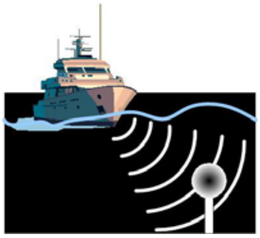

DRAFT ANSI S12.64- 200X
Revision 08, March 20, 2009

WG-47 Committee Draft – Not for Public Distribution
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AMERICAN NATIONAL STANDARD

Quantities and Procedures for Description and Measurement of Underwater Sound from Ships -

Part 1: General Requirement

Secretariat:

Acoustical Society of America

Draft - Not approved by:

American National Standards Institute, Inc.

Abstract

This standard describes the measurement systems, procedures and methodologies used for the beam aspect measurement of underwater sound pressure levels from ships for a given operating condition. The resulting quantities are nominal source level values. It does not require the use of a specific ocean location, but the requirements for an ocean test site are provided. The underwater sound pressure level measurements are performed in the far-field and then corrected to a reference distance of 1 meter. This standard is applicable to any and all surface vessels either manned or unmanned. This standard is not applicable to submerged vessels or to aircraft. Measurement systems are described for measurement of underwater sound pressure levels and also the distance or range between the underwater transducers and subject vessel. Processing and reporting of the data is described and informational guidance is provided. This standard does not specify underwater noise criteria.

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Contents

Figures

Tables

Deleted: 7
Deleted: 8
Deleted: 8
Deleted: 8
Deleted: 9
Deleted: 11
Deleted: 11
Deleted: 13
Deleted: 13
Deleted: 13
Deleted: 14
Deleted: 15
Deleted: 16
Deleted: 17
Deleted: 17
Deleted: 17
Deleted: 18
Deleted: 19
Deleted: 9
Deleted: 10
Deleted: 12
Deleted: 6
Deleted: 18

Foreword

[*This Foreword is for information only, and is not a part of the American National Standard ANSI S12.64 - 200X American National Standard Quantities and Procedures for Description and Measurement of Underwater Noise from Ships*].

This standard comprises a part of a group of definitions, standards, and specifications for use in noise. It was developed and approved by Accredited Standards Committee S12 Noise, under its approved operating procedures. Those procedures have been accredited by the American National Standards Institute (ANSI). The Scope of Accredited Standards Committee S12 is as follows:

> *Standards, specifications, and terminology in the field of acoustical noise pertaining to methods of measurement, evaluation, and control, including biological safety, tolerance, and comfort, and physical acoustics as related to environmental and occupational noise.*

This standard is not comparable to any existing ISO Standard.

At the time this Standard was submitted to Accredited Standards Committee S12, Noise for approval, the membership was as follows:

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Working Group S12/WG 47, Underwater Noise Measurement of Ships, which assisted Accredited Standards Committee S12, Noise, in the development of this standard, had the following membership.

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Suggestions for improvements of this standard will be welcomed. They should be sent to Accredited Standards Committee S12, Noise, in care of the Standards Secretariat of the Acoustical Society of America, 35 Pinelawn Road, Suite 114E, Melville, New York 11747-3177. Telephone: 631-390-0215; FAX: 631-390-0217; E-mail: asastds@aip.org

Introduction

Reduction of all types of vessel emissions have become an issue in the past ten years, most notably ballast water and engine NOx emissions. More recently, these emissions have included underwater noise, for the purpose of reducing the impact on marine animals. Excessive underwater noise interferes with a marine animal's ability to navigate, communicate, find food, etc. As such, the environmental impact reports of underwater projects (pipe laying, oil exploration) are now including assessment of underwater noise impacts. This standard addresses one of the needed areas of improved technology.

This part of ANSI/ASA S12.64 was written to provide a standardized measurement method for the accurate and repeatable quantification and qualification of a ship's underwater (radiated) noise. More specific discussions of advanced measurement systems, along with technical rational/tradeoffs, computation examples will be included in subsequent parts of this standard. These parts will also contain recommendations concerning issues such as: hydrophone suspension, narrowband processing/reporting, shallow water measurements and factors that affect the accuracy and repeatability of the data.

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American National Standard

Quantities and Procedures for Description and Measurement of Underwater Sound from Ships

1 Scope

This first part of ANSI/ASA S12.64 describes the general measurement systems, procedures and methodologies used for the measurement of underwater sound pressure levels from ships at a prescribed operating condition. It contains 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 meter. Since the underwater sound pressure levels are affected by the presence of the free surface (and sometimes the bottom), such quantities are considered "affected source levels", herein referred to as source 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 standard does not specify underwater noise criteria or the potential effects of noise on marine mammals.

This standard is applicable to any and all underway surface vessels, either manned or unmanned. The methods have no inherent limitation on minimum or maximum vessel size. This standard is not applicable to submerged vessels or to aircraft. This standard shall be limited to vessels operating at speeds no greater than 50 knots (25.70 m/s). The measurement methods mitigate the variability caused by Lloyd's Mirror coherence effects (see 3.15), but do not exclude a possible influence of bottom reflections. No specific computational adjustments for these effects are part of this standard. It does not require the use of a specific ocean location, but the requirements for an ocean test site are provided.

The intended uses of the products described in this standard are: to show compliance with contract requirements to enable periodic signature assessments, and in research and development. The intended users include: government agencies, research vessel operators, and commercial vessel owners that need to operate in acoustically sensitive waters.

