PUBLICLY AVAILABLE SPECIFICATION

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Acoustics — Quantities and procedures for description and measurement of underwater sound from ships —

Part 1: General requirements for measurements in deep water

Acoustique — Grandeurs et modes de description et de mesurage de l'acoustique sous-marine des navires —

Partie 1: Exigences générales pour les mesurages en eau profonde

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

In other circumstances, particularly when there is an urgent market requirement for such documents, a technical committee may decide to publish other types of document:

— an ISO Publicly Available Specification (ISO/PAS) represents an agreement between technical experts in an ISO working group and is accepted for publication if it is approved by more than 50 % of the members of the parent committee casting a vote;

— an ISO Technical Specification (ISO/TS) represents an agreement between the members of a technical committee and is accepted for publication if it is approved by 2/3 of the members of the committee casting a vote.

An ISO/PAS or ISO/TS is reviewed after three years in order to decide whether it will be confirmed for a further three years, revised to become an International Standard, or withdrawn. If the ISO/PAS or ISO/TS is confirmed, it is reviewed again after a further three years, at which time it must either be transformed into an International Standard or be withdrawn.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO/PAS 17208-1 was prepared by Technical Committee ISO/TC 43, *Acoustics*, Subcommittee SC 1, *Noise*. However, by the time of its publication, responsibility for this document, as well as for future underwater acoustics work, had been transferred to Subcommittee SC 3, *Underwater acoustics*.

ISO/PAS 17208 consists of the following parts, under the general title *Acoustics — Quantities and procedures for description and measurement of underwater sound from ships*:

— *Part 1: General requirements for measurements in deep water* [Publicly Available Specification]

Measurements in shallow water is to form the subject of a future part of ISO 17208.

Introduction

This part of ISO 17208 was developed to provide a standardized measurement method for the quantification and qualification of a ship's underwater (radiated) noise, and is aimed at promoting consistency of reported sound measurements from shipping sources. Reduction of all types of vessel emissions — most notably, ballast water and engine emissions — became an issue in the decade prior to its publication. More recently, those concerns came to include underwater noise and its the impact on marine animals.

Excessive underwater noise has the potential to interfere with a marine animal's ability to perform a variety of critical life functions, including navigation, communication and finding food. Because of this, the environmental impact statements of underwater projects such as pile-driving, pipe-laying and oil exploration now include assessments of the impact of underwater noise.

Acoustics — Quantities and procedures for description and measurement of underwater sound from ships —

Part 1: General requirements for measurements in deep water

1 Scope

This part of ISO 17208 describes the general measurement systems, procedures and methodologies to be used to measure underwater sound pressure levels from ships at a prescribed operating condition. It presents a methodology for the reporting of one-third-octave band sound pressure levels. The resulting quantities are the sound pressure levels normalized to a distance of 1 m. Since the underwater sound pressure levels are affected by the presence of the free surface (and sometimes the bottom), such quantities are sometimes called “affected source levels” (see ANSI/ASA S12.64-2009). This part of ISO 17208 refers to the result of these measurements as “radiated noise levels”.

The underwater sound pressure level measurements are performed in the geometric far field and then adjusted to the 1 m normalized distance for use in comparison with appropriate underwater noise criteria. However, this part of ISO 17208 does not specify or provide guidance on underwater noise criteria or address the potential effects of noise on marine organisms.

This part of ISO 17208 is applicable to any and all underway surface vessels, either manned or unmanned. Its methods have no inherent limitation on minimum or maximum vessel size. It is not applicable to submerged vessels or to aircraft, and is limited to vessels transiting at speeds no greater than 50 knots (25,70 m/s). The measurement methods mitigate the variability caused by Lloyd's mirror surface image coherence effects, but do not exclude a possible influence of propagation effects such as bottom reflections, refraction and absorption. No specific computational adjustments for these effects are given. A specific ocean location is not required for the application of this part of ISO 17208, but requirements for an ocean test site are provided.

Among the applications of this part of ISO 17208 are the showing of compliance with contract requirements, the enabling of periodic signature assessments and in research and development. Intended users include government agencies, research vessel operators and commercial vessel owners operating in acoustically sensitive waters.

This part of ISO 17208 offers three grades of measurement — A, B and C — each with a stated applicability, test methodology, uncertainty, system repeatability and complexity. A summary of the attributes of each grade is given in Table 1. Application of the three grades of measurement to the same ship under the same conditions does not necessarily result in the same radiated noise level.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60565, *Underwater acoustics — Hydrophones — Calibration in the frequency range 0,01 Hz to 1 MHz*

IEC 61260, *Electroacoustics — Octave-band and fractional-octave-band filters*

ANSI S1.1, *American National Standard Acoustical Terminology*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ANSI S1.1 and the following apply:

3.1
acoustic centre
position at which it is assumed that all of the noise sources are co-located as a single point source

NOTE For the purposes of this document, the position is on a ship.

3.2
background noise
noise from all sources (biotic and abiotic) other than the source under test

NOTE 1 For the purposes of this document, the source under test is a ship.

NOTE 2 See 6.2 for background noise adjustments.

[SOURCE: ISO 11202:2010, 3.17, modified]

3.3
beam aspect
direction to either side of the ship under test

NOTE Beam aspect is in reference to the location of the hydrophones. Another approach for hydrophone measurement (not applied here) is *bottom aspect*, where the hydrophone(s) are mounted at or near the sea floor.

3.4
frequency response
frequency range a system is able to measure, for a given uncertainty and repeatability, from the lowest frequency to the highest stated frequency

3.5
closest point of approach
CPA
point at which the horizontal distance (during a test run) from the acoustic centre of ship under test is the closest to the hydrophone(s)

NOTE The distance at the closest point of approach is defined by the symbol d_{CPA} as used in Equation (1).

3.6
commence exercise
COMEX
start test range location
position of the vessel under test when twice (2×) the "start data" distance ahead of the CPA

NOTE See Figure 4.

3.7
data window angle
angle subtended at the hydrophone, between the start data location and the end data location

NOTE The data window angle is expressed as a value in degrees, as shown in Figure 4. For all grades of measurement, the data window angle is ±30°.

3.8
data window length
DWL
distance between the start data location and end data location

NOTE The DWL is defined by the distance at CPA and the data window angle of ±30°, as given in Equation (1) and shown in Figure 4.

3.9
data window period
DWP
time taken by the vessel under test to travel the data window length at a certain speed

NOTE See Equation (2) and Figure 4.

3.10
end data location
position of the acoustic centre of the vessel under test where data recording is ended

NOTE End data location is one data window length after the start data location. See Figure 4.

3.11
finish exercise
FINEX
end test range location
position of the vessel under test when twice (2×) the "start data" distance past the CPA

NOTE See Figure 4.

