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Underwater Noise from Ships, Full Scale Measurements

1. PURPOSE OF THE GUIDELINES

The purpose of this guideline is to provide general procedures and methodologies to be used in measuring underwater noise from surface ships. For the purposes of this document underwater noise is meant the sound generated by a ship as measured in terms of sound pressure levels. Current interest in measurement of surface ship underwater noise is driven by recognition of the importance of anthropogenic (human-made) noise in the ocean and its environmental impact. The reported significance of this environmental impact has led to establishment of national and international rules on acceptable levels of ship-generated underwater noise. The current procedures and guidelines only address the measurement of underwater ship noise and do not comment on the impact of such noise.

It is noted that the subject of measuring under water ship acoustic signatures is currently being examined by many different International Committees and a few standards have been issued. Reference to these standards is provided in §2. Of particular note in this regard are the publications issued by the ANSI, ISO and DNV organizations concerning deep water measurements. Much of the material provided in this Procedures and Guidelines is drawn from these publications. It is recommended that the current Recommended Procedures and Guidelines be revisited and updated as necessary when further International Standards for this topic are established. In the case of shallow water, careful attention must be given to measurements to account for bottom effects, particularly if such results are used for predicting performance where bottom effects are different.

To gauge the level of activity in measurement of underwater ship noise within the ITTC Organization, a Questionnaire on Full-Scale Noise Measurement Methods was sent to all ITTC member Organizations. This survey questionnaire was companion to a Model-Scale Noise Measurements questionnaire similarly solicited to ITTC member Organizations. A total of eleven responses to the Full-Scale Noise Measurements Methods questionnaire were received from eight countries; France, Germany, Italy, Japan (2), Korea (2), Netherlands (2), Spain and the United States. The Full-Scale Noise Measurements Methods questionnaire solicited responses to questions related to five general categories; 1) Test site information, 2) Full-Scale Hull/Propeller, 3) Hydrophone Information, 4) Data Acquisition and Processing, and 5) Correction Methods to Obtain Noise Source Levels. These Recommended Procedures and Guidelines are drafted from the responses from this questionnaire and from various Standards and technical reports on this topic.

2. NORMATIVE REFERENCES

The following referenced documents are used to develop the present guidelines.

ANSI/ASA, 2009, “Quantities and procedures for description and measurement of underwater sound from ships, Part 1: General requirements”, ANSI/ASA S12.64-2009/Part 1.

ISO, 2012, "Acoustics-Quantities and procedures for description and measurement of underwater sound from ships, Part 1: General requirements for measurements in deep water", ISO/PAS 17208-1:2012(E).

DNV, 2010, "Silent Class Notation", Det Norske Veritas (DNV), Rules for Ships, January 2010, Pt 6, Ch. 2.

ISO, 2013, "Ships and marine technology-Protecting marine ecosystem from underwater radiated noise- Measurement and reporting of underwater sound radiated from merchant ships", ISO/CD 16554.

TNO, 2011, "Standard for measurement and monitoring of underwater noise, Part 1: physical quantities and their units", TNO-DV 2011 C235

Van der Graaf, A.J., Ainslie, M.A., André, M., Brensing, K., Dalen, J., Dekeling, R.P.A., Robinson, S., Tasker, M.L., Thomsen, F. and Werner, S., 2012, European Marine Strategy Framework Directive - Good Environmental Status (MSFD GES): Report of the Technical Subgroup on Underwater noise and other forms of energy.

3. MEASUREMENT REQUIREMENTS AND PROCEDURE

3.1 Introduction

Documentation and reporting of information regarding the test site where underwater measurements are made are critical to the resulting usefulness of the measurements. Once measurements are obtained at a test site there needs to be sufficient information to allow appropriate test configuration and site/environmental related corrections to be made to arrive at noise source levels for the ship. This provides test site independent noise source levels which are used with noise propagation models to estimate ship noise impact when the ship is operating at other locations or in other oceanic environments. The discussion in other sections of this document address issues related to the requisite range corrections.

