hull, ballast tanks, ...) which radiate sound in the acoustic cavity. The availability of "acoustic masking" materials offers now some ways to control that noise contribution by covering the back sides of the acoustic cavity.

As a result, the prediction of the T.B.L. self noise in the preliminary design stage of a new sonar array appears difficult by using only numerical tools ; and early tests on the prototypes of the acoustic elements are required.

Obviously, the direct measurements of that noise contribution on a given acoustic array element is very difficult in classical water tunnels, because they remain most of the time intrinsically noisier than the level to be measured.

2 - DEVELOPMENT OF LOW T.B.L. NOISE SENSITIVE ARRAYS

As a result of the previous discussion on T.B.L. noise contributions, the development of solid integrated arrays appears as an interesting compromise and opens the possibility of a direct implementation on the pressure hull ("flank arrays", "conformal arrays", etc). A typical array structure includes (from front to back) (cf. fig. 5) :

- an elastic acoustically transparent layer,
- the sensing elements,
- eventually, an acoustic reflector to enhance (by x 2 factor) the acoustic sensitivity of the hydrophones,
- an acoustic mask to stop the noise radiation of the vibrations of the supporting structures.

The ultimate T.B.L. noise reduction requires thus :

-> the optimization of the elastic layer (most of the time, it is made from polyurethane chemistry which allows precise adjustments of longitudinal and transverse sound speeds and damping)

-> the optimization of the shape of the sensing element itself

-> the optimization of its vibratory compensation.

In the first design stage, we use at METRAVIB R.D.S.'s a set of coupled analytical and FEM tools (cf. fig. 6) to validate the array concept and identify some interesting design alternatives. The detail of these methods is out of the scope of the present paper, and will be presented in other congresses. (UTD 91 in particular).
The critical step is the validation on real scale prototypes and mock-ups of these design concepts, with as objectives :

- the previous modelizations contain some simplifications and approximations. They were supposed to be of second order influence, but that needs to be verified.

- these prototypes and mock-ups help to identify the technological difficulties of innovatives designs. Some of them may have an influence on nominal acoustic sensitivity and self-noise sensitivities (e.g. poling process, sheer transmission to the sensing element, vibrational coupling, etc).

It is the reason why the French DCN (GERDSM, ECN Toulon) decided to build a specific test facility, called LIMANDE.

3 - LIMANDE : GENERAL OVERVIEW

LIMANDE is a towed fish which bears six acoustical panels, three on each flank. Figure 7 gives the shape of the fish and the panel locations. The length is roughly 12 meters long and the whole system is designed to be underwater towed, without any self propulsion capability.
The operating velocities are between 4 to 15 knots. Each panel studied here contains four hydrophones, two punctual hydrophones and two extended hydrophones (10 x 10 cm). These hydrophones are coated in the panels with different coating materials ; the acoustical properties, regarding the hydrodynamic noise, are then evaluated in full scale experiments.
The standard size of such panels is 0,7 m x 1 m and their thickness up to 150 mm.

Measurements :

An acquisition system is located in a waterproof cavity inside LIMANDE : this acquisition system allows to record signals from the hydrophones in the panels as well as other signals for the general monitoring of the experiment.

Among these signals are :

- 8 reference hydrophones located in the ballast and used as environmental noise references,
- 6 accelerometers (among them 2 low frequency accelerometers) used to detect abnormal vibrations in the structure,
- a temperature sensor,
- a pressure sensor,
- a microphone located in the waterproof cavity.

Safety systems are also present to detect fire or water intrusion and to operate emergency cases through the use of air bags and droppable ballast weight. The recorded signals for scientific and technological analysis are the 6 x 4 = 24 signals from the acoustical panels, in the frequency range 5 Hz - 40 kHz.

During an experimental survey the LIMANDE fish is towed several times across a lake with a remote recording command sent to the acquisition system : analog records are then available with acoustical signals acquired during the experiment as well as with the monitoring sensors outputs.

For the GRP window panel, some measurements were made with a damped GRP (two plates with a damping material between them), reaching tg δ above 0.2 in the whole frequency range.

The punctual hydrophones were commercially available hydrophones, with a - 200 dB sensitivity.
The other hydrophones have been developped by METRAVIB R.D.S. for that special purpose : they are PVDF hydrophones with a - 202 dB sensitivity (see figure 9).
The table 1 summarizes the different tested panels (fig. 10).