3.12
field calibration
method of using known inputs, possibly using physical stimuli (such as a known and calibrated/traceable acoustic or vibration source) or electrical input (charge or voltage signal injection) at the input (or other stage) of a measurement system in order to ascertain that the system is responding properly (i.e. within its stated uncertainty) to the known stimulus

3.13
geometric far field
horizontal distance from the ship under test at which the assumption of source co-location causes less than 1 dB of error when adjusting to the reference distance

3.14
hydrophone cable drift angle
angle between the vertical axis and the line created between the fixed support of the hydrophone cable and the hydrophone

3.15
insert voltage calibration
known, calibrated and traceable input stimulus in the form of an electrical input injected at the input (or other stage) of a measurement system in order to ascertain that the system is, in fact, responding properly (i.e. within the system's stated uncertainty and repeatability) to a known stimulus

3.16
Lloyd's mirror surface image coherence effects
alteration of radiated-noise levels caused by the presence of a free (pressure release) surface

NOTE Radiation from the "surface image" constructively and destructively influences the source's direct radiation. For the purposes of this document, these effects are considered as part of the source's radiation, causing it to exhibit a vertical directivity, necessitating the acquisition angle(s) be defined for each grade.

3.17
measurement uncertainty
maximum difference between the measured resulting signature radiated noise level and the true signature radiated noise level stated in decibels for a given measurement system, for one-third-octave bands using a given measurement method (averaging time, bandwidth-time product, etc.)

NOTE This concept is extensively treated in ISO/IEC Guide 98-3:2008 (GUM).

3.18
measurement repeatability
expected difference between signature-radiated noise levels resulting from successive measurements on the same vessel at the same operating condition, carried out under the same conditions of measurement with the same equipment at the same location, stated in decibels and in one-third-octave bands

NOTE This concept is extensively treated in ISO 3534-1.

3.19
measurement system
data acquisition system consisting of, but not limited to, one or more transducer(s), conditioning amplifier(s), analogue-to-digital converter(s), digital signal processing computer and ancillary peripherals

3.20
omni-directional hydrophone
underwater sound pressure transducer that responds equally to sound from all directions

3.21
slant range
distance from the acoustic centre of the vessel under test to each hydrophone

3.22
overall ship length
longitudinal distance between the forward-most and aft-most perpendicular of a ship

3.23
resulting signature-radiated noise level
measure of the underwater noise radiated by a surface vessel, obtained by averaging the far-field sound pressure level and scaling this quantity according to spherical spreading to a standard reference distance of 1 m from the acoustic centre of the source

NOTE 1 The signature-radiated noise level is defined as the outcome of the procedure in Clause 6. Specifically, it is the variable, L_s, on the left hand side of Equation (9).

NOTE 2 The signature-radiated noise level is also sometimes referred to as an “affected source level” or “signature.”

3.24
sound speed profile
measure of the speed of sound in seawater as a function of depth, measured vertically through the water column

3.25
start data location
position of the acoustic centre of vessel under test where data recording is started

NOTE See Figure 4.

3.26
test site
location at which the underwater noise measurements are performed

3.27
underwater sound pressure level
SPL
L_p
ten times the logarithm to the base 10 of the ratio of the time-mean-square pressure of an underwater sound, in a stated frequency band, to the square of a reference value, p_0, expressed in decibels

$$L_p = 10\lg \frac{p^2}{p_0^2} \text{dB}$$

where the reference value, p_0, is 1 μPa

NOTE 1 The reference value for underwater is different from that for airborne sound, which is 20 μPa.

NOTE 2 In this part of ISO 17208, the averaging time for the sound pressure level is the DWP (3.9).

[SOURCE: ISO/TR 25417:2007, 2.2, modified]

4 Instrumentation

4.1 General

In order to quantify the underwater sound from a marine vessel, three main instrumentation components are required: hydrophone(s) and signal conditioning; data acquisition, recording, processing and display system; and distance measurement system. The requirements for each of the three components will depend on which of the three grades of measurement is desired. Detailed specifications for each of the measurement systems are given below. A summary of the attributes of each grade is given in Table 1.

4.2 Hydrophone and signal conditioning

The terms "hydrophone", "underwater electro-acoustic transducer" and "underwater microphone" may be used synonymously, but for the purposes of this part of ISO 17208, *hydrophone* is used, and includes any signal conditioning electronics either within or exterior to the hydrophone. The hydrophone(s) should have the sensitivity, bandwidth and dynamic range necessary to measure the ship under test and meet the performance for each intended grade in accordance with Table 1.

For all grades of measurement, the hydrophone(s) should be omni-directional across the required frequency range for the grade. However, directional hydrophones may be used, as long as the directional characteristics are accounted for in the final data processing (see 6.3). The number of hydrophones used to perform the measurement depends on the grade. The hydrophones may or may not have integral cable. However, the required performance shall be obtained with the full cable length to be used during the test.

When portable hydrophones are used, they shall be laboratory-calibrated every 12 months in accordance with IEC 60565 for all required one-third-octave bands. When fixed (i.e. permanently installed underwater) hydrophones are used, they shall be laboratory-calibrated before installation in accordance with IEC 60565 for all required one-third-octave bands. The fixed hydrophone calibration shall be confirmed by a comparative measurement utilizing a calibrated underwater sound source every 12 months.

For Grades A and B, the full measurement system shall be field-calibrated prior to, and daily throughout, the measurement series, using insert voltage methods (3.15) for all required one-third-octave bands. For Grade C, the full measurement system shall be field-calibrated prior to, and daily throughout, the measurement series, using either insert voltage methods for all one-third-octave bands or a single-frequency device (such as a pistonphone).

4.3 Data acquisition, recording, processing and display

For all grades of measurement, the data acquisition, recording, processing, and display system shall be capable of accurately acquiring, recording, processing and displaying data from the hydrophone(s). Such systems may comprise tape recorders, computer-based data acquisition systems or hardware-specific devices (such as spectrum analysers) or combinations of these. The data acquisition system should have an appropriate sampling rate following Nyquist requirements and appropriate dynamic range for either analogue or digital systems. All frequency domain-averaging shall be linear, with sampling consistent with the data window period (DWP) (see 6.1).

For Grade A, the time domain signal from each hydrophone shall be acquired and recorded simultaneously and shall be sample-accurate for all three channels. Tracking and time stamp data (see 4.4) shall be recorded synchronously with the acoustic data to enable reconstruction of the track and data processing.

For Grade A measurements, the broadband processing shall cover the one-third-octave bands from 10 Hz to 50 000 Hz in accordance with IEC 61260, Class 1. Narrow-band processing shall be in appropriate bandwidths relative to the frequencies to be determined up to 5 000 Hz, or higher, as needed.

For Grade B measurements, the broadband processing shall cover the one-third-octave bands from 20 Hz to 25 000 Hz in accordance with IEC 61260, Class 1. Narrow-band processing shall be in appropriate bandwidths, relative to the frequencies to be determined up to 5 000 Hz, or higher, as needed.