In this section on Measurement Requirements and Procedures are described: test site requirements, measurement configuration, testing configuration and environmental conditions such as sea state and associated weather conditions.

3.2 Test site configurations

The procedures and methods employed for full-scale noise measurements are dictated by the objectives and purpose of the measurements program; for example whether the measurements are made on commercial, military, or possibly research vessels. The ANSI and ISO standards listed in §2 provide measurement standards that depend on the quality of measurements needed. Specifications for three grades of measurement quality are provided; precision grade, engineering grade, or survey grade. As reference, of the eleven questionnaire responses, three were for sites that predominantly conduct underwater noise measurements of military ships.

Testing is generally done using either fixed or mobile measurement equipment with the majority of the sites responding to the questionnaire being of the latter, in part due to the intensity and cost of fixed facilities. It is noted that the three fixed sites also employ mobile equipment and were those that predominantly support measurements of military ships. Additionally, five responding organizations reported using on-board measurement equipment, four of which use such equipment in addition to fixed and/or mobile range equipment.

All test sites employ some variation of two basic configurations for deploying hydrophones used to measure underwater noise; hydrophones(s) suspended from a surface buoy, or a configuration using a bottom anchor and subsurface riser buoy combination onto which the hydrophones are attached. Four of the responses to the questionnaire used some variation of bottom mounting of which three were sites that predominantly support military measurements. Five responses used a configuration either suspended from a ship or a buoy.

Water depth at a test site is an important issue in terms of the quality of measurements that can be obtained and the type of deployment system that is used. While preference is naturally for deep water test sites, the infrastructure needed to make measurements in deep water is more complicated and periods of low background noise (low sea state conditions) are less often.

Acoustically, shallow water conditions are regarded as those for which acoustic propagation is influenced by both the sea surface and the sea bottom. The typical depth-to-wavelength ratio defining shallow water is about 10 to 100 for long range propagation. However, it is difficult to accurately distinguish shallow water from deep water since acoustic wave propagation strongly depends on the complicated ocean environment and on the source-receiver configuration.

The depth of water in which measurements should be made depends on the frequencies of interest, the noise characteristics of the ship and the geo-acoustic characteristics of the bottom. To minimize bottom effects the ANSI and ISO standards recommend tests be conducted with minimum water depth of 300 m or three times ship length for the highest grade measurements, 150 m or 1.5 times ship length for middle grade measurements and 75 m or 1 times ship length for the lowest grade measurements.

If shallow water testing is required it is recommended that information on the geo-acoustic characteristics of the floor (bottom) of the test site be acquired. This information can then be used as input to noise propagation models to correct measured results for the influence of bottom effects.

Bottom effects on sound propagation can be estimated from either measurements (towed known source) and/or calculations of transmission loss. When directly measuring transmission loss, the known source should be towed along the same path as the target ship, keeping a depth nominally the same as the acoustic center of the test ship. Either a set of single frequencies or broad band noise can be used for the known source. Both the sound speed profile of the water column and geo-acoustic properties of the bottom are needed for numerically estimating the transmission loss. When estimating transmission loss it is recommended a numerical model be used that includes near field effects, especially if application is for short source-receiver configurations.

Measurement Configuration

Underwater acoustic measurements are made using hydrophones either singularly or multiple hydrophones comprising an array. If hydrophone arrays are employed they may be used individually to provide spatially distributed sampling of a ship's acoustic signature or may be coherently summed in some fashion to provide spatial discrimination, such as against ambient noise. The former approach is used most often to aid in correction for propagation issues such as due to surface reflections (Lloyd mirror) and/or possibly bottom bounce for shallow water sites. Further discussions on hydrophones and data acquisition are provided below.

Sufficient supporting information regarding the manner in which the hydrophones, and possibly on-board equipment, are used to measure underwater noise should be provided to allow the measurements to be properly corrected to yield range-independent estimates of ship underwater noise source levels and also confidence levels for the estimates. Such information includes, in part: manner by which hydrophone(s) are deployed and maintained in position; distance of each hydrophone from the surface and the bottom; manner of determining and maintaining position of hydrophone(s); hydrophone signal telemetry and recording procedures; method of determining position of the test ship relative to the hydrophones during entire period for which measurements are made; and, signal conditioning, processing and analysis procedures used to arrive at measured underwater noise levels.