This standard offers three Grades of measurement, each with a stated applicability, test methodology, instrumentation accuracy, system repeatability, and complexity. A summary of the attributes of each "Grade" (denoted A, B and C) is given in Table 1.

2 Normative references

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

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

ANSI S1.11, American National Standard Specification for Octave-Band and Fractional-Octave Band Analog and Digital Filters

Deleted: This standard describes the measurement systems, procedures and methodologies used for the measurement of underwater sound pressure levels from ships at a given operating condition. It does not require the use of a specific ocean location, but the requirements for an ocean test site are provided. The resulting quantities are the sound pressure levels normalized to a distance of 1 meter. Since the underwater sound pressure levels are affected by the presence of the free surface (and sometimes the bottom), such quantities are considered affected source levels", herein referred to as source 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 standard does not specify underwater noise criteria.¶
This standard is applicable to any and all surface vessels, either manned or unmanned. The methods have no inherent limitation on minimum or maximum vessel size. This standard is not applicable to submerged vessels or to aircraft. This standard shall be limited to vessels operating no greater than 50 knots (25.70 m/s). The measurement methods mitigate the variability caused by Lloyd's Mirror (see 3.15) effects, but do not exclude a possible influence of bottom reflections. No specific computational adjustments for these effects are part of this standard.¶
The intended use of the standard is as a test method to show compliance with contract requirements, to enable periodic signature assessments, or in research and development. The intended users include: government agencies, research vessel operators, and commercial vessel owners that need to operate in acoustically sensitive waters.¶
This standard offers three Grades of measurement, each with a stated applicability, test methodology, instrumentation accuracy, system repeatability, and complexity. A summary of the attributes of each "Grade" (denoted A, B and C) is given in Table 1.¶

ANSI S1.20, *American National Standard Procedures for Calibration of Underwater Electroacoustical Transducers*

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

ISO 18431, *Mechanical vibration and shock – Signal processing – Part 2: Time domain windows for Fourier Transform analysis*

ISO 18431-2:2004/COR. 1:2008 Technical Corrigendum 1 to ISO 18431-2:2004.

3 Terms and definitions

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

3.1
acoustic center
position on the ship where it is assumed that all of the noise sources are co-located as point source.

3.2
background noise
the noise from all sources other than the ship being measuredNOTESee clause 6.2 for background noise adjustments, also referred to as signal-to-noise adjustments.

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3.3
beam aspect
to either the side of the ship

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

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

3.5
closest point of approach (CPA)
the horizontal distance (during a test run) where the centerline of ship under test is the closest to the hydrophone(s)

3.6
COMEX (Commence Exercise)
start test range location
position of the vessel under test: two times (2x) the “Start Data” distance ahead of the CPA point

NOTE See Figure 4.

3.7
data window angle
the angle scribed between the start data location and end data location using the hydrophone position as the center point

NOTE The data window angle is expressed as a value in degrees as shown in Figure 3. For all grades of measurement the data window angle is ±30°.

3.8
data window length (DWL)
the distance between the start data point and end data point along the vessel course with the CPA centered on this total length.

NOTE See equation 1 and Figure 4.

3.9
data window period (DWP)
the time it takes 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 vessel under test one data window length after the start data location

NOTE See Figure 4.

3.10
FINEX Finish Exercise
end test range location
position of the vessel under test two times (2x) the "Start Data" distance past the CPA point

NOTE See Figure 4.

3.11
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, in fact, responding properly (i.e. within the system's stated uncertainty and accuracy) to the known stimulus

3.12
geometric far field
the horizontal distance at which the assumption of source co-location causes less than 1 dB of error when adjusting to the reference distance.

3.13
hydrophone cable drift angle
angle between the vertical axis and the line created between the fixed support of the hydrophone cable and the hydrophone

3.14
insert voltage calibration
a 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 accuracy) to a known stimulus

3.15
Lloyd's Mirror 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 this standard, these effects are considered as part of the source's radiation, causing it to exhibit a vertical directivity, necessitating the acquisition angle(s) defined for each Grade.

3.16
measurement uncertainty
maximum difference between the measured resulting signature source level and the true signature source 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.)

3.17
measurement repeatability
expected difference between resulting signature source levels, stated in decibels, in one-third octave bands, taken at different times, given that the same vessel under test, conditions, and measurement are used

3.18
measurement system
data acquisition system consisting of, but not limited to, one or more transducer(s), conditioning amplifier(s), analog-to-digital converter(s), digital signal processing computer and ancillary peripherals

3.19
omni-directional hydrophone
underwater sound pressure transducer that responds equally to sound from all directions

3.20
slant range
linear distance from the acoustic center of the vessel under test to each hydrophone.

3.21
overall ship length
the longitudinal distance between the forward-most and aft-most perpendicular .

3.22
resulting signature source level
final affected underwater sound pressure level, adjusted for range, sometimes referred to as a "source level" or "signature".

NOTE: The resulting signature source level that are final reported results, are the computations from Equation (9) for Grades A, B and C, respectively.

Deleted: is determined using Equations (9), (10) & (11)

3.23
sound speed profile
measure of the speed of sound in seawater as a function of depth, measured vertically through the water column.

3.24
start data location
position of the vessel under test where data recording is started

NOTE: See Figure 4.