For Grade C measurements, the broadband processing shall cover the one-third-octave bands from 50 Hz to 10 000 Hz in accordance with IEC 61260, Class 1. Narrow-band measurements should be performed only as needed using the appropriate bandwidth and frequency ranges necessary to quantify any discrete frequency components.

For monitoring purposes, audio output and display of the data are recommended.

4.4 Distance measurement

Distance measurement is required to determine the horizontal separation between the acoustic centre of the vessel under test and the position on the sea surface above the hydrophone(s) — continuously and throughout the data acquisition and processing period for Grade A, and only at the closest point of approach (CPA) for Grades B and C. The distance measurement device may utilize any method (e.g. optical, acoustical, GPS, radar) as long as the required accuracy is achieved. For Grades A and B, the distance measurement system shall be accurate to 2 % of the distance at CPA. For Grade C, the distance measurement system shall be accurate to 5 % of the distance at CPA.

For all grades of measurement with surface-suspended hydrophones, the distance measurement systems need only determine the horizontal distance from the sea surface position above the hydrophone(s) to the acoustic centre of the vessel under test. The slant range from the vessel under test to the hydrophone(s) may be computed during post-processing of the data in accordance with 6.4. It is not necessary to take into account any drift that the hydrophones could experience after they are deployed, provided the hydrophone cable drift angle does not exceed 5°. If the drift angle does exceed 5°, then it shall either be reduced or the drift angle shall be taken into account when determining the slant range.

For all grades of measurement with bottom-supported hydrophones, the distance range-finding instrumentation shall only determine the horizontal distance from the sea surface position above the hydrophone(s) to the vessel under test. The slant range from the vessel under test to the hydrophone may be computed during post-processing of the data in accordance with 6.4. It is not necessary to take into account any drift which the hydrophones could experience after they are deployed, provided the hydrophone cable drift angle does not exceed 5°.

The hydrophone cable drift angle may be estimated by the use of depth gages that indicate the difference in depth between the hydrophones. If the drift angle is believed to exceed 5°, it can be reduced by attaching a weight to the end of the hydrophone cable or using a larger buoy for bottom-supported configurations. Drift angles are usually smaller for free-floating suspensions that do not utilize a data transmission cable (e.g. an acoustic or electromagnetic data link).

For Grade A, distance data shall be recorded to determine the vessel track, horizontal range, and speed for the entire measurement run (start to end) at a sampling rate no less than the acoustic data. For Grades B and C, only the distance at CPA shall be recorded, which may be accomplished by recording the subject distance in a test log.

Table 1 — Summary of measurement grades

Parameter	Grade		
	A **Precision method**	**B** **Engineering method**	**C** **Survey method**
Achievable measurement uncertainty	1,5 dB	3,0 dB	4,0 dB
Measurement repeatability	±1,0 dB	±2,0 dB	±3,0 dB
Bandwidth	One-third-octave band		
Frequency range (one-third-octave bands)	10 Hz to 50 000 Hz	20 Hz to 25 000 Hz	50 Hz to 10 000 Hz
Narrowband measurements	Required	Required	As needed
Number of hydrophones	Three	Three	One
Hydrophone geometry	See Figure 1	See Figure 1	See Figure 2
Nominal hydrophone depth(s)	15°, 30°, 45° angle	15°, 30°, 45° angle	20°± 5° angle (see 5.4)
Minimum water depth	Greater of 300 m or 3× overall ship length	Greater of 150 m or 1,5× overall ship length	Greater of 75 m or 1× overall ship length
Minimum distance at closest point of approach (CPA)	Greater of 100 m or 1× overall ship length		
Distance ranging uncertainty (at CPA)	2 %	2 %	5 %
Acoustic centre location	Determined during testing (see 4.5)	Halfway between the engine room and the propeller	
Data window angle (±CPA)	±30°		
Data window length, m	Determined using Equation (1), shown in Figure 4		
Data window time, s	Determined Using Equation (2), shown in Figure 4		
Data window averaging time	≤1 s	One overall sample	
Minimum number of runs per vessel condition	Six total: three port three starboard	Four total: two port two starboard	Four total: at least one starboard and one port
Recommended weather/sea conditions	Wind speed ≤20 kn (see 5.3)		
Portable hydrophone calibration	Laboratory calibration every 12 months Field calibration as below daily during measurements		
Fixed hydrophone calibration	Laboratory calibration prior to installation Confirmation using calibrated sound source every 12 months Field calibration as below daily during measurements		
System field calibration	Insert voltage calibration	Insert voltage calibration	Single frequency
Auxiliary measurements	Engine shaft speed, wind speed and direction, sound speed profile (others listed in Clause 8)	Engine shaft speed, wind speed and direction (others listed in Clause 8)	Engine shaft speed, wind speed and direction (others listed in Clause 8)

4.5 Acoustic centre

The assumption that all the sound comes from the acoustic centre further assumes that the ship is a directive point source at the surface, with the same location for all frequencies. For Grade A, the acoustic centre shall be determined by the user. For example, the location of the acoustic centre can be defined by the maximum broadband hydrophone output during each run. For Grades B and C, the acoustic centre is assumed to be located halfway between the centre of the engine room and the propeller for all test conditions.

5 Measurement requirements and procedure

5.1 Introduction

In order to perform an accurate measurement of a ship's underwater sound, a number of factors have to be addressed correctly, e.g. selection of an appropriate test site, proper deployment of hydrophones, and proper operation of the vessel under test. A complete discussion of these factors is given below.

5.2 Test site requirements

This part of ISO 17208 does not require the use of a specific ocean location for the measurement test site. It is up to the test organization and vessel owner's representative (vessel owner, shipyard, etc.) to determine the suitability of the proposed test site for the intended measurements. Nevertheless, there is a specific requirement for water depth. Some of the other factors to consider are ambient noise, vessel traffic, oceanography, bottom type, local weather, vessel manoeuvrability and safety.

For all grades, the background noise should be low enough to permit measurement of the underwater sound of the vessel under test over the frequency range of interest for the grade. Where the background noise limits the measurements, corrections shall be applied (see 6.2).

There are circumstances where the problem of background noise limiting the measurable frequencies is insurmountable. In such cases, where measured levels are background limited and no correction is possible (see 6.2), these data shall either be designated as background-limited or not presented.

The required water depth at the test site depends on the measurement grade and is related to the overall ship length. For Grade A measurements, the minimum water depth shall be 300 m or three times (3×) the overall ship length, whichever is greater. For Grade B measurements, the minimum water depth shall be 150 m or one and one-half times (1,5×) the overall ship length, whichever is greater. For Grade C measurements, the minimum water depth shall be 75 m or one (1×) overall ship length, whichever is greater. In certain locations, it may not be possible to meet this minimum water depth requirement. Measurements taken in shallower waters will result in greater uncertainty at frequencies below approximately 200 Hz.