The testing sequence for measurements of underwater noise entails the test vessel sailing along a straight course past a sea surface reference point that is indexed to the location where the measurement hydrophones are deployed. During the passage, the ship maintains a predetermined speed and equipment line-up. Data from the hydrophones are continuously obtained during the period of vessel passage from a predetermined comex (start) to finex (end) of a test run (see Figure 1). The comex and finex positions of the ship along its track are set to provide the measurements needed to properly report, as described below, underwater noise levels.

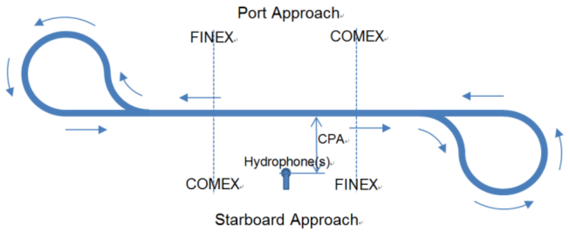

Figure 1 Path of ship during double run

For commercial vessels, speed and power (S/P) trials are carried out at various engine powers before delivery of the vessel. During the S/P trials, at least four double runs including EEDI (Energy Efficiency Design Index as formulated by IMO) power are to be performed. So, it is recommended that measurements of underwater noise are to be performed during S/P trials at Contract and EEDI power. In case of series ship, measurement results of the first vessel represent noise performance of the other vessels.

The track of the vessel is such that it passes the array with a closest point of approach (CPA) that is selected to meet specific test requirements. CPA is the closest horizontal distance the test vessel passes to the array index location as measured from the ship 'acoustic center'. Ship acoustic center is a defined reference position on the ship which is meant to represent the location from which all underwater noise originates as if ship acoustic radiation is from a single point source. While specifically defining the acoustic center to be at the location where most acoustic radiation originates is helpful in later analysis, it is not critical and any corrections for source location versus defined acoustic center that may be needed are straight forward.

Due in part to the significant impact of the air-water interface at the sea surface has on propagation characteristics of underwater ship noise, it is important that special attention be given to positioning of measurement hydrophone(s) relative to the sea surface. The deployment arrangement for hydrophones recommended in the ANSI and ISO standards depends on the grade of measurement needed. For the two higher grades it is recommended that a vertical string of three hydrophones be deployed at depths such that when the test ship is at CPA, the geometrical configuration of ship-to-hydrophones be such that the hydrophones are at angles of 15°, 30° and 45°, from the ship as measured from the sea surface. Measurements from a single hydrophone positioned at the 45° depth can be used for the lowest grade measurements. For the higher grade measurements using multiple hydrophones, measurements from the individual hydrophones are power summed, as described later, to reduce the influence of the sea surface (Lloyd mirror) effects. It is recommended that the ship track provide a minimum CPA of 100 m or one ship length. Signal propagation losses and possible resulting reductions in signal-to-noise need to be considered if very long CPA tracks are run.

3.3 Testing Configuration

The manner and procedures followed for measuring underwater noise can vary amongst measurement sites due to site-specific requirements/restrictions, test objectives, and customer requirements. As such, information regarding testing procedures should be documented. Of particular importance is a clear description of the manner in which measurements were obtained as related to the ship track relative to the hydrophone(s).

Depending on the type of ship and associated noise mechanisms, the frequency range of underwater noise being measured, characteristics of the test site, and due to the air-water sea interface (free surface), measured underwater noise can vary depending on the aspect to the ship for which it is measured. As a result, underwater noise may be measured and reported as a function of ship aspect for the range of ship operating conditions (speed, machinery line-up, etc.) of interest. Here ship aspect refers to the azimuthal location where measurements are made relative to the ship with bow, starboard-beam, port-beam, and stern being cardinal aspects. In addition to azimuthal aspects, for some ships measurements for a keel aspect may also be made.