Deleted: The distance is determined with Equation (1) and shown in

3.25
test site
location where the underwater noise measurements are performed

3.26
underwater sound pressure level
ten times the logarithm to the base ten of the ratio of the time-mean-square pressure of an underwater sound, in a stated frequency band, to the square of the reference sound pressure of 1 μ Pa. Unit decibel (dB); abbreviation, SPL; symbol, Lp.

4 Instrumentation

4.1 Introduction

In order to quantify the underwater sound from a marine vessel, three main instrumentation components are required: (1) hydrophone and signal conditioning, (2) data acquisition, recording, processing and display system and (3) distance measurement system. The requirements for each of the three components will depend on which of the three Grades of measurement are desired. Detailed specifications of each of the measurement systems are given below.

4.2 Hydrophone and signal conditioning

For the purposes of this standard, the terms "hydrophone", "underwater electro-acoustic transducer" or "underwater microphone" may be used synonymously. In this Standard the term "hydrophone" is used and includes any signal conditioning electronics either within or exterior to the hydrophone. The hydrophone(s) should have sensitivity, bandwidth and dynamic range necessary to measure the ship under test and meet the performance for each intended Grade as noted in Table 1.

For all Grades of measurement the hydrophone 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 Clause 6.3). The number of hydrophones used to perform the measurement will depend 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 to ANSI S1.20, or 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 to ANSI S1.20, or 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.

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For Grades A and B, prior to and daily throughout the measurement series the full measurement system shall be field calibrated using insert voltage methods (See 3.14) for all required one-third octave bands.

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For Grade C, prior to and daily throughout the measurement series the full measurement system shall be field calibrated using either insert voltage methods (See 3.14) for all one-third octave bands or single frequency device (such as a pistonphone).

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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 analyzers) or combinations of such. The data acquisition system should have an appropriate sampling rate following Nyquist requirements and appropriate dynamic range for either analog or digital systems. All frequency-domain averaging shall be linear with sampling consistent with the Data Window Period (DWP, see Clause 6.1)

Table 1 – Summary of measurement grades

Grade	A	B	C
Grade name	**Precision Method**	**Engineering Method**	**Survey Method**
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 (1/3- octave bands)	10 to 50,000 Hz	20 to 25,000 Hz	50 to 10,000 Hz
Narrowband Measurements	Required	Required	As Needed
Number of Hydrophones	Three	Three	One
Hydrophone Geometry	Figure 1	Figure 1	Figure 2
Nominal Hydrophone Depth(s)	15°, 30°, 45° angle	15°, 30°, 45° angle	20° ± 5° angle (See 5.2)
Minimum Water Depth	Greater of 300 m or 3x overall ship length	Greater of 150 m or 1.5x overall ship length	Greater of 75 m or 1x overall ship length
Minimum Distance at Closest Point of Approach (CPA)	Greater of 100 m or 1x overall ship length		
Distance Ranging Uncertainty (at CPA)	2%	2%	5%
Acoustic Center Location	Determined during testing (See 4.5)	Determined during testing (See 4.5)	Halfway between the Engine Room and the Propeller
Data Window Angle (± CPA)	±30°		
Data Window Length, meters	Determined using Equation (1), Shown in Figure 4		
Data Window Time, seconds	Determined Using Equation (2), shown in Figure 4		
Data Window Averaging Time	≤ 1 seconds	≤ 2 seconds	One overall sample
Minimum Number of Runs per Condition	6 Total 3 Port 3 Starboard	4 Total 2 Port 2 Starboard	4 Total, at least one starboard and one port
Recommended weather/sea conditions	Wind Speed <= 20 knots (See Clause 5.3)		
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)
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

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

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For Grade A measurements, the broadband processing shall cover the one-third octave bands from 10 to 50,000 Hertz in accordance with ANSI S1.11, Class 1. Narrowband 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 to 25,000 Hertz in accordance with ANSI S1.11, Class 1. Narrowband 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 to 10,000 Hertz in accordance with ANSI S1.11, Class 1. Narrowband 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

A distance measurement is required to determine the horizontal separation between the acoustic center of the vessel under test and the position on the sea surface above the hydrophone(s) continuously throughout the data acquisition and processing period for Grades A and B and only at the Closest Point of Approach (CPA) for Grade C.

The distance measurement device may utilize any method (optical, acoustical, GPS, radar) as long as the following accuracy is provided. 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 center 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 as noted in Clause 6.4. It is not necessary to take into account any drift that the hydrophones may experience after they are deployed as long as the hydrophone cable drift angle does not exceed 5°. If the drift angle exceeds 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 for 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 as noted in Clause 6.4. It is not necessary to take into account any drift which the hydrophones may experience after they are deployed as long as 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 weight to the end of the hydrophone cable or use of 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 Grades A and B, distance data shall be recorded in order 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 Grade C, only the distance at CPA shall be recorded which may be by manual methods.

4.5 Acoustic Center

The acoustic center of the vessel under test assumes that the ship is a directive point source at the surface, with the same location for all frequencies. For Grades A and B, the acoustic center shall be determined by the user. For example, the location of the acoustic center can be defined by the maximum broadband hydrophone output during each run. For Grade C, the acoustic center is assumed to be located halfway between the center 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 several 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, etc.). A complete discussion of all factors is given below.