5.3 Sea surface conditions

The sea surface conditions during testing are of concern, since rough seas can cause added background noise and instability of the ship under test and its propulsion system. For example, rougher surface conditions can increase the background noise in the water as well as contribute to measurement array excitation, thereby creating limitations because of signal-to-noise adjustments (see 6.2). Of concern in this respect is the repeatability of the surface vessel's radiated noise level in various sea surface conditions. For example, wave heights can cause broaching of a propulsor, causing significant radiated noise level differences between low vs. high surface wave conditions.

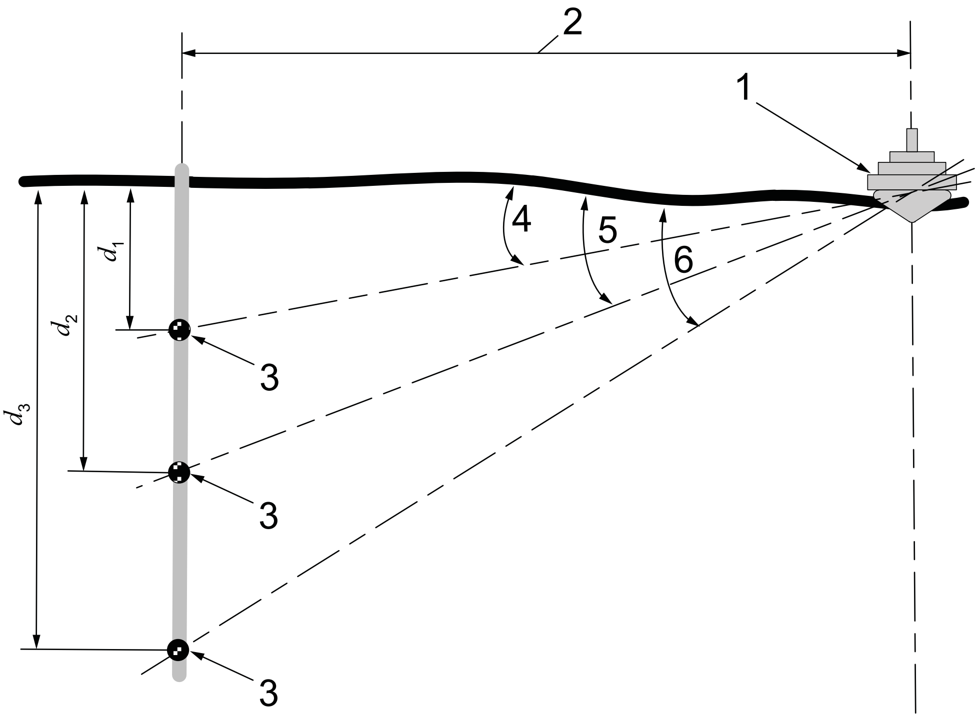
The limiting surface conditions affecting the radiated noise levels are a function of numerous variables (wave-height, period, direction relative to ship course, ship seakeeping characteristics, source depth, etc.). In general, smaller length vessels require lower wave heights to attain consistent radiated noise level measurements. The recommended wind speed limitation of ≤20 kn (10,28 m/s) provides a nominal value for vessels greater than 100 m. Smaller vessels could require more benign surface conditions while larger vessels might tolerate larger surface conditions.

5.4 Hydrophone deployment

For all grades, the hydrophone(s) shall be arranged vertically in the water column. The hydrophone(s) shall be located so as to measure the beam aspect of the vessel under test. For all grades, the hydrophone(s) shall not be located on the seabed.

For Grades A and B, the hydrophones shall be positioned vertically in the water column at depths which result from nominal 15°, 30° and 45° angles from the sea surface at a distance equal to the nominal distance at CPA (see Figure 1). For Grade C, the hydrophone shall be positioned vertically in the water column at a depth that results from a 20° angle from the sea surface and at a distance equal to the nominal distance at CPA (see Figure 2). For Grade C only, the angle to the hydrophone shall have a tolerance of ±5°.

Provisions shall be made to mitigate the effects of cable strum and sea surface effects on the measurements. Figure 3 shows potential deployment approaches, but other solutions are allowed, as long as the physical locations of Figures 1 and 2 and requirements with respect to the measurement uncertainty are fulfilled.



$d_1 = d_{CPA} \tan(15°)$

$d_2 = d_{CPA} \tan(30°)$

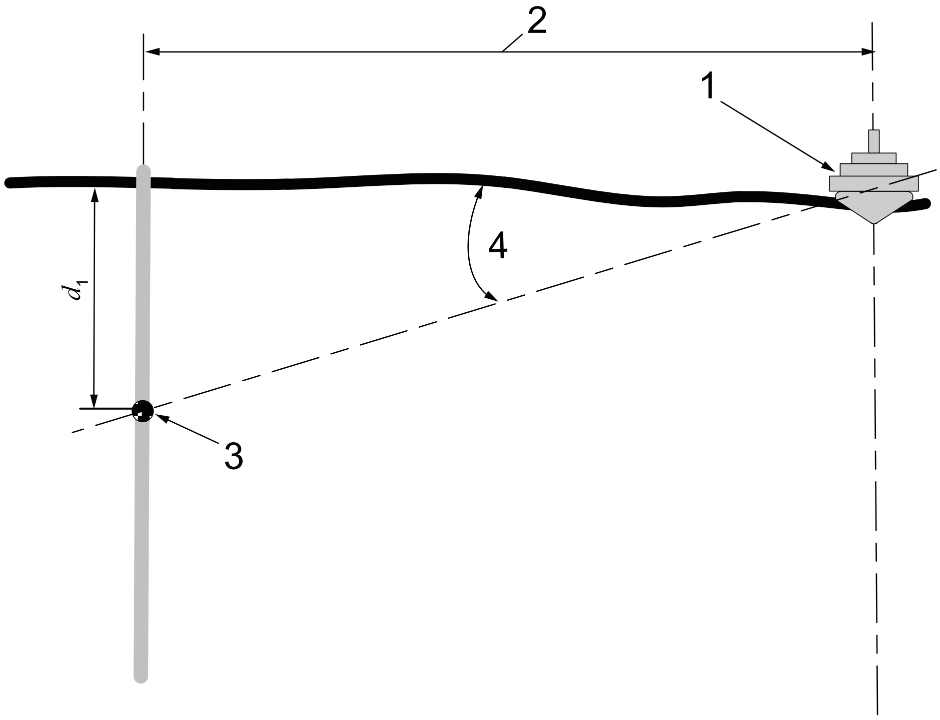
$d_3 = d_{CPA} \tan(45°)$

d_{CPA} = 100 m or one overall ship length, whichever is the greater.

Key

1 vessel under test
2 distance, d_{CPA}, at closest point of approach
3 hydrophone
4 15° angle between surface and shallowest hydrophone
5 30° angle between surface and middle hydrophone
6 45° angle between surface and deepest hydrophone

Figure 1 — Hydrophone geometry — Grades A and B



$d_1 = d_{CPA} \tan(20°)$. Use actual angle (4).

d_{CPA} = 100 m or one overall ship length, whichever is the greater.