While there is consensus on what is meant by beam aspect, which is the most common aspect reported, there is a lack of common definition for what is meant by keel, bow or stern aspects. Much of this ambiguity is due not only to individual testing objectives but also to capability limitations at a given test site. Thus a clear description of test configurations should be provided if aspects other than beam are reported.

Beam aspect levels are defined as the average noise levels measured over the time period for which the ship tract is ±30° of CPA. If high accuracy estimates are needed, the continuous noise measurements over the ±30° sector should be subdivided into short time intervals (typically 1 second) and individually corrected for propagation effects and then power averaged over the ±30° sector to arrive at the estimate for beam aspect levels. Lower grade estimates can be made based on a simple time average of levels covering the full period over which the ship is sailing the ±30° sector.

It is recommended that for each operating condition of interest, a minimum of two sets of measurements be acquired for both port and starboard aspects to allow for averaging and determination of any possible port-starboard asymmetry that needs to be accounted for. For high grade measurements, as defined in the ANSI and ISO standards, it is recommended that three runs for each aspect and condition be obtained. Whether port and starboard levels are averaged to provide a single beam aspect level depends in part on the similarity of levels between the two sides.

3.4 Environmental Conditions

Environmental conditions at the time of underwater noise measurements can significantly influence not only the understanding of, but also the quality of results obtained and thus need to be well documented. For example: information regarding water quality and characteristics may be needed to make proper range corrections; wind speed and direction may have an influence on ship hydrodynamic performance, and hence acoustic performance, and must be considered during a measurement regime; and, ambient underwater noise, which sets a noise floor for ship underwater noise measurements, is a function of wind speed and wave height. It is recommended that the following environmental conditions be monitored during measurements of underwater noise and reported as considered necessary.

Probably the most important environmental parameter to monitor is background noise. It is recommended that whenever possible, background noise be monitored during the conduct of all underwater noise measurements and that all reported underwater noise measurements be accompanied with a statement of the background noise levels that existed at the time the measurements were made. This statement is usually given in terms of a signal-to-noise (SNR) estimate expressed as the number of dB the ship noise levels were above ambient levels. It is noted that background noise levels are also commonly reported in terms of noise levels for equivalent Sea State levels (or, in terms of equivalent Beaufort levels). That is for example, ambient noise levels were Sea State 3.

Wind direction and velocity, and wave height and direction should be monitored and reported as considered important to having potentially impacted underwater noise measurements. Often limitations due to elevated background noise levels occur prior to limitations resulting from wind/wave issues. Depending on location and situation of the test site, it may be necessary to monitor and report water current at both the surface and at the hydrophone(s) location. Water depth should be monitored and to the extent it is not constant, reported along with the reporting of underwater noise levels.

The final set of environmental parameters that are recommended to be monitored and reported as necessary are, water temperature and density as a function of depth, and air temperature. Water temperature and density profiles are potentially needed for purposes of range correcting underwater noise measurements.

In addition to the environmental considerations it is recommended that a maintenance inspection be made of the conditions of the below water-line hull and propeller(s), as close in time to the testing period as possible, and preferably prior to testing to allow for any possible corrective actions that may be determined to be needed. Particular attention should be given to the conditions of the propeller(s) and the possibility of excessive marine growth. Results of this inspection should be included in the final reporting.

4. DATA ACQUISITION AND PROCESSING

4.1 Introduction

During the underwater noise measurements, accurate data acquisition, recording, processing, and displaying data from the hydrophone(s) is of great importance. Such systems may comprise tape recorders, self-recording hydrophone(s), computer-based data acquisition systems or hardware-specific devices or combinations of these. Apart from these functions, the sound data processing system shall have a capability to estimate background noise levels so that products such as background noise adjusted levels and distance (range) normalized levels can be provided, as well as assessments of data quality and accuracy.