5.2 Test site requirements

This standard 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. 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 maneuverability and safety.

For all Grades, the background noise should be sufficiently low to measure the radiated noise 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 Clause 6.2).

There will be 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 Clause 6.2), these data may be designated as background limited or shall not be 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 meters or three times (3x) the overall ship length whichever is greater. For Grade B measurements, the minimum water depth shall be 150 meters or one and a half times (1.5x) the overall ship length, whichever is greater. For Grade C measurements, the minimum water depth shall be 75 meters or one times (1x) the 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 water than above will result in greater uncertainty at frequencies below approximately 200 Hz. Measurements in shallow water will be the subject of another part of this standard.

5.3 Sea Surface Conditions

The sea surface conditions during testing are of concern from both the measurement noise interference and cause for instability of the source. For example, rougher surface conditions can increase the ambient noise in the water as well as contribute to various measurement array excitation causing limitations because of signal-to-noise adjustments (6.2). Of limiting concern is the repeatability of the surface vessels source level in various sea surface conditions. For example, wave heights can cause broaching of a propulsor causing significant source level differences between low versus high surface wave conditions.

The limiting surface conditions affecting the source levels are a function of numerous variables (wave-height, period, direction relative ship course, ship seakeeping characteristics, source depth etc.). As a generality smaller length vessels will require lower wave heights to attain consistent source level measurements. The recommended wind speed limitation of ≤ 20 knots (10.28 m/s), provides a nominal value for vessels greater than 100 meters. Smaller vessels may require more benign surface conditions while larger vessels may 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 to measure the beam aspect of the vessel under test. For all Grades, the hydrophone(s) shall not be located on the sea bed.

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 CPA (Figure 1). For Grade C, the hydrophone shall be positioned vertically in the water column at a depth that results from a 20° [see earlier] angle from the sea surface at a distance equal to CPA (Figure 2). For Grade C only, the angle to the hydrophone shall have a tolerance of ±5°.

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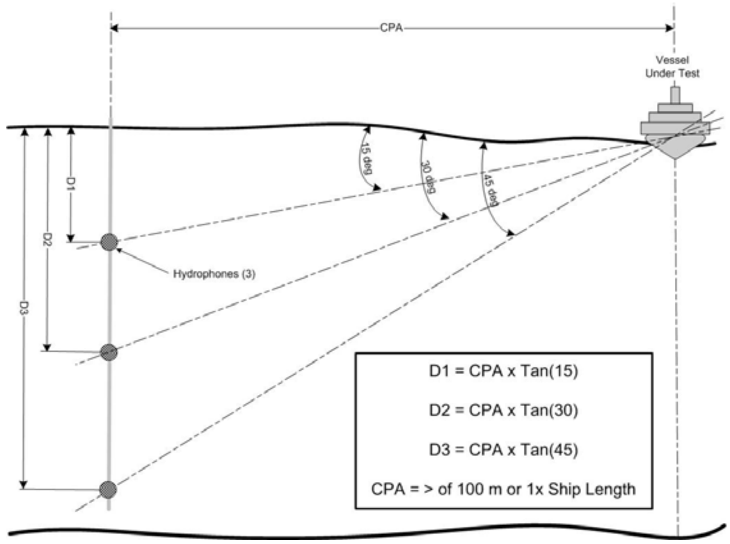

Figure 1 – Grades A and B Hydrophone Geometry.

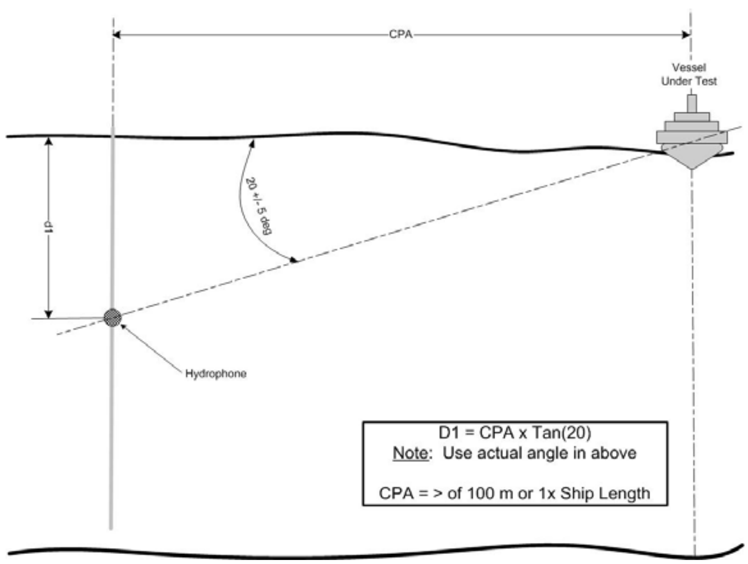

Figure 2 – Grade C Hydrophone Geometry.