Key

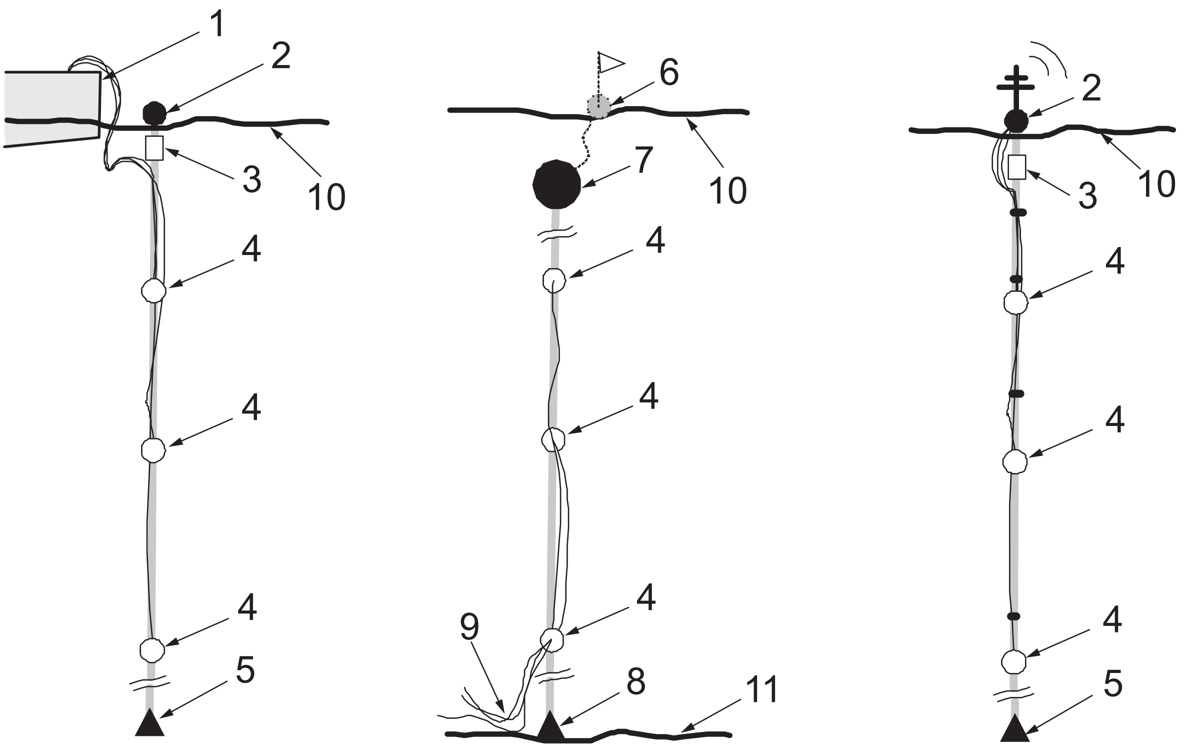
1 vessel under test

2 distance, d_{CPA}, at closest point of approach

3 hydrophone

4 20° ± 5° angle between surface and hydrophone

Figure 2 — Hydrophone geometry — Grade C



a) Support-vessel-deployed **b) Bottom-anchored** **c) Remote-transmitted**

Key

1 support vessel
2 surface buoy
3 suspension device
4 hydrophone
5 weight
6 surface buoy (optional)
7 subsurface buoy
8 bottom anchor
9 signal lines to shore
10 ocean surface
11 ocean bottom

NOTE Figure not to scale. See 5.2 and 5.4 for hydrophone arrangement details.

Figure 3 — Typical hydrophone deployment configurations usable for any grade

5.5 Test course and vessel operation

The run configuration is shown in Figure 4 for all grades. The vessel under test shall transit a straight line course to achieve the required distance at CPA. The starting point of the run (or the COMEX) is twice the data window length (DWL) before the CPA. The ending point of the run (or the FINEX) is twice the DWL after CPA. At COMEX, the vessel under test shall have achieved the required run conditions. Unless required by the run plan, the vessel under test shall maintain constant speed, fixed machinery conditions and minimum use of helm to maintain course through FINEX.

5.6 Test sequence

When all aspects of the underwater noise survey are in place, steps a) to j), below, shall be performed for each test run. For Grade A, six runs, comprising three runs for each side of the ship (alternating port and starboard aspect), shall be performed for each vessel condition to be tested. For Grade B, four runs, comprising two runs for each side of the ship (alternating port and starboard aspect) shall be performed for each vessel condition to be tested. For Grade C, four runs for either aspect (port or starboard) shall be performed for each vessel condition to be tested, with a minimum of one port and one starboard aspect measurement.

a) The vessel captain, master or owner's representative shall confirm that the necessary propulsion machinery line-up and auxiliary machinery conditions are set as required.

b) Acoustic test personnel operating the measurement instrumentation shall confirm that all measurement systems are operational.

c) Initially, the vessel under test shall move to a position at least 2 km from the hydrophones and come to a quiet condition. All vessel systems, including diesel generators, shall remain in operation. When in position, the vessel under test shall notify the acoustic test personnel. Background noise measurements may be performed at this time.

d) When background noise measurements are completed, acoustic test personnel shall notify the vessel under test to proceed toward the hydrophones at the required vessel operating conditions and speed.

e) When the vessel under test reaches the COMEX, all vessel operating conditions (speed, machinery configurations) shall remain unchanged until the FINEX location is reached. See Figure 4 for a diagram of the two locations.

f) For Grade A, measurement systems may be started at COMEX, but shall be started before the start data location. For Grades B and C, the measurement systems shall be started at the start data location.

g) For all grades, the distance at CPA shall be measured and recorded.

h) When the DWP is completed, the acoustic test personnel shall announce that the end data location has been reached. The vessel under test shall continue course to the FINEX before making any changes in vessel operation, direction or speed.

i) At FINEX, the vessel under test shall perform the *Williamson curve* manoeuvre shown in Figure 4 so as to run back through the test range on the opposite side and repeat steps e) to h) inclusive. Depending on the grade, this process shall be repeated for the number of runs, as given above.

j) Background noise measurements, in accordance with steps c) and d), shall be taken at the beginning and end of each test period (i.e. day to half-day of measurements). If weather or traffic conditions significantly change, i.e. changes in wind greater than 5 kn (2,57 m/s), sea state, ship population or precipitation, the survey shall be suspended and measurements shall be taken to determine background noise levels and confirm that background noise requirements are still valid.

6 Post-processing

6.1 General

When testing as given in Clause 5 has been completed, post-processing will be required to adjust sound pressure levels for background noise conditions, sensitivity adjustments, and to normalize the data for distance differences. This process is the same for Grades A, B and C. The next step will be to combine multiple hydrophones (Grades A and B only) and multiple runs (all grades). This process is slightly different for each grade, as given below.