4.2 Data Acquisition

4.2.1 Frequency range

The measurement system should be capable of covering at least the frequency range of 10 Hz to 20 kHz with an appropriate sampling rate following Nyquist requirements. Resolution shall be at least 16 bits in the dynamic range of analogue-to-digital data sampling.

4.2.2 Hydrophone information

The hydrophone(s) should have the bandwidth, sensitivity and dynamic range necessary to measure underwater noise from the ship under test. Usually, commercially available hydrophones of piezoelectric type are used for measurement of underwater sound pressure levels. Hydrophone(s) should be omnidirectional across the required frequency range. The usable frequency range starts from about a few Hz or even less and the upper limit is usually of about 100 kHz. The maximum operating pressure ranges between 40 atm and 100 atm, with the latter allowing measurements down to 1000 m ocean depth. A built-in preamplifier can be of great importance to provide signal conditioning, particularly for transmission over long underwater cable.

The sensitivity should be as high as possible and consistent with the usable frequency range. Typical values range between –165 to –215 dB re: 1 V/μPa.

The number of hydrophones employed for ship noise measurements varies depending on the application and typically range between 1 and 10. As discussed above, for example the ANSI and ISO standards recommend the use of 3 hydrophones for the array configuration for higher grade measurements.

4.2.3 Calibration of instrument

System calibration can be undertaken either as a full system calibration, or a calibration of individual components. For full system calibration, the complete measurement chain (hydrophone, amplifiers, cabling, filters, signal conditioning equipment, and analogue-to-digital converter (ADC)) should be tested before deployment to ensure that the equipment fulfils specifications using known electrical input signals and/or a hydrophone-calibrator. For calibration of individual components, the instruments should be tested using known electrical input signal and a hydrophone-calibrator. The calibration should cover the full frequency range of use and be compliant to national or international standards such as IEC 60565 (2006) or ANSI S1.20-2012.

Electronic filters should be used for: anti-aliasing purposes, to reduce influence of very low frequency parasitic signals, signal equalization across the frequency range, and might also be used after amplification to condition the signal before digitization. Filters must be characterized over the full operating frequency range of the system.

4.2.4 System self-noise

The system self-noise, or electrical noise, is a crucial parameter when measuring underwater noise. The noise equivalent pressure level may be calculated from the system electrical noise using the system sensitivity. To achieve acceptable signal-to-noise ratios when measuring acoustic signals, the system self-noise equivalent sound pressure level should be at least

10 dB below the lowest noise level to be measured in the frequency range of interest.

4.2.5 Dynamic range

The system dynamic range should ideally be sufficient to enable both the highest and the lowest expected sound pressure levels to be recorded faithfully without distortion or saturation. It is usually assessed as a function of SNR. The resolution of the recording should be at least 16-bit, but if possible 24-bit.

4.2.6 Sensitivity

The calibration of the hydrophone and recorder should be done with an overall uncertainty of about 1 dB (expressed at a 95 % confidence level). The calibration should be taken both before and after the measurements. It is not necessary to specify the required sensitivity to within a narrow tolerance band, as long as it is accurately known. Considering the required noise performance and dynamic range, and the performance range of available electronic components, the system sensitivity is recommended to be in the range –165 to –185 dB re: 1 V/μPa.

4.2.7 Background noise measurements and auxiliary data

Background noise measurements must be performed with the same instrumentation and acquisition system used for ship noise measurements and with the ship sufficiently far from the hydrophone (typically more than 2 km) and in stationary condition so as not to contaminate the background noise measurements. All vessel systems including diesel generators remain in operation.

To the extent possible, background noise levels should be periodically monitored and at a minimum background noise measurements should be taken and documented at the beginning and the end of each test period (typically day or half-day of measurements) unless traffic or weather conditions (wind, sea state) significantly change (e.g. wind variation >5 Knots). When weather conditions or background noise levels sensibly change, but not such as to prevent the execution of measurements, new background noise measurements need to be obtained. Acceptable sea state levels for which ship noise measurements can be made are generally set as requiring that ship noise levels be a specified number of dB higher than background noise levels (see §4.3.1).