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

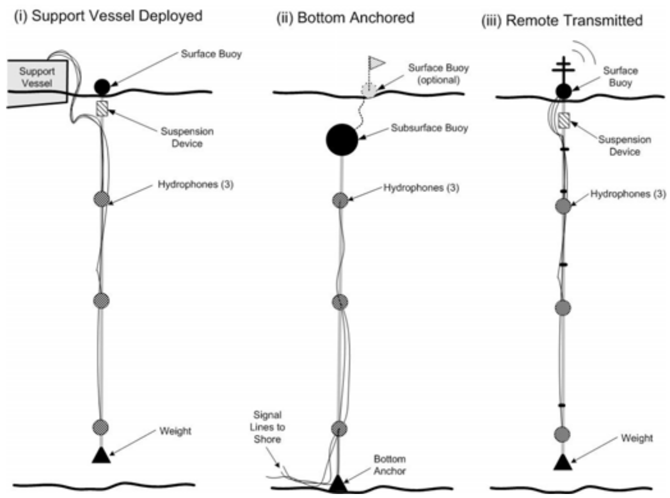

Figure 3 – Typical Hydrophone Deployment Configurations. May be used for any Grade.

5.5 Test course and vessel operation

For all grades, the run configuration is shown in Figure 4. The vessel under test shall transit a straight line course to achieve the required CPA. The starting point of the run (or COMEX) is twice the data window length (DWL) before the CPA. The ending point of the run (or 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 the following steps shall be used to conduct each test run. For Grade A, six (6) runs with three (3) for each side of the ship (alternating port and starboard aspect) shall be performed for each condition to be tested. For Grade B, four (4) runs with two (2) for each side of the ship (alternating port and starboard aspect) shall be performed for each condition to be tested. For Grade C, four (4) runs for either aspect (port or starboard) shall be performed for each 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 all measurement systems operational.

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

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 “Start Test Range” (COMEX) location, all vessel operating conditions (speed, machinery configurations) shall remain unchanged until “End Test Range” (FINEX) location is reached. See Figure 4 for diagram of the two locations.

f) For Grades A & B, measurement systems may be started at COMEX, but must be started before the Start of Data Window location. For Grade C, the measurement systems shall be started at the start of the data window.

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g) For all Grades, the CPA shall be measured and recorded.

h) When the Data Window Period (DWP) is completed, the acoustic test personnel shall announce that the “End Data” point is reached. The vessel under test shall continue course to “End Test Range” (FINEX) point before making any changes in vessel operation, direction or speed.

i) At the “End Test Range” (FINEX) point, the vessel under test shall perform the “Williamson Curve” maneuver shown in Figure 4 to run back through the test range on the opposite side and repeat steps (e) through (h). Depending on the Grade, this process shall be repeated for the number of runs as given above.

j) Background noise measurements, 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 knots (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.

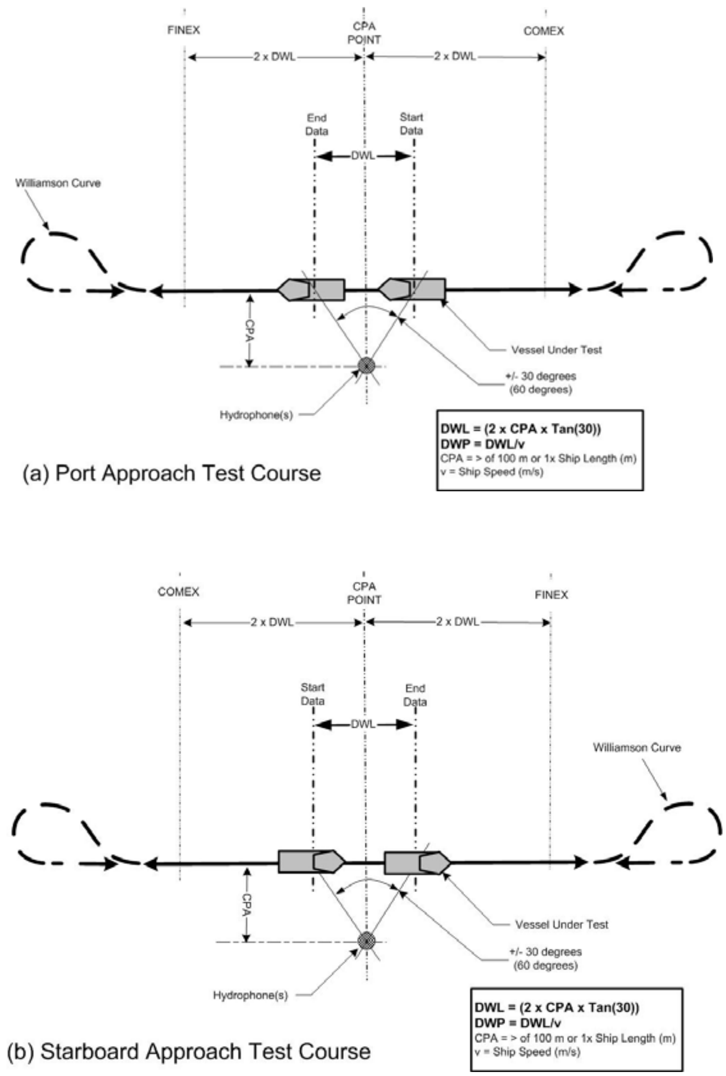

Figure 4 – Test course configuration, (a) port and (b) starboard approaches.

6 Post processing

6.1 Introduction

When the testing is completed as given in Clause 5, post processing will be required to adjust sound pressure levels for signal-to-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 CPA shall be as specified for each Grade, but in all cases no greater than twice the water depth. The Data Window Length (DWL) is the distance traveled by the ship under test within the ±30° window as given in Equation (1).

$$DWL = (2) \times (CPA) \times Tan(\theta) \qquad (1)$$

Where

DWL is the data window length, meters

CPA is the Closest Point of Approach, meters

θ = 30 degrees; Tan(30°) is 0.5773.