For all grades of measurement, the data window angle shall be ±30° from the CPA, as shown in Figure 4. The distance at the CPA shall be 100 m or one (1×) overall ship length, with a tolerance of ±10 %. The data window length, DWL, in metres, is equal to the distance travelled by the ship under test within the ±30° window, as given in Equation (1):

$$\text{DWL} = 2d_{\text{CPA}} \tan(\theta) \quad (1)$$

where

d_{CPA} is the distance at the closest point of approach (CPA), in metres;

θ is equal to 30°, and tan(30°) equals 0,577 3.

The data window period, DWP, expressed in seconds, shall be the time to travel the data window length as a function of ship speed, as given in Equation (2):

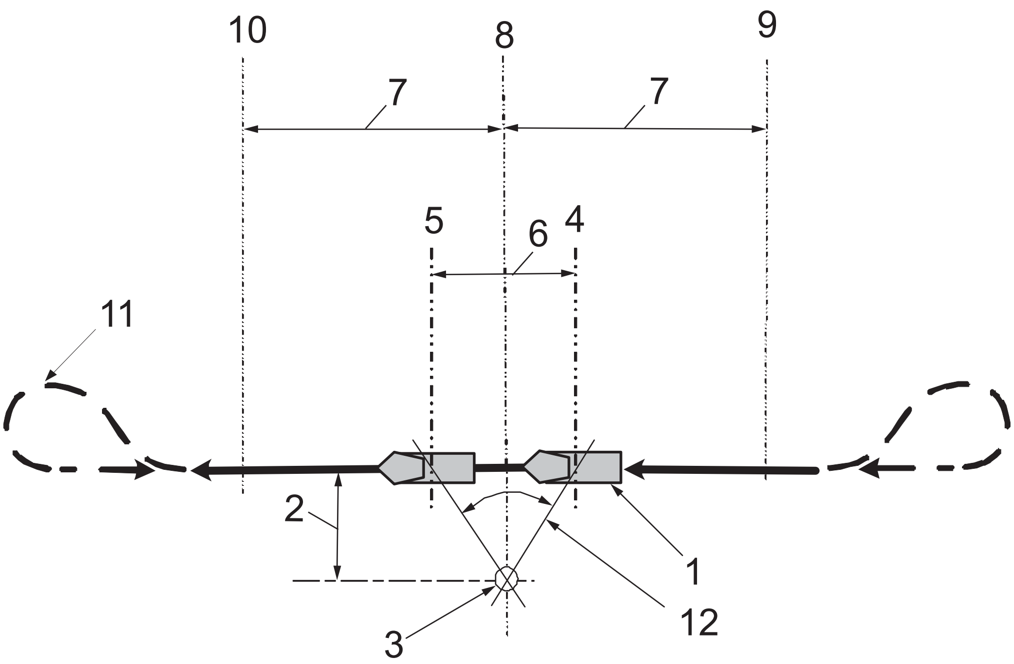
$$\mathrm{DWP} = \left(\frac{\mathrm{DWL}}{v} \right) \tag{2}$$

where

DWL is the data window length, in metres;

v is the ship's speed, in metres per second[1)].

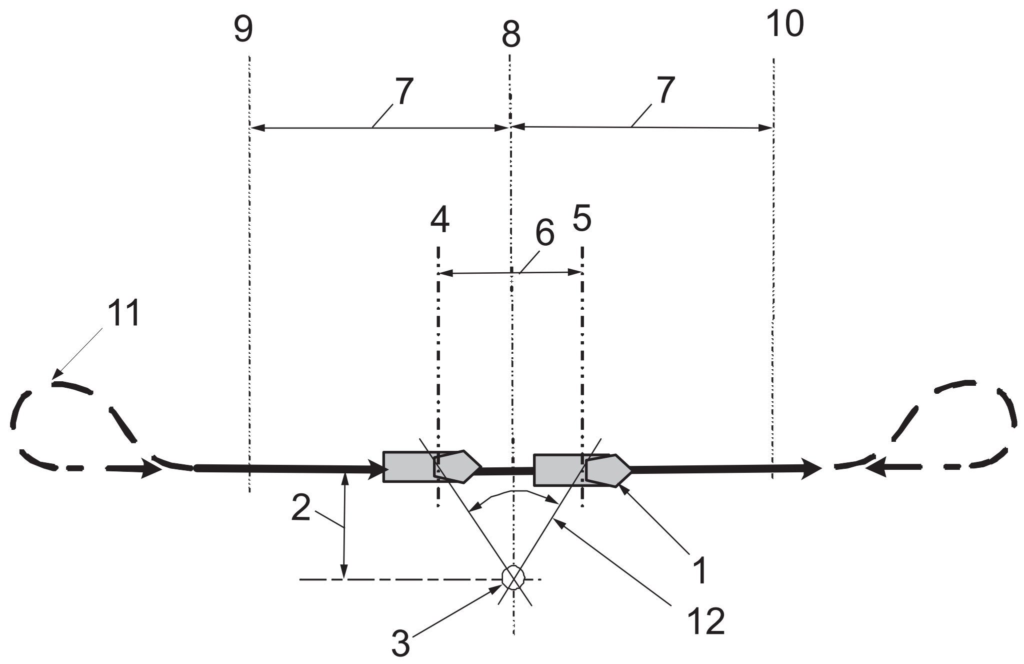
For Grade A, the DWP shall be divided into independent samples, each of which is ≤1 s. For Grades B and C, the DWP shall be one overall sample.



a) Port approach

Figure 4 (*continued*)

1) To obtain the speed in m/s, multiply knots or nautical miles/hour by 0,514 44.



b) Starboard approach

DWL = $2d_{\text{CPA}}$ tan(30°), where d_{CPA} = 100 m or one overall ship length, whichever is the greater.

$\text{DWP} = \left(\frac{\text{DWL}}{v}\right)$, where v is the ship's speed, in m/s.

Key

1 vessel under test
2 distance, d_{CPA}, at closest point of approach (CPA)
3 hydrophone(s)
4 start data
5 end data
6 DWL
7 2 × DWL
8 CPA point
9 COMEX
10 FINEX
11 Williamson curve
12 ±30° (total = 60°)

Figure 4 — Test course configurations

6.2 Background noise adjustments (all grades)

A background noise data set shall be assigned to each measurement run in order to compare the measured level of the vessel under test to the background noise at the approximate time of the test. The signal-plus-noise-to-noise ratio, ΔL, is defined by Equation (3):

$$\Delta L = L_{p_{\text{s+n}}} - L_{p_{\text{n}}} = 10\lg\left(\frac{{p_{\text{s+n}}}^2}{{p_{\text{n}}}^2}\right)\text{dB} \tag{3}$$

where

ΔL is the signal-plus-noise-to-noise ratio computed using Equation (3) for each one-third-octave band;

$p_{\text{s+n}}$ is the sound pressure at the hydrophone in micropascals (μPa), which value includes both the desired signal and undesired background noise;

p_n is the sound pressure of the background noise at the hydrophone in µPa;

L_{ps+n} is the sound pressure level in decibels (dB) with the vessel under test present for each run;

L_{pn} is the background sound pressure level with the vessel under test not influencing the measurement (at 2 km from hydrophones), in dB.

