
# EVALUATION OF MEASUREMENT UNCERTAINTIES IN THE ASSESSMENT OF THE NOISE IMPACT OF SHIPS

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Measurement operations are all inevitably affected by uncertainty, that is defined as the "degree of uncertainty" with which the measurement process obtains the result. It produces a range of values in which the true value of the measurand is present with a certain probability.
In the specific case of the evaluation of the acoustic emissions associated with ships, this degree of uncertainty is referable to several causes, better understandable if the measurement procedures indicated by the reference standards are described (for example ASA (Acoustical Society of America) S12.64-2009/PART 1), adopted for all types of ship (with no limitation in size) that transits at a speed not exceeding 50 kn in deep water.
The standard offers three degrees of measurement (A, B or C), which differ in terms of uncertainty, complexity and repeatability. In general, information is given on the characteristics of the instruments, signal processing and positioning of hydrophones. The standard is valid only in deep water and this represents its main limit: in the case, for example, of very large ships it is difficult to reach the great depths with the instruments.

From the analysis of the prescriptions, it clearly follows that noise measurements in water are intrinsically affected by measurement errors that can be reported to the following three macro-types:

1. Error due to the degree of precision of the measurement chain
2. Error due to relative positioning between source and receivers
3. Error due to the characteristics of the measurement environment

In the present work, all these possible sources of error have been evaluated on the basis of numerical simulation models whose results have been validated by experimental tests at sea, to arrive at the definition of a procedure for estimating the overall error inherent in the measurement and thus defining procedures for the control of the same.

Keywords: **Underwater ship noise, noise measurements, underwater noise propagation**

## 1. Introduction: le  incertezze di misura nella valutazione del rumore emesso da navi

The standard measuring  procedure of the noise radiated by ships was issued by ANSI (American National Standards Institute) and ASA (Acoustical Society of America) S12.64-2009/PART 1, adopted for all types of ship (with no limitation in size) that transits at a speed not exceeding 50 kn in deep water. The standard offers three degrees of measurement (A, B or C), which differ in terms of uncertainty, complexity and repeatability. In general, information is given on the characteristics of the instruments, signal processing and positioning of hydrophones. The standard is valid only in deep water and this represents its main limit: in the case, for example, of very large ships it is difficult to reach the great depths with the instruments.

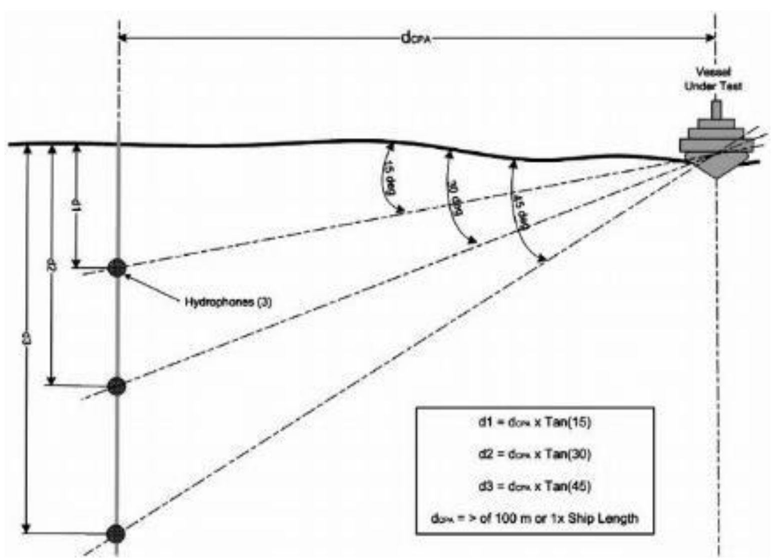


*Figure 1 Positioning hydrophones in the ANSI-ASA standard.*

The use of multiple hydrophones is essential to highlight the directivity of the source in the vertical plane and to mitigate possible differences in sound levels due to sound transmission phenomena. Generally, for each operating condition the test is carried out with hydrophones that can be held in place differently (as shown in Figure 2 below).