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

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

Where

DWP is the data window period, seconds

v is the ship speed in meters/second (multiply knots or nautical miles/hour by 0.51444 to get speed in meters/second),

For Grade A, the data window period shall be divided into independent samples that are less than or equal to 1 seconds each. For Grade B, the data window period shall be divided into independent samples that are less than or equal to 2 seconds each. For Grade C, the data window period shall be one overall sample.

6.2 Signal-to-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-to-noise ratio or Δ is defined in Equation (3).

If Δ is greater than 10 dB, then no adjustments are necessary. If Δ is between 3 and 10 dB and if the ambient 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 Δ is less than 3 dB then the data shall be so noted or discarded.

$$\Delta = 20\log\left(\frac{p+n}{n}\right) = 10\log\left(\frac{p+n}{n}\right)^2 = L_{p+n} - L_n \qquad (3)$$

Where

Δ is the signal-to-noise ratio computed using Equation (3) for each one-third octave band.

$p+n$ is the sound pressure at the hydrophone which is $10^{(Lp+n/20)}$ in µPa. This value includes both the desired signal and undesired background noise.

n is the background noise pressure which is equal to $10^{(Ln/20)}$ in µPa.

L_{p+n} is the sound pressure level in decibels with vessel under test present for each run, and

L_n is the sound pressure level with the vessel under test not present (at 2 kilometer location) (i.e. the background noise level) in decibels.

$$L'_p = 10\log\left(10^{(L_{p+n}/10)} - 10^{(L_n/10)}\right) \quad (4)$$

Where

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

Equation (4) is only used if Δ is greater than or equal to 3 dB.

Since unexpected changes in background noise often occur (e.g., a passing ship or a rain squall) a signature measurement's background shall be assessed at the beginning of each event in order to estimate any background noise contributions to the measurement SPL and perform remedial adjustments to the data, if necessary. With the ship stationary, a background measurement (30 second average) is made when the ship's is at 2 kilometers 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.

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6.3 Sensitivity adjustments (all Grades)

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

Deleted: hydrophone sensitivity, hydrophone directivity and hydrophone cable sensitivity

Deleted: These sensitivity adjustments are necessary to provide absolute pressure levels.

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

Where,

L''_p is the sensitivity adjusted measured sound pressure level (after background adjustment).

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

All sensitivity adjustments are made to one-third octave data and can be measured by the user or provided by the hydrophone vendor.

Deleted: A_{DIR} is the adjustment for hydrophone directivity, and ¶
A_{CABLE} is the adjustment for cable sensitivity.¶

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6.4 Distance normalization (all Grades)

The final adjustment of the measured sound pressure levels L''_p is normalization for distance. The typical distance from the moving ship to the measurement transducer is one ship length or 100 meters whichever is greater. However, due to current and seas this distance may vary by ±10%, which is acceptable as long as the distance from the hydrophones to the acoustic center of the ship is known.

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Depending on measurement technology used (GPS, Sonar, or Laser), the distance from the ship to the hydrophone may need to be computed using two separate distances: (1) horizontally from the ship's acoustic center to the sea surface above the hydrophone(s) and (2) vertically from the sea surface to each hydrophone. The total distance from the ship to each hydrophone is determined using Equation (6) below.

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

Where

d_{Total} is the total distance to be used the distance normalization Equation (7) below.

d_{Horz} is the horizontal distance from the acoustic center of the vessel under test to the surface buoy supporting the hydrophone(s). This distance would be what is determined by the distance ranging system (i.e. GPS System, Sonar or Laser Range Finder). The following corrections to the measured ranging value may be needed: to the center-line, to the waterline and to the acoustic center.

d_{Vert} is the depth of the each hydrophone (h, where h1 for shallow hydrophone, h2 for middle hydrophone and h3 for deep hydrophone).

The underwater sound source level for each run and each hydrophone is determined by Equation (7) as given below.

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$$L_S(r,h) = L''_p 20Log(d_{Total} / d_{ref}) \qquad (7)$$

Where

$L_S(r,h)$ is the underwater sound source level at a reference distance of 1 meter as a function of run number (r) and hydrophone location (h, where h1 for shallow hydrophone, h2 for middle hydrophone and h3 for deep hydrophone).

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

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 as part or the source and the underwater sound pressure level is specific for the beam aspect at elevation angles between 15 and 45 degrees).

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 sound source levels in decibels relative to 1 micro-Pascal (dB re 1µPa at 1 m) from 10 to

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50,000 Hertz. 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 through 6.4 above. This Clause 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 sound source level from all three hydrophones (h1, h2 and h3) which results in the sound source level for each run, $L_S(r)$ given by Equation (8).

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$$L_S(r) = 10Log\{(10^{L_S(r,h1)/10} + 10^{L_S(r,h2)/10} + 10^{L_S(r,h3)/10})/3\} \qquad (8)$$

Where

$L_S(r)$ is the power-averaged underwater sound source level at the reference distance of 1 meter for three hydrophones for run number *r*.

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$L_S(r,h1)$ is the underwater sound source level for the shallow (h1) hydrophone for run number *r*.