Material / Thickness	GRP e = 15 mm tgδ < 0.06	GRP e = 15 mm tgδ > 0.2	**Elastomer** low C_t	**Elastomer** standard C_t	**Elastomer** high C_t
Adjustable thickness	20 à 100mm	20 à 100 mm			
h = 50				tgδ ≤ 0.07	
				tgδ ≥ 0.3	
			tgδ = 0.2		tgδ = 0.2
h = 25				tgδ = 0.2	
h = 85				tgδ = 0.2	
h = 100				tgδ = 0.2	

fig.10:Table

The first survey was conducted with different coating materials either with a "dome" principle (GRP acoustical window, and hydrophones in the water behind), or with coating materials containing the hydrophones.

The analysed parameters were :

- coating thickness (or distance hydrophones/ac. window),
- longitudinal velocity,
- transverse velocity, of the ac. window or of the coating material
- and damping factor.

The given constraints for the choice of different elastomers were :

- operating temperature between 5°C and 10°C,
- frequency band (1 kHz to 10 kHz),
- minimal longitudinal velocity : 1500 m/s,
- maximum acoustical impedance : 1.8 10^6 (5°C, 10 kHz).

One reference set of panel was based on :
$tg\ \delta_T = 25$ %
$C_T = 200$ m/s

Other tested panels were based on :
1) $tg\ \delta_T = 20$ % $C_T = 70$ m/s
2) $tg\ \delta_T = 20$ % $C_T = 450$ m/s
3) $tg\ \delta_T = 7$ % $C_T = 160$ m/s
4) $tg\ \delta_T = 40$ % $C_T = 240$ m/s

The reference panels and these four panels were designed with a 50 mm thickness.
Three other thicknesses were tested, with the same material as in reference panel :
6) Thickness : 25 mm.
7) Thickness : 85 mm.
8) Thickness : 100 mm.
The hydrophones are located 20 mm above a reflector (see fig. 8).

4 – RESULTS

Initial tests have been performed to ensure that the LIMANDE could deliver good quality signals without too many environmental noise. The objective is to measure <u>only</u> hydrophonic noise as far as it is possible.

Global tests (buoyancy, stability, etc) as well as detailed tests (comparison of results with some panels at different locations, comparison of results at symmetrical locations, etc) have been performed with significantly good results, for six identical reference panels.
Then the tested panel have been used at different locations on the LIMANDE board.

The main results are given below.

a) The hydrodynamic noise could be identified with velocities starting from 3 m/s. The typical velocities during experiments were between 4 and 7 m/s.
The theoretical law $S_{(f)}$ could be observed with a typical slope

$$\frac{d\acute{s}\,(f)}{df}$$

proportional to f. (see figure 11 with a curve at 7 m/s)

A typical pressure law $P = kV^{10/3}$ has been observed in good agreement with theory.

b) We did not put into evidence any noticeable difference between punctual hydrophones and PVFD sensors, even above 1 kHz (fig. 12 and fig. 13).

c) <u>Coating materials</u> :
The filtering effect of the coating material is better with thicknesses of 100 mm and 85 mm than with 50 mm or 25 mm. Nevertheless this is not extremely significant if the standard is taken as reference point (50 mm).
A low transverse velocity is better for hydrodynamic noise attenuation.

d) <u>GRP window</u> :

Above 1 kHz and sometimes above 500 Hz a significant improvement is due to this type of protection, especially with the highly damped window domped material and at high flow velocities.

Apart from these main results it was difficult to come with definitive conclusions because of different factors :

- The transition zone was located in front of the first panel so that more or less the same results were available for the three locations front, middle, rear.

- The hierarchy between the different coating solutions is depending on the chosen criteria : the difference between attenuation figures does not remain the same when the analysed velocity changes or when the frequency domain of interest changes. It then comes to be difficult to give an opinion concerning all velocities and a large enough frequency band.

- The global incertainty was around 2 to 3 dB (estimated after analysis of the six identical panels results) : this is not so far from the theoretical self noise reduction factors predicted with our technological models.

CONCLUSION

The particular experimental fish was proved a good hydrodynamic noise recording vector. A full confidence was established in the recorded data and allowed an interesting comparison between technological solutions as well as between actual data and theoretical predictions.