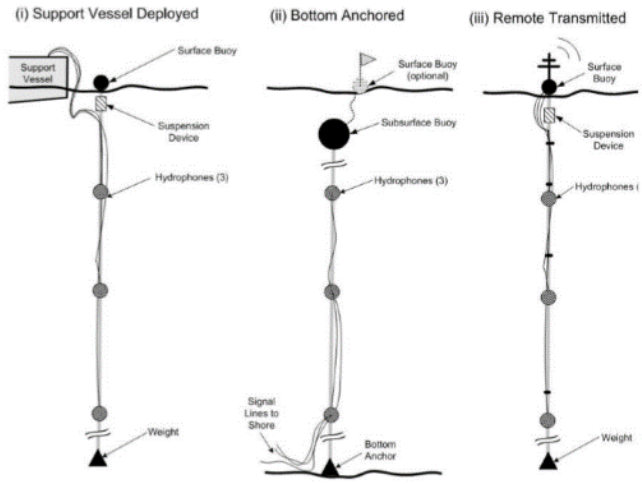


*Figure 2 Positioning of hydrophones in the ANSI-ASA standard***.**

The measurement layout, with the positioning in the plane of the ship route and the relative positioning of the measuring points is illustrated in the following figure 3.

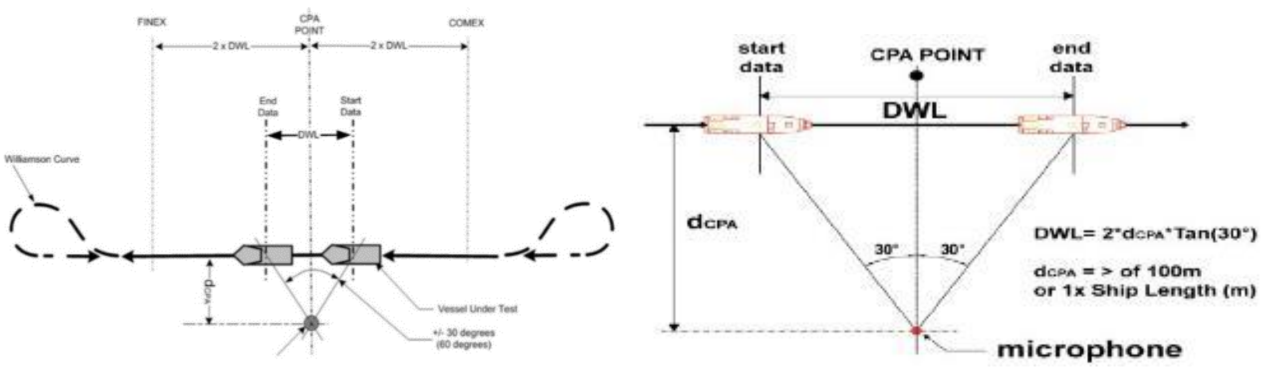


*Figure 3 Characteristics of the measurement layout*

The sound level is recorded in a time interval centered at the CPA point, the closest point of approach. The length of the time interval depends on the distance between the buoy and the course of the ship, which in turn depends on the size of the ship itself.

From the measurement of the pressure values detected to the hydrophones, we then move on to the evaluation of the pressure level at 1 meter from the ship, by means of the propagation law that suggests considering the typically spherical pressure field:

$$\Delta L = 20 \log r \qquad (1)$$

where "$\Delta L$" is the change in sound level and "r" is the distance between the ship and the buoy.

A slightly different procedure is adopted within the DNV Standard but same consideration as for the ANSI standard can be done with reference to the error evaluation.