If ΔL is greater than 10 dB, then no adjustments are necessary. If ΔL is between 3 dB and 10 dB and if the background noise is sufficiently stationary, then adjustments to the measurements are required using Equation (4). It shall be clearly identified in the report that such corrections have been applied. If ΔL is less than 3 dB, then the data are background controlled and shall be so noted or discarded.

$$L'_p = 10\ \lg\left[10^{\left(L_{p\text{s+n}}/10\right)} - 10^{\left(L_{p\text{n}}/10\right)}\right]\text{dB} \quad (4)$$

where L'_p is the background-noise-adjusted sound pressure level of the vessel under test, computed in one-third-octave bands.

Use Equation (4) only used if ΔL is greater than or equal to 3 dB and less than 10 dB.

Since unexpected changes in background noise (e.g. a passing ship or a rain squall) can often occur, a signature measurement's background shall be assessed as described in 5.6 c). With the ship stationary, a background measurement (30 s average) is made when the ship is 2 km from the hydrophone(s). If the data need to be modified, the adjustments are made to one-third-octave data. Attempts to adjust discrete frequency data have usually led to undesirable results and are not recommended.

6.3 Sensitivity adjustments — All grades

Additional adjustments to the L'_p value given in 6.2 shall be made for any miscellaneous adjustments such as directivity, cable sensitivity, or amplifier gain. Sensitivity adjustments shall be made using Equation (5):

$$L''_p = L'_p + A_{\text{SEN}} \quad (5)$$

where

L''_p is the unweighted sound pressure level after background adjustment;

A_{SEN} is the adjustment for miscellaneous hydrophone sensitivities.

All sensitivity adjustments are made to one-third-octave-band data. Such adjustments may be measured by the user or provided by the instrumentation vendors.

NOTE L''_p is the unweighted sound pressure level. L'_p is a weighted sound pressure level, where the weighting characterizes the frequency response of the hydrophone and processing chain. This weighting is corrected for by applying a correction, A_{SEN}, in each one-third-octave bands. If the frequency response was flat in the frequency range of interest, then A_{SEN} = 0 dB and L''_p is equal to L'_p, and both are equal to the unweighted sound pressure level.

6.4 Distance normalization — All grades

The final adjustment of the sensitivity-adjusted measured sound pressure level, L''_p, is normalization for distance. The typical distance from the moving ship to the measurement transducer is one ship length or 100 m, whichever is the greater of the two. However, because of the effects of currents and seas, this distance may vary by ±10 %, which is acceptable, provided the distance from the hydrophones to the acoustic centre of the ship is known.

Depending on measurement technology used (e.g. GPS, sonar or laser), the distance from the ship to the hydrophone may need to be computed using two separate distances: horizontally from the ship's acoustic centre to the sea surface above the hydrophone(s), and vertically from the sea surface to each hydrophone. The total distance from the ship to each hydrophone is determined using Equation (6):

$$d_{\text{Total}} = \sqrt{d_{\text{Horz}}^2 + d_{\text{Vert}}^2(\text{h})} \tag{6}$$

where

d_{Total} is the total distance to be used in the distance normalization formula, Equation (7);

d_{Horz} is the horizontal distance from the acoustic centre of the vessel under test to the surface buoy supporting the hydrophone(s), which distance would be that determined by the distance ranging system (i.e. GPS System, sonar, or laser range finder) — corrections to the centreline, waterline and acoustic centre for the measured ranging value could be needed;

d_{Vert} is the depth of each hydrophone, h, (h_1 represents a shallow hydrophone, h_2 a middle hydrophone and h_3 a deep hydrophone).

The underwater radiated noise level for each run and each hydrophone is determined using Equation (7):

$$L_{\text{s}}(r,\text{h}) = L''_p + 20\lg\left(\frac{d_{\text{Total}}}{d_{\text{ref}}}\right)\text{dB} \tag{7}$$

where

$L_{\text{s}}(r,\text{h})$ is the underwater radiated noise level at a reference distance of 1 m, as a function of run number, r, and hydrophone location h (h_1 represents a shallow hydrophone, h_2 a middle hydrophone and h_3 a deep hydrophone);

d_{Total} is the total distance from the vessel under test to each hydrophone (metres);

d_{ref} is the reference distance of 1 m.

This normalization assumes that the ship is a directive source at the surface (i.e. the surface image is considered part of the source and the underwater sound pressure level is specific for the beam aspect at elevation angles between 15° and 45°).

6.5 Grade A-specific post-processing

For Grade A, the resulting data set from measurements performed in Clause 5 shall be one-third-octave-band radiated noise levels relative to 1 µPa in decibels (dB) at 1 m from 10 Hz to 50 000 Hz. Such data sets shall be prepared for three hydrophones and for six measurement runs, three per aspect (port or starboard). For Grade A, port and starboard aspect runs shall be kept separate. These multiple data sets shall be adjusted and normalized according to 6.2 to 6.4. This subclause describes how to combine the eighteen data sets for each condition into one set of values in one-third-octave bands.

The first step in final Grade A post-processing is to determine the power average of the radiated noise level from all three hydrophones (h_1, h_2 and h_3), which results in the radiated noise level for each run, $L_{\text{S}}(r)$, using Equation (8):

$$L_{\text{s}}(r) = 10\ \lg\left[\frac{10^{L_{\text{s}}(r,\text{h}_1)/10} + 10^{L_{\text{s}}(r,\text{h}_2)/10} + 10^{L_{\text{s}}(r,\text{h}_3)/10}}{3}\right]\text{dB} \tag{8}$$

where

$L_s(r)$ is the power-averaged, underwater radiated noise level at the reference distance of 1 m for three hydrophones for run r;

$L_s(r,h_1)$ is the underwater-radiated noise level for the shallow (h_1) hydrophone for run r;

$L_s(r,h_2)$ is the underwater radiated noise level for the middle (h_2) hydrophone for run r;

$L_s(r,h_3)$ is the underwater radiated noise level for the deep (h_3) hydrophone for run r.

The six runs of data are then arithmetically averaged to determine the final sound source value for each run using Equation (9):

$$L_s = \frac{\sum_{r=1}^{r=k} L_s(r)}{k} \tag{9}$$

where

L_s is the resulting signature-radiated noise level for k runs as computed in Equation (9);

$L_s(r)$ is the power-averaged underwater radiated noise level at the reference distance of 1 m for three hydrophones for run r, as determined using Equation (8);

k is the total number of runs — for Grade A, k = 6 or 3 (for port- and starboard-only computations), and for Grades B and C, k = 4 or 2 (for port- and starboard-only computations).