The LIMANDE testing facility at Castillon lake is now fully operational, and may be available for any future ASW systems developments.
It permits not only to get these full scale T.B.L. noise responses (versus time, but also spectra, cross spectra, etc or any form to be used to simulate the T.B.L. noise on process sonar signals), but also to validate and correct the numerical tools used in the preliminary design stages, and to check the T.B.L. models by themselves. As a result, it helped to give to METRAVIB R.D.S. and GERDSM a skilled expertise in self-noise reduction by direct "physical" optimization of the mechanical structure of the sonar arrays of recent design.

This full scale facility is now one of those available at the experimental site at Castillon lake (French Navy) : it brings a useful complementary tool to the scale 1 hull sections used in parallel to evaluate the baffling effect of the hull and the array response to mechanical excitations behind the hull (acoustic barriers efficiency).

ACKNOWLEDGMENTS :

This work has been carried out with the support of the French DGA : ECN Toulon, G.E.R.D.S.M. ; and we thank them gratefully to have permitted this publication.

EXPERIMENTAL STUDY...

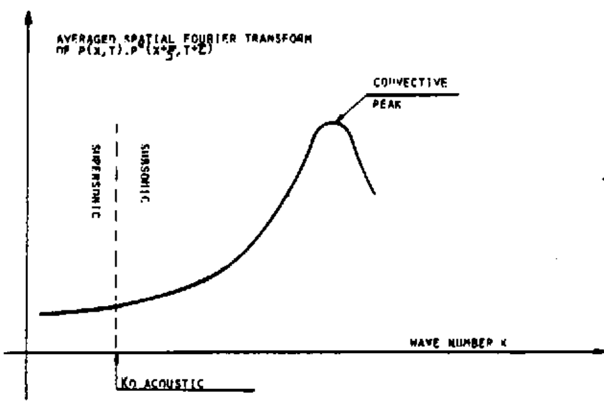

fig.1:Typical TBL excitation spectrum

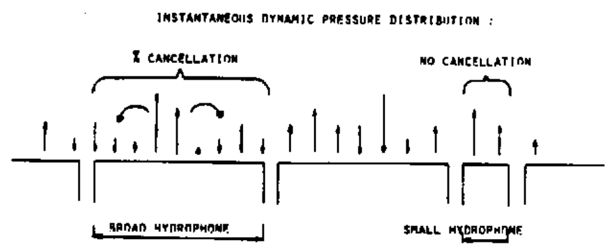

fig.2:TBL pressure fluctuations integration VS hydrophone size

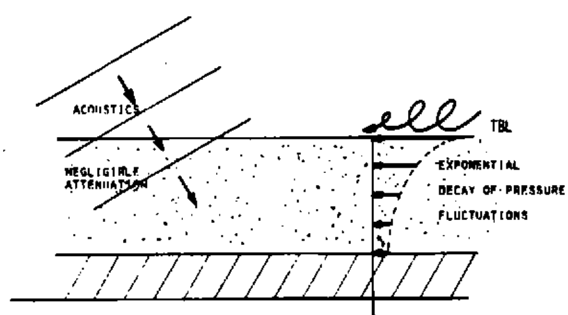

fig.3:Interest of an acoustical transparent external layer

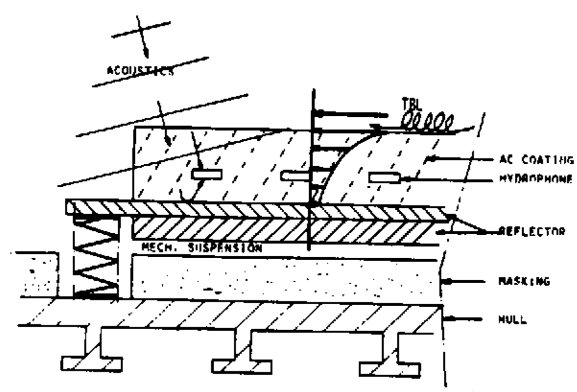

fig.5:Typical set-up of a sonar flank array

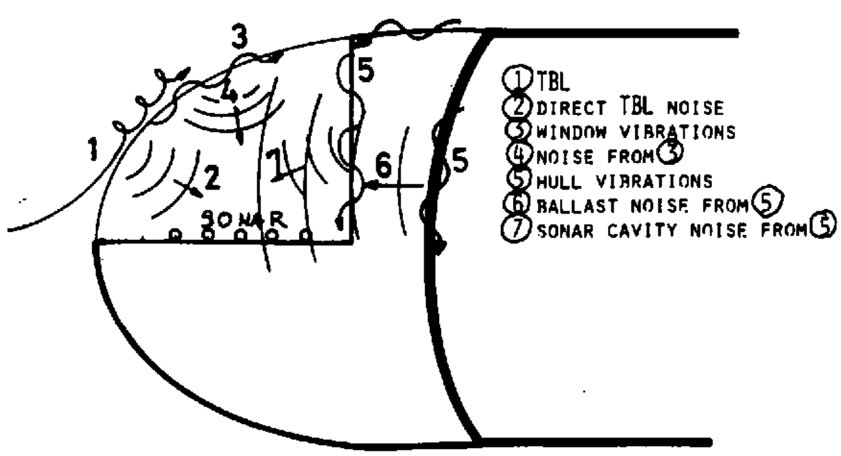

fig.4:Different paths of TBL self noise in a typical bow sonar

EXPERIMENTAL STUDY...

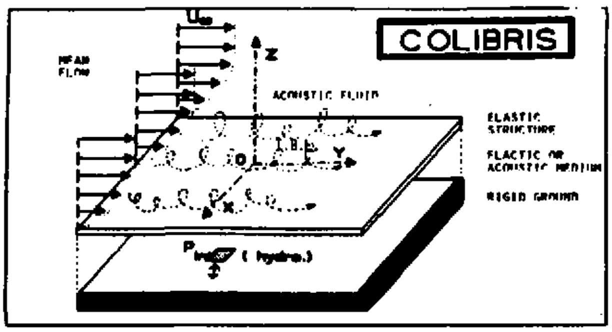

fig.6:Example of dedicated software:COLIBRIS Prediction of baffled hydrophones response to T.B.L. excitation through elastic media

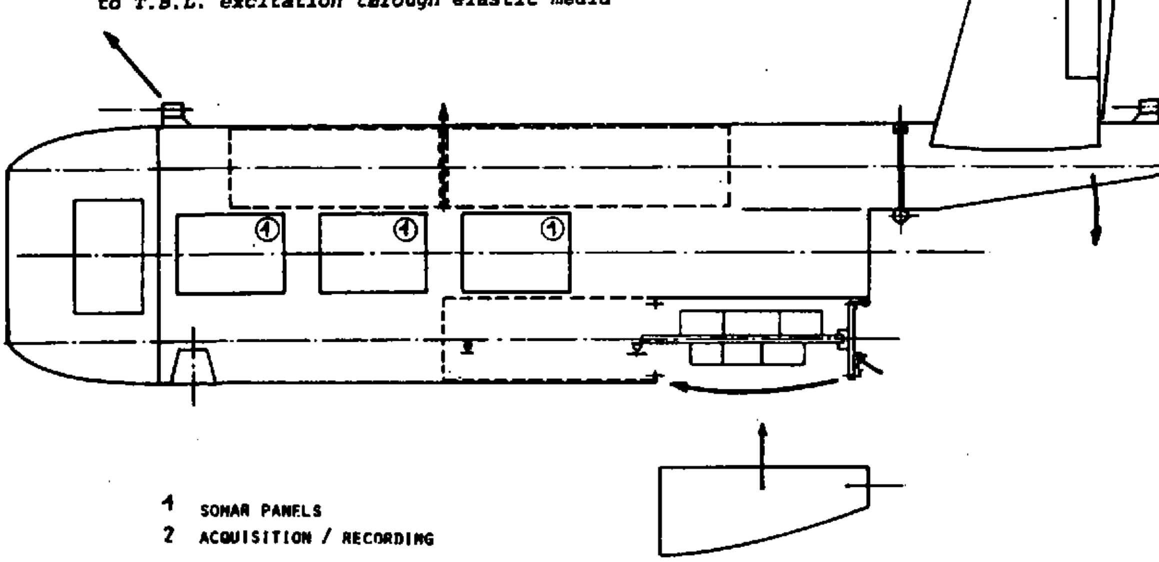

fig.7:The LIMANDE towed "fish"