From what has been exposed, it seems therefore evident, that noise measurements in water are intrinsically affected by measurement errors that can be reported to the following three macro-types:

1. Error due to the degree of accuracy of the measuring chain
2. Error due to relative positioning between source and receivers
3. Error due to the characteristics of the measurement environment

The **type A** error is in principle easily determined on the basis of the technical characteristics of the various elements that make up the measurement chain (essentially hydrophones and acquisition system) and can therefore be considered a known fact since the beginning of the Experimentation campaign.

The **type B** error, in a three-dimensional domain in which the source and receivers are in relative motion (refer to the diagram of figure 2.3 for movement in the plane and scheme 2.1 to introduce the depth component), can in turn be decomposed into several components:

1. Height of the ship's acoustic center
2. Deviation of the nal path from the ideal trajectory
3. Deviation of the position of the hydrophone line (distance between buoy point and ship line due for example to rotten currents and/or wave motion)
4. Non-alignment vertically of the hydrophones (due to sempio to sea currents varying with the depth)

The **type C** error, in a three-dimensional fluid domain in which the propagation of sound depends on the characteristics of the medium and its boundary conditions, can in turn be decomposed into several components:

1. Effect of Water Column Stratification Compared to Standard Reference Conditions
2. Effect of remelting from the bottom compared to standard reference conditions
3. Effect of free-haired reflections compared to standard reference conditions

## 2. Proposed methodological approach and calculation tools

As part of this activity, for the evaluation of the error intrinsically related to a specific experimental measure, a methodological approach was adopted based on the combined use of a commercial code (AcTUP) and a specific calculation code developed within the project (NoiseAround).

AcTUP (Acoustics Toolbox front-end) is a code developed in Matlab environment, which allows the calculation of the Transmission Loss at the points of a given fluid environment as the characteristics of the environment itself vary; the code also implements the different acoustic propagation codes available in the literature.

The following figure shows a summary diagram of the conditions of use of the different calculation algorithms.

| Model type | Applications | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Shallow water | | | | Deep water | | | |
| | Low frequency | | High frequency | | Low frequency | | High frequency | |
| | RI | RD | RI | RD | RI | RD | RI | RD |
| Ray theory | ○ | ○ | ◑ | ● | ◑ | ◑ | ● | ● |
| Normal mode | ● | ◑ | ● | ◑ | ● | ◑ | ◑ | ○ |
| Multipath expansion | ○ | ○ | ◑ | ○ | ◑ | ○ | ● | ○ |
| Fast field | ● | ○ | ● | ○ | ● | ○ | ◑ | ○ |
| Parabolic equation | ◑ | ● | ○ | ○ | ◑ | ● | ◑ | ◑ |

Low frequency (<500 Hz) RI: Range-independent environment
High frequency (>500 Hz) RD: Range-dependent environment

● Modeling approach is both applicable (physically) and practical (computationally)
◑ Limitations in accuracy or in speed of execution
○ Neither applicable nor practical

*Figure 4: Applicability of calculation models for sound propagation in water*

Using the AcTUP code, it was possible to evaluate the trend of the Transmission Loss as the characteristics of the propagation environment (size of the fluid domain, characteristics of the water column, characteristics of the seabed, roughness conditions of the free hair) and the noise source (depth of the acoustic center of the ship) variation.