To avoid signal contamination from noise due to the moorings, or local pressure fluctuations from turbulence due to interaction of the water flow with the measuring system, careful design of the deployment system is necessary. It is suggested to measure the acceleration of the hydrophone mount structure to assess the influence of vibrations on measured underwater noise. In general, it is recommended to record any auxiliary data that may be relevant, as described in the summary table of section 4.4, so that these may be correlated with the measured noise levels during analysis.

4.3 Data Processing

Measured underwater noise radiated from a test vessel shall be processed to adjust for background noise contamination and distance normalization to equivalent levels measured at 1 m from the acoustic center. The processing should be conducted by narrow band (typically 1 Hz) analysis in the frequency range between 20 Hz to 2 kHz and one-third octave band throughout the 20 Hz to 20 kHz frequency range. Background noise pressure, p_n, shall be determined as described in §4.2.7, following the same analysis procedures and in the same bandwidths as the underwater noise. Other corrections that are usually made are for bottom and free surface effects.

For reference, it is noted that in the context of noise assessment, the sound pressure level (in dB) is the fundamental quantity of sound pressure, and it is defined in terms of a pressure ratio as follows:

$$L_p = 10 \log_{10}\left(\frac{\bar{p}_{rms}^2}{p_{ref}^2}\right) \quad (4.1)$$

where L_p is the sound pressure level in dB, $\bar{p}_{\mathrm{rms}}$ is the root-mean-square of the acoustic pressure, and p_{ref} is the reference pressure set normally to 1 µPa for water.

Calculation of the power sum of levels from individual hydrophones, when the levels from the individual hydrophones are expressed in dB, is given as:

$$L_{\mathrm{sum}} = 10 \log_{10}\left[\sum_{i=1}^{N} 10^{(L_i/10)}\right] \quad (4.2)$$

where, L_{sum}, is the power sum in dB, L_i is the level given in dB for the i-th hydrophone, and N is the number of hydrophones to be summed. If a power averaged value is wanted, the sum inside the [] bracket should be divided by N.

4.3.1 Correction for background noise

Background noise corrected radiated noise, L'_p, shall be calculated from the measured underwater sound pressure levels radiated from the test ship, $L_{p_{\mathrm{s+n}}}$, which are a sum of both ship sound plus contaminating background noise, $L_{p_{\mathrm{n}}}$. Calculations of background noise corrected noise levels are made by the following equation:

$$L'_p = 10 \log_{10}\left[10^{\left(L_{p_{\mathrm{s+n}}}/10\right)} - 10^{\left(L_{p_{\mathrm{n}}}/10\right)}\right] \quad (4.3)$$

where:

L'_p: Underwater sound pressure level (dB) of the test ship after background noise adjustment

$L_{p_{\mathrm{s+n}}}$: Underwater sound pressure level (dB) including background noise obtained at measurement for the test ship

$L_{p_{\mathrm{n}}}$: Underwater background noise level (dB)

As a measure of background noise contamination, the difference in level, ΔL (expressed in dB), between measured underwater sound pressure levels for the test ship and background underwater sound pressure levels should be calculated for each measurement frequency band as:

$$\Delta L = L_{p_{\mathrm{s+n}}} - L_{p_{\mathrm{n}}} = 10 \log_{10}\left(\frac{p_{\mathrm{s+n}}^2}{p_{\mathrm{n}}^2}\right) \quad (4.4)$$

If the value of ΔL is less than 3 dB, the background noise is considered too large in comparison with the measured sound pressure level and the measurement for the test ship should be regarded as "less quality". On the contrary, if ΔL is greater than 10 dB then no adjustments are necessary. Finally if 3 dB ≤ ΔL <10 dB, adjustment if measurements, following eq. (4.1), are required.

