UNDERWATER ACOUSTICS - TASK 1: TERMINOLOGY

A report prepared by TNO for the Joint Industry Programme on E&P Sound and Marine Life

JIP Topic - Sound source characterisation and propagation

E&P SOUND & MARINE LIFE PROGRAMME

2016

About the E&P Sound & Marine Life Programme

The ocean is filled with a wide variety of natural and man-made sounds. Since the [early 1990s], there has been increasing environmental and regulatory focus on man-made sounds in the sea and on the effects these sounds may have on marine life. There are now many national and international regimes that regulate how we introduce sound to the marine environment. We believe that effective policies and regulations should be firmly rooted in sound independent science. This allows regulators to make consistent and reasonable regulations while also allowing industries that use or introduce sound to develop effective mitigation strategies.

In 2005, a broad group of international oil and gas companies and the International Association of Geophysical Contractors (IAGC) committed to form a Joint Industry Programme under the auspices of the International Association of Oil and Gas Producers (IOGP) to identify and conduct a research programme that improves understanding of the potential impact of exploration and production sound on marine life. The Objectives of the programme were (and remain):

1. To support planning of E&P operations and risk assessments
2. To provide the basis for appropriate operational measures that are protective of marine life
3. To inform policy and regulation.

The members of the JIP are committed to ensuring that wherever possible the results of the studies it commissions are submitted for scrutiny through publication in peer-reviewed journals. The research papers are drawn from data and information in the contract research report series. Both Contract reports and research paper abstracts (and in many cases full papers) are available from the Programme's web site at www.soundandmarinelife.org.

Contents

1 List of abbreviations

Abbreviation	**Stands for**
CSA	Continental Shelf Associates
DIS	Draft international standard
ISO	International Organization for Standardization
JIP	E&P Sound and Marine Life Joint Industry Programme
TNO	Nederlandse Organisatie voor Toegepast Natuurwetenschappelijk Onderzoek (Netherlands Organisation for Applied Scientific Research)

2 Introduction

This document is the first deliverable in the project 'Standard Procedures for Underwater Noise Measurements for Activities Related to Offshore Oil and Gas Exploration and Production. Phase I: Processing and Reporting Procedures' carried out by TNO, in collaboration with CSA and Bioacoustics Consulting, for the Sound and Marine Life Joint Industry Programme (JIP). The objectives of this project are [ref TNO proposal "Standard Procedures for Underwater Noise Measurements for Activities Related to Offshore Oil and Gas Exploration and Production. Phase I: Processing and Reporting Procedures, 15 October 2015, TNO-reference DHW-TS-2015-0100209351)]:

1) to ensure that processing of selected acoustic metrics such as level, duration, and frequency content ('acoustical processing'), used to describe the characteristics of a sound signal propagating in water, can be analyzed in a consistent and systematic manner;
2) to ensure that the results of such acoustical processing can be reported in such a way that the results reported from two or more studies can be appropriately compared;
3) to define the correspondence between the acoustic metrics to be reported and metrics used in selected previous scientific publications.

The term "acoustical processing" is used here to mean the conversion from time series (e.g., sound pressure vs. time) to processed metrics such as sound pressure level or sound exposure level. This processing is required to provide metrics that are consistent with one another and with the definitions of [ISO 2016], and thus facilitate like with like comparison.

The main purpose of this document is to provide unambiguous standardized terminology for use in the rest of the project, henceforth referred to as the "Project Terminology". It has been agreed in discussion with the JIP's project support group to supply definitions in terms of the standard terminology of the second DIS [ISO (2016)]. The use of international standard terminology facilitates interpretation and reduces the risk of re-inventing the wheel.

The Project Terminology is introduced in a series of tables in the following categories:
- General terminology (Sec. 3);
- Quantities derived from sound pressure (Sec. 4);
- Quantities derived from sound particle displacement (Sec. 5);
- Quantities derived from sound particle velocity (Sec. 6);
- Quantities derived from sound particle acceleration (Sec. 7).