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$L_S(r,h2)$ is the underwater sound source level for the middle (h2) hydrophone for run number *r*.

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$L_S(r,h3)$ is the underwater sound source level for the deep (h3) hydrophone for run number *r*.

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The six runs of data are then arithmetically averaged to determine the final sound source value for each run as given in Equation (9).

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$$L_S = \{\sum_{r=1}^{r=k} L_S(r)\}/k \qquad (9)$$

Where

L_s is the resulting signature source level for k runs as computed in Equation (9).

k *is the total number of runs, for Grade A k = 6, Grades B and C k = 4.*

It should be determined for each ship conditions of each side of the ship (i.e. port aspect and starboard aspect). This is the final set of values as function of one-third octave band for that condition that is 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 sound source levels in decibels relative to 1 micro-Pascal (dB re 1μPa at 1m) from 20 to 25,000 Hertz. 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 through 6.4 above. This Clause describes how to combine the twelve data sets into one set of values in one-third octave bands.

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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 to 25,000 Hertz and there is only four runs (k=4). All computations are the same as given in Clause 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 source levels in decibels relative to 1 micro-Pascal (dB re 1μPa at 1m) from 50 to 10,000 Hertz. 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 Clause 6.2 through 6.4 above. This Clause describes how to combine the four data sets into one set of values in one-third octave bands.

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The Grade C post-processing will only require use of Equation (9) since only one hydrophone is used for this Grade. Also, Grade C will combine 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 may introduce systematic bias into the measurements.

For the sound pressure level (L_p) determined on each measurement run, the total standard uncertainty will include the combined effect of several components of typical value between 0.5 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 will have a combined uncertainty of typically 1.3 dB (calculated as the root of the sum of the squares of the individual values).

Resulting signature (L_S) source level calculations for each hydrophone will have increased uncertainty because of the range adjustment errors. These uncertainties (which are typically of order 1 dB) must quantify errors in the horizontal range; the inaccuracy of assumptions about the acoustic center and other system parameters; and errors in hydrophone depth, thermal gradient, etc. The overall standard uncertainty for a source 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). This is the typical value specified for naval acoustic ranges.

When comparing data acquired using different measurement grades, data differences may be expected because of the systematic bias errors associated with each of the measurement grades. Proximity of the surface and bottom usually causes biases in the data. The amount of bottom contribution is minimised when the ratio of measurement distance to bottom depth is also minimised. This ratio is about 1.0 for Grade C, about 0.67 for Grade B and about 0.33 for type A. Comparisons between the types for the same ship will be affected by these biases as well as other factors such as ship's directionality. For simple bottoms, the biases should be within 1 dB of the values shown in the Table 2.

Table 2 – Typical data comparison differences caused by surface and bottom contributions

Data comparison	**Grade A data compared to Grade B data**	**Grade A data compared to Grade C data**	**Grade B data compared to Grade C data**
Typical result above 400 Hz	Grade B data 1 dB greater than Grade A	Grade C data 2-3 dB greater than Grade A	Grade C data 1-2 dB greater than Grade B

	data		
Typical result below 400 Hz	Grade B data 1-2 dB greater than Grade A data	Grade C data 3-4 dB greater than Grade A	Grade C data 2-3 dB greater than Grade B

Repeatability for the measurements addressed by this standard 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 source levels are also affected by the repeatability of the radiation from the ship.

It should be noted that the estimates given above merely represent typical values provided for guidance, and should not be regarded as exact. Some sources of uncertainty will inevitably depend upon the particular implementation of the measurement method (for example, the uncertainties arising from instrument and hydrophone calibration will depend on the calibration uncertainties for the particular equipment in use). It is recommended that users undertake their own uncertainty assessment based on the guidance in this standard, and the standard guides for the expression of uncertainty in measurement[3, 5]. However, with careful implementation of the methodology described in this standard, the overall uncertainties described above are achievable.

Deleted: Measurement uncertainty is affected by a combination of random errors and bias errors. For the sound pressure level (L_p) for each one run, the total random error includes the combined effect of several 0.5 to 1 dB errors associated with the acquisition system, typical values being: calibration (0.5 dB); sensitivity (<1 dB); data processing (0.5 dB) and amplifier gains (0.5 dB). These errors have an rms (root mean square) value of about 1.25 dB. ¶
Resulting signature (L_S) source levels calculations for each hydrophone have increased uncertainty because of the range adjustment errors. These errors (~1 dB) include errors associated with uncertainty in the horizontal range, assumption about the acoustic center and other system parameters; hydrophone depth, thermal gradient, etc. The rms random error for a source level estimation characterized by errors such as these would be about 2 dB, and the average of three hydrophones would be <1.5 dB (some errors, such as ranging, would be the same for each hydrophone), the value specified for navy acoustic ranges.¶
When comparing data acquired using different measurement grades, data differences may be expected because of the bias errors associated with each of the types. Proximity of the surface and bottom usually causes biases in the data. The amount of bottom contribution is smallest when the ratio of measurement distance to bottom depth is the smallest. This ratio is about one for Grade C, about 0.67 for Grade B and about 0.33 for type A. Comparisons between the types for the same ship will be affected by these biases as well as other factors such as ship's directionality. For simple bottoms, the biases should be within 1 dB of the values shown below. The values in parenthesis are estimates of the combined effects of surface and bottom below 400 Hz.¶
Table 2 – Typical data comparison differences caused by surface and bottom contributions¶
¶
Data comparison ... [1]