4.3.2 Correction for propagation loss

Propagation loss from the sources (or from 1 m reference distance) to the measurement point should be measured. If such measurements are not possible, distance normalization can be applied assuming spherical spreading. For spherical spreading underwater sound radiated noise level L_{s} can be calculated according to the following equation:

$$L_{\mathrm{s}} = L'_p + 20 \log_{10}\left[\frac{d}{d_{ref}}\right] \quad (4.5)$$

where d_{ref} is the reference distance of 1 m and d (in meters) is the distance between the test ship acoustic center and the locations of the hydrophone(s).

The location of the acoustical source center depends on applications but is generally placed either at the propeller shaft center, at $0.7R$ above the shaft center, halfway between engine room and propeller, or at the ship acoustic center.

4.3.3 Correction for bottom and free surface effects

For hydrophones deployed from the sea bottom in a fixture with hydrophone height above the bottom less than 0.2 m, reflections could affect measurements. In this case the suggested correction factor, arising from the assumption that all incident energy is scattered and redistributed into the water with no transmission into the bottom, is to reduce levels by 5 dB (Jensen et al., 2011, Urick, 1983).

Measurements of underwater noise from surface ships need to be interpreted with recognition of the influence of the sea surface which acts as reflecting plane with the acoustic signal reflecting from the sea surface being out of phase with the primary acoustic signal. The acoustic pressure measured by a hydrophone exhibits the spatially-dependent constructive/destructive pattern (Lloyd mirror) resulting from the coherent sum of the two signals. The complex interference pattern that forms is a function of both source and receiver locations and the conditions of the sea surface, all of which are difficult to fully and accurately account for during field measurements.

To minimize the influence of sea surface reflections it is recommended that reported ship noise levels be calculated as the power average of the range corrected L_S levels measured at each of the three hydrophones in the vertical array of hydrophones described in §3. This provides a spatial averaging that greatly reduces constructive/destructive effects.

4.4 Uncertainty analysis

4.4.1 Sources of uncertainty or error

There are three primary sources of uncertainty in determining the underwater acoustic signature of a ship: errors in the data acquisition and processing system; variations in, or improper accounting for source-to-receiver transmission issues (bottom and surface effects); and, repeatability of the ship signature itself. In reporting ship signature levels, attention should be given to providing some quantification, or bounding, of the magnitude of each of these uncertainties or errors. It is noted that many of the earlier recommendations and procedures were made to minimize these types of uncertainties.

4.4.2 Quantification and minimization of errors

Following the recommendations and procedures in §4 estimates of error resulting from the data acquisition and processing system can be made using standard procedures such as those provided by the ISO documents listed at the end of this section. Adopting modern data acquisition procedures, dedicating particular attention to system maintenance, and performing scheduled calibrations should result in these errors being of marginal concern.

As discussed in §3, measurements of underwater ship signatures are greatly influenced by on-range environmental conditions which include both the effects on source-to-receiver propagation characteristics (transmission) of the sea surface and ocean bottom and the contamination effects of background ocean noise. To minimize propagation-related errors, range propagation characteristics should be well documented based on dedicated acoustic calibrations such as those from towed known source calibrations. Results of calibrations of this type should be included in any reporting of underwater ship noise measurements to allow the customer to estimate the impact of this error when using the reported ship noise measurements. Procedures for accounting for background noise were provided in §4.3. To minimize this error, careful attention should be given to monitoring background noise and ensuring that for each underwater noise measurement there is a measurement of background noise representative of what existed during the ship noise measurement. It is also offered that if possible, the conduct of test runs be modified during the testing period so that if testing of specific ship conditions are expected to result in lower underwater noise levels, these test be conducted during period of low background noise.

The third source of error is that of repeatability. Repeatability issues arise predominantly from either variations in the ship signature or variations in conduct of the test. Ship signature variations may occur due to unrealized changes in ship operations (equipment line-up, speed, etc.) or due to variations resulting from changes in seaway conditions (currents, wave action, etc.). Errors due to ship operations are minimized by careful attention to ship conditions and indoctrination of ship's crew as to the impact of ship operations on the signature. There is little control over errors resulting from seaway conditions other than conducting tests only during favorable weather conditions, which is generally not possible. Careful documentation should be made of both weather and seaway conditions for all ship signature measurements so that the possible influence of this error can be assessed. To minimize seaway-related errors it is recommended that multiple sets of measurements be made for each condition with the reported signature being an average of these individual results. §3.4 provides a discussion of the multiple sets recommended by both the ISO and ANSI standards.