For each ship condition, L_s should be determined separately for each side of the ship (i.e. port aspect and starboard aspect) and then for both sides together. L_s is the resulting signature-radiated noise level for each vessel-operating condition. It is a function of one-third-octave bands and shall be the values that are reported, compared to limits or compared to other data sets.

6.6 Grade B-specific post processing

For Grade B, the resulting data set from measurements performed in Clause 5 shall be one-third-octave-band radiated noise levels, relative to 1 µPa, expressed in decibels (dB at 1 m) from 20 Hz to 25 000 Hz. Such data sets shall be prepared for three hydrophones and for four measurement runs, two per aspect (port or starboard). For Grade B, port and starboard aspect runs shall be kept separate. These multiple data sets shall be adjusted and normalized according to 6.2 to 6.4. This subclause describes how to combine the 12 data sets into one set of values in one-third-octave bands.

The Grade B post-processing is exactly the same as the Grade A post-processing, except that the one-third-octave-band data set is only from 20 Hz to 25 000 Hz and there are only four runs (k = 4). All computations are the same as those given in 6.5.

6.7 Grade C-specific post processing

The resulting data set from measurements performed in Clause 5 shall be one-third-octave-band sound- radiated noise levels, expressed in decibels, relative to 1 µPa (dB re 1 µPa at 1 m) from 50 Hz to 10,000 Hz. Such data sets shall be prepared for one hydrophone and for four measurement runs (port and starboard). For Grade C, port and starboard aspect runs may be averaged together. These multiple data sets shall be adjusted and normalized according to 6.2 to 6.4. This subclause describes how to combine the four data sets into one set of values in one-third-octave bands.

The Grade C post-processing only requires the use of Equation (9), since only one hydrophone is used for this grade. In addition, Grade C combines port and starboard runs into one data set. Equation (9) is used to determine the arithmetic average of the four measurements runs (k = 4).

7 Measurement uncertainty

The overall measurement uncertainty is evaluated from a combination of components, which describe random errors (where the uncertainty may be estimated from the measurement repeatability) and errors caused by effects that can introduce systematic bias into the measurements.

For the sound pressure level, L_p, determined on each measurement run, the total standard uncertainty includes the combined effect of several components of typical value between 0,5 dB to 1 dB. These components derive from errors associated with the acquisition system, with typical values being calibration (0,5 dB), sensitivity (<1 dB), data processing (0,5 dB) and amplifier gains (0,5 dB). The above has a typical combined uncertainty of 1,3 dB (calculated as the root of the sum of the squares of the individual values).

Resulting signature, L_s, radiated-noise-level calculations for each hydrophone has increased uncertainty because of the range adjustment errors. These uncertainties (which are typically in the order of 1 dB) quantify errors in the horizontal range, the inaccuracy of assumptions about the acoustic centre and other system parameters, and errors in hydrophone depth, thermal gradient, etc. The overall standard uncertainty for a radiated noise level estimation characterized by errors such as these would typically be about 2 dB, and the average of three hydrophones would be <1,5 dB (some of the systematic errors, such as ranging, would be the same for each hydrophone). The typical uncertainty specified for a naval acoustic range is about 1,5 dB to 2 dB.

When comparing data acquired using different measurement grades, data differences can be expected because of the systematic bias errors associated with each of the measurement grades. Bias errors between Grade A and Grades B and C are about 0,5 dB, based on the use of one point for the distance at CPA vs. a series of distances. Proximity of the surface and bottom usually causes biases in the data. The amount of bottom contribution is minimized when the ratio of measurement-distance-to-bottom-depth is also minimized. This ratio is about 1,0 for Grade C, about 0,67 for Grade B and about 0,33 for Grade A. Comparisons between the grades for the same ship are affected by these biases as well as other factors, such as ship's directionality. For example, Lloyd's mirror effects cause Grade C data to be 2 dB to 5 dB lower than Grade A or B data below about 200 Hz, depending on the measurement angle and bottom type.

Repeatability for the measurements addressed by this part of ISO 17208 is affected by the ranging random error and signal processing random error, these being the errors that differ from run to run. Taking the average of two or more runs mitigates the repeatability by a factor which is the square root of the number of runs. The radiated noise levels are also affected by the repeatability of the radiation from the ship.

The estimates given above are provided as representative values for guidance and should not be considered to be exact. Some sources of uncertainty inevitably depend upon the particular implementation of the measurement method — for example, the uncertainties arising from instrument and hydrophone calibration depend on the calibration uncertainties for the particular equipment in use. It is recommended that users of this part of ISO 17208 determine their own assessment of uncertainty based on the guidance given in this part of ISO 17208 and the methods described in References [1] and [10] on expression of uncertainty in measurement. With careful implementation of the methodology given in this part of ISO 17208, the overall uncertainties described above are achievable.

8 Reporting example

For Grades A, B and C measurements, the test report should include as much of the following information as possible and/or pertinent to the measurement survey.

Ship characteristics

a) Name/classification

b) Reason for the measurements

c) Shipyard and year constructed

d) Dimensions

   1) Hull form
   2) Length
   3) Beam
   4) Draft
   5) Tonnage
   6) Ballast conditions

e) Propulsion characteristics

   1) Power source
   2) Drive train
   3) Number of shafts
   4) Number of propulsor blades
   5) Turns per knot
   6) Modifications to propulsion line since the last measurement
   7) Known problems or concerns that may affect underwater sound levels
   8) Condition of the hull, last time the hull and propellers were cleaned

Testing characteristics

f) ISO/PAS 17208-1 measurement grade

   — Mitigations/deviations

g) Location/environment

   1) Date
   2) Latitude / longitude
   3) Nominal environmental conditions

      i) Wave height/sea state/wind/rain

      ii) Vessel traffic

      iii) Bottom depth/bottom type

      iv) Nominal salinity/temperature/sound speed profile

h) Measurement system

1) Suspension system description/diagram
2) Hydrophone depths
3) Hydrophone type/model/directionality/nominal sensitivity
4) System component description and diagram
5) Factory calibration details (performed by, dates and certificates)
6) Field calibration methods and results

i) Testing scenario

1) Nominal CPA
2) Selection of centre of integration window
3) Manoeuvring geometry
4) Background noise levels

Reporting concerns

j) Final results in one-third-octave bands:

1) Averaged value of all runs [result of Equation (9)]
2) Minimum value of all runs (when range is greater than 3 dB or as requested by user)
3) Maximum value of all runs (when range is greater than 3 dB or as requested by the user)
4) Range of all runs (when the range is greater than 3 dB or as requested by the user)

k) Equivalent spectrum level correcting

— Broadband to narrowband

l) Environmentally manipulated data

1) Ambient/background adjustments
2) Sensor effects
   i) Cable strum/hydrophone acceleration
   ii) Hydrophone directionality
   iii) Temperature dependence
3) Array streaming

m) Narrowband

1) Effective bandwidth
2) Source tonal vs. time dependence
3) Doppler
4) Table of significant highest tones

n) Graphics

1) Reference range
2) Bandwidth

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