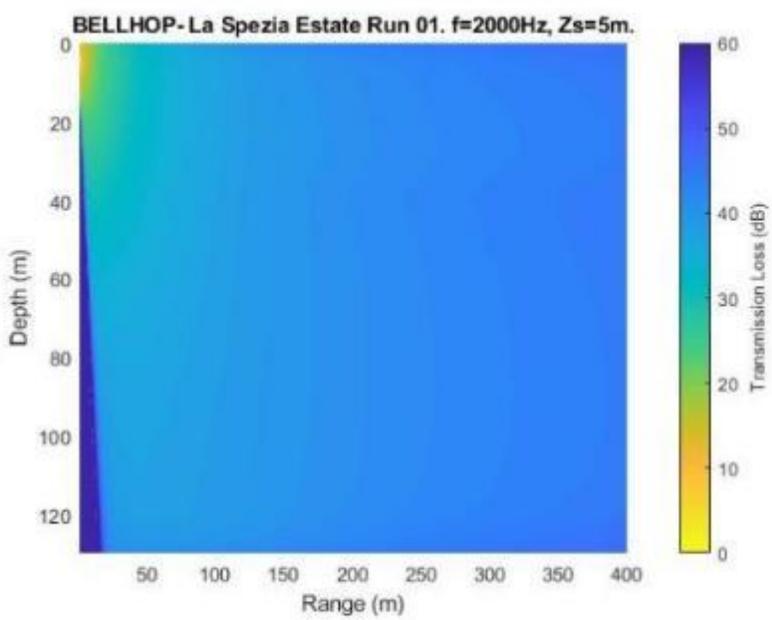


*Figure 5: Example of ACTUP output across the entire trace domain*

AcTUP, on the other hand, does not allow the analysis of the other variables indicated in paragraph 1 and also has strong limitations in the posthumous management of the processed data.

To meet these last two needs, the NoiseAround code was developed, also developed in the Matlab environment.

The calculation code, developed in matlab R2018b environment, allows the calculation of the cumulative measurement uncertainty that could be affected by a measurement of noise propagation in water (or better than in the evaluation of the relative Transmission Loss) and allows a graphical visualization of the distribution of this uncertainty around the ideal point of measurement.

The code uses the results of simulation models generated by the ACTUP code allowing to extract the information in well-defined circles of the investigated fluid domain and subsequently allowing to process this information to determine how much of specific interest.

In practice, starting from a simulation scenario as illustrated in Figure 5, it is possible to select specific positions of the fluid domain that correspond to the positions of the sensors with reference to the position of the ship (which in the ACTUP code is always abscissa equal to zero, being able to vary only the depth).

These sensors, ideally positioned at known and fixed coordinates, can undergo coordinate variations due to the combined effect of several factors.

Two images are shown below that clearly indicate the error ranges with respect to the vertical (depth of measurement) and horizontal (distance between source (ship) – and receptor (hydrophone)) and that graphically illustrate the logical process of data extraction.

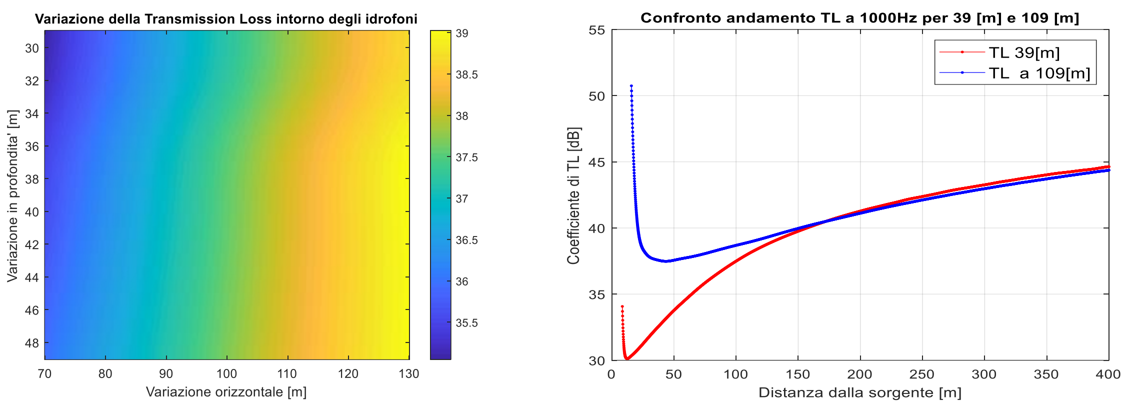


*Figure 6: Example of NoiseAround output across the specific area of interest*

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