4.4.3 Uncertainty Analysis Regulations and Recommendations

Customers should be informed of the uncertainty assessment methodology that will be used and which uncertainties can be expected for the underwater noise measurements. The uncertainty assessment methodology should inform about the magnitude of the following errors and how they are accounted for in the reported ship signature levels:

1) System calibration (hydrophone through to A/D system)
2) Random and bias errors associated with signal processing (narrowband, one-third-octave analysis, etc.)
3) Source-to-receiver transmission errors/variability (typically given as ± dB)
4) Signal-to-Noise levels for reported ship signatures
5) Error bounds based on analysis of repeatability (typically given as maximum and minimum levels bounding reported level), and
6) Where possible, both random and bias error estimates should be provided.

The uncertainty analysis should be done in accordance with the following regulations/recommendations:

ISO, 1992, "Measurement Uncertainty," ISO/TC 69/SC 6.

ISO, 1993a, "Guide to the Expression of Uncertainty in Measurement," ISO, First edition, ISBN 92-67-10188-9.

ISO, 1993b, “International Vocabulary of Basic and General Terms in Metrology,” ISO, Second edition, ISBN 92-67-01075-1.

5. REQUIRED AND RECOMMENDED DATA

In addition to the recommendations provided in §3, particulars of the test ship, measurement system, graphic of the measurement results and environmental condition shall be considered during noise measurements.

The particulars can be categorized into "required data " and in "recommended data ". If the latter are considered, the reliability and the quality of the measurements will considerably be improved. Required and recommended data are illustrated in Table 1

6. REFERENCES

ANSI, 2003, “American National Standard Procedures for Calibration of Underwater Electroacoustic Transducers”, ANSI S1.20-1988 (R2003).

IEC, 2006, “Underwater acoustics-hydrophones- calibration in the frequency range 0.01 Hz to 1 Mhz”, IEC 60565.

Jensen, F.B., Kuperman W., Porter, M, and Schmidt, H., 2011, Computational Ocean Acoustics, 2nd edition Springer.

Urick, R.J., 1983, Principles of underwater sound, 3rd edition, McGraw-Hill Ryerson.

Table 1; Required and recommended data

	Required	**Recommended**
General information (Ship, propeller operating conditions)	● Type of ship ● Engine power, RPM and ship speed for each run ● Propeller main particulars ● Shaft immersion and number of shafts ● Tip clearance ● Known problems or concerns that may affect underwater sound levels	● IMO number ● Classification ● Year of construction ● Ship main particulars ● Propeller geometry data (Section, Pitch, Chord distribution, etc.) ● Propeller design conditions ● Drawing of stern shape including arrangement of appendages
Position and time of the measurements	● GPS-coordinates of the measurement system and the test ship positions ● Depth of water	● Distance to coast ● Sea bottom type/sediment type ● Date and time of measurement at each run
Environmental conditions	● Water temperature ● Weather and sea-state ● Background noise level ● Hull and propeller(s) inspection	● Salinity of the water ● Wind speed and rate of rainfall ● Vessel traffic
Design of measurement system	● Deployment of the system ● Number of hydrophone(s) ● Position of hydrophone(s) ● Depth of hydrophone(s) deployment	● Hydrophone manufacture, model number and sensitivity
Instrumentation	● Review of data acquisition system ● Type, frequency range, directionality, sensitivity ● Data sampling rate ● Type and settings of amplifier and filters	● Field calibration method and results ● Factory calibration data
Measured results and analysis	● Measuring period ● Underwater sound pressures ■ 1/3 octave band ■ Narrowband ■ Source levels	● Vibration characteristics of ship hull ● Operating machineries ● Time series