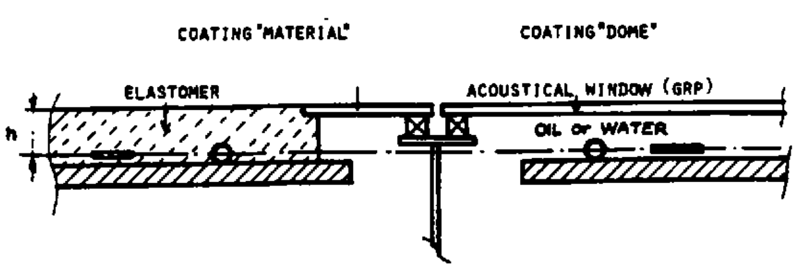

fig.8:Two coating types

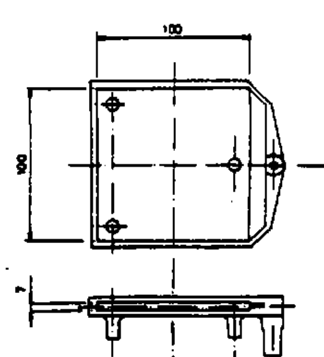

fig.9:PVFD hydrophone set-up

EXPERIMENTAL STUDY...

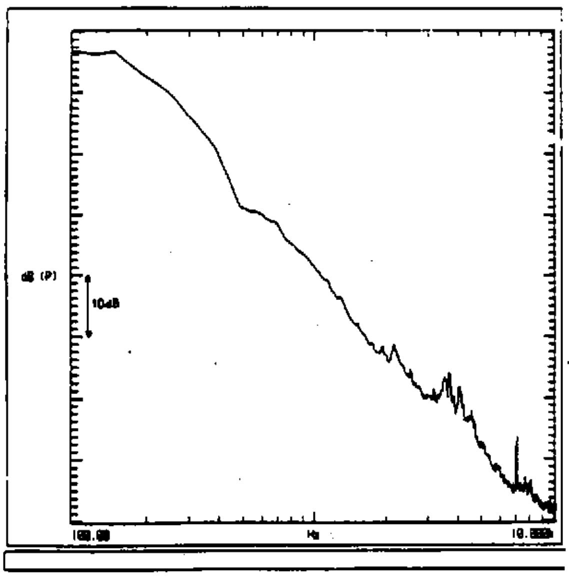

fig.11:"Typical spectrum at 7 m/s"

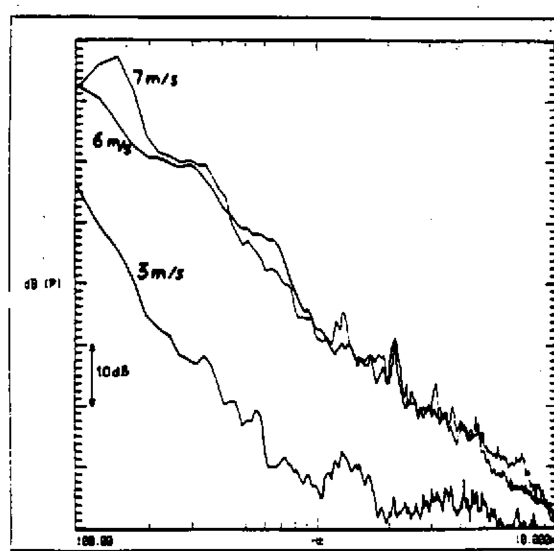

fig.12:"Punctual hydrophone results"

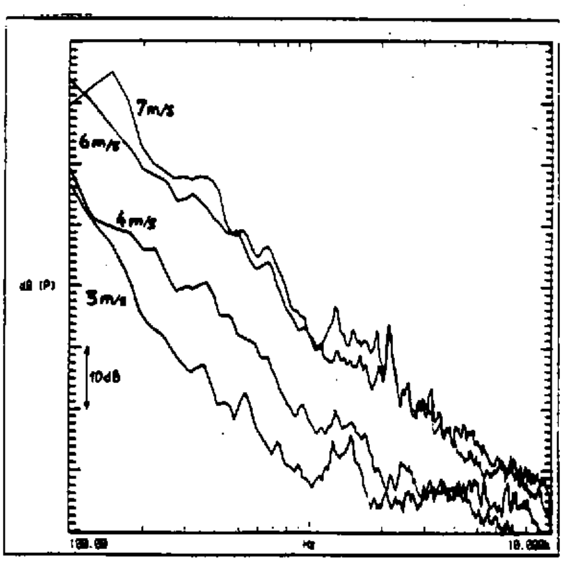

fig.13:"PVFD hydrophone results"