8 Reporting Example

For Grades A, B and C measurements, the test report could include the following information:

1. Ship Characteristics
- 1.1. Name / Classification
- 1.2. Reason for the measurements
- 1.3. Shipyard and year constructed
- 1.4. Dimensions
  - 1.4.1. Hull Form
  - 1.4.2. Length
  - 1.4.3. Beam
  - 1.4.4. Draft
  - 1.4.5. Tonnage
  - 1.4.6. Ballast conditions
- 1.5. Propulsion Characteristics
  - 1.5.1. Power Source
  - 1.5.2. Drive Train
  - 1.5.3. Number of Shafts
  - 1.5.4. Number of Propulsor Blades
  - 1.5.5. Turns per knot
  - 1.5.6. Modifications to propulsion line since the last measurement.
  - 1.5.7. Known problems or concerns that may affect underwater sound levels
  - 1.5.8. Condition of the hull, last time the hull and propellers were cleaned.

2. Testing Characteristics
- 2.1. ASA Measurement Grade
  - 2.1.1. Mitigations / Deviations
- 2.2. Location / Environment
  - 2.2.1. Date

2.2.2. Latitude / Longitude
2.2.3. Nominal Environmental Conditions
2.2.3.1. Wave Height / Sea State / Wind / Rain
2.2.3.2. Vessel Traffic
2.2.3.3. Bottom Depth / Bottom Type
2.2.3.4. Nominal Salinity / Temperature / Sound Speed Profile
2.3. Measurement System
2.3.1. Suspension System Description / Diagram
2.3.2. Hydrophone Depths
2.3.3. Hydrophone Type / Model / Directionality / Nominal Sensitivity
2.3.4. System Component Description and Diagram
2.3.5. Factory calibration details (performed by, dates and certificates)
2.3.6. Field calibration methods and results
2.4. Testing Scenario
2.4.1. Nominal CPA
2.4.2. Selection of Center of Integration Window
2.4.3. Maneuvering Geometry
2.4.4. Background noise levels

3. Reporting Concerns

3.1. Equivalent Spectrum Level Correcting
3.1.1. Broadband to Narrowband
3.2. Environmentally Manipulated Data
3.2.1. Ambient / Background Adjustments
3.2.2. Sensor Affects
3.2.2.1. Cable Strum / Hydrophone Acceleration
3.2.2.2. Hydrophone Directionality
3.2.2.3. Temperature Dependence
3.2.3. Array Streaming
3.3. Narrowband
3.3.1. Effective Bandwidth
3.3.2. Source tonal vs time dependence
3.3.3. Doppler
3.3.4. Table of significant highest tones
3.4. Graphics
3.4.1. Reference range
3.4.2. Bandwidth

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Measurement uncertainty is affected by a combination of random errors and bias errors. For the sound pressure level (L_p) for each one run, the total random error includes the combined effect of several 0.5 to 1 dB errors associated with the acquisition system, typical values being: calibration (0.5 dB); sensitivity (<1 dB); data processing (0.5 dB) and amplifier gains (0.5 dB). These errors have an rms (root mean square) value of about 1.25 dB.

Resulting signature (L_S) source levels calculations for each hydrophone have increased uncertainty because of the range adjustment errors. These errors (~1 dB) include errors associated with uncertainty in the horizontal range, assumption about the acoustic center and other system parameters; hydrophone depth, thermal gradient, etc. The rms random error for a source level estimation characterized by errors such as these would be about 2 dB, and the average of three hydrophones would be <1.5 dB (some errors, such as ranging, would be the same for each hydrophone), the value specified for navy acoustic ranges.

When comparing data acquired using different measurement grades, data differences may be expected because of the bias errors associated with each of the types. Proximity of the surface and bottom usually causes biases in the data. The amount of bottom contribution is smallest when the ratio of measurement distance to bottom depth is the smallest. This ratio is about one for Grade C, about 0.67 for Grade B and about 0.33 for type A. Comparisons between the types for the same ship will be affected by these biases as well as other factors such as ship's directionality. For simple bottoms, the biases should be within 1 dB of the values shown below. The values in parenthesis are estimates of the combined effects of surface and bottom below 400 Hz.

Table 2 – Typical data comparison differences caused by surface and bottom contributions

Data comparison	**Grade A data compared to Grade B**	**Grade A data compared to Grade C**	**Grade B data compared to Grade C data**
Typical result above 400 Hz	Grade B data 1 dB higher than Grade A data	Grade C data 2-3 dB higher than Grade A	Grade C data 1-2 dB higher than Grade B
Typical result below 400 Hz	Grade B data 1-2 dB higher than Grade A data	Grade C data 3-4 dB higher than Grade A	Grade C data 2-3 dB higher than Grade B

Repeatability for the measurements addressed by this standard is affected by the ranging random error and signal processing random error, the errors that differ from run to run. The average of two or more runs mitigates the repeatability by the square root of the number of runs. The estimates given above are typical, not exact. The source levels are also affected by the repeatability of the radiation from the ship.

[Errors can be minimized by 1. conducting the runs on the same side of the hydrophones (important when close to shore, on a sloping seabed, or in a fjord) and 2. keep values through the measurement system as real and only rounding to the nearest dB for display.