The Project Terminology is related to selected publications in Sec. 8.

The following conventions are used:
- terms in **bold Arial** font is defined in the Project Dictionary (this document);
- terms in *italic Cambria* font is defined in ISO/DIS 18405.2.

3 General terminology

General terms and concepts for later use are defined in Table 1.

Table 1 General terms.

term	symbol	unit	definition	notes
acoustic signal			*sound* from a specified source	
acoustic noise			unwanted *sound*	
background noise			combination of *ambient noise* and *acoustic self-noise* based on [ISO 2016]	all *sound* except the **acoustic signal**
transient acoustic emission			**acoustic signal** from a sound source emitting continuously from time t_1 to t_2, with no *sound* emitted before t_1, no *sound* emitted after t_2	
transient acoustic signal transient			**acoustic signal** at a specified location from a single specified **transient acoustic emission**	between the start and end of a transient acoustic signal there can be periods dominated by *background noise*, even though the source transmits *sound* continuously, e.g. due to multipaths or periods of low *signal to noise ratio*
sound pressure	p	Pa	difference between total pressure and pressure that would exist in the absence of *sound* source: ISO/DIS 18405.2, 2.1.2.3	
sound particle displacement	$\boldsymbol{\delta}$	m	displacement of a material element from what would be its position in the absence of *sound waves* source: ISO/DIS 18405.2, 2.1.2.3	

term	symbol	unit	definition	notes
sound particle velocity	$\boldsymbol{u}$	m/s	contribution to velocity of a material element caused by the action of *sound waves* source: ISO/DIS 18405.2, 2.1.2.3	
sound particle acceleration	$\boldsymbol{a}$	m/s^2	contribution to acceleration of a material element caused by the action of *sound waves* source: ISO/DIS 18405.2, 2.1.2.3	

4 Quantities derived from sound pressure

Quantities derived from sound pressure are defined in Table 2. In this table, the symbol $p(t)$ represents either noise sound pressure, $p(t) = p_\mathrm{N}(t)$, if there is no signal, or signal plus noise sound pressure, $p(t) = p_\mathrm{S+N}(t)$, if a signal is present. In the following, the subscripts N, S and S+N are used to mean "noise", "signal" and "signal plus noise", respectively. Definitions applicable to signal only can be obtained by first defining the signal sound pressure as $p_\mathrm{S}(t) \equiv p_\mathrm{S+N}(t) - p_\mathrm{N}(t)$ and then applying the same concepts to a hypothetical sound pressure defined as $p(t) = p_\mathrm{S}(t)$, which is the sound pressure that would exist if there were no background noise. Definitions obtained in this way are listed in Table 3. In underwater acoustics, quantities are often reported as levels, in decibels.
Where applicable, levels of the quantities listed in Table 2 and Table 3 are defined in Table 4 and Table 5, respectively.

Table 2 Quantities derived from sound pressure, applicable to noise only or signal plus noise. Compare Table 3, which defines similar quantities applicable to signal only.

term	symbol	unit	definition	notes
zero-to-peak sound pressure	$p_\mathrm{0-pk}$	Pa	greatest magnitude of the *sound pressure* during a specified time interval, for a specified frequency range source: ISO/DIS 18405.2, 2.1.2.3	
mean-square sound pressure	$\overline{p^2}$	Pa^2	integral over a specified time interval of squared *sound pressure*, divided by the duration of the time interval, for a specified frequency range source: ISO/DIS 18405.2, 2.1.3.1	
sound pressure exposure	$E_{p,T}$	Pa^2 s	integral of the square of the *sound pressure*, p, over a specified time interval or event, for a specified frequency range source: ISO/DIS 18405.2, 2.1.3.5	
sound pressure exposure spectral density	$E_{p,f}$	Pa^2 s/Hz	distribution as a function of frequency of the *sound pressure exposure* per unit bandwidth of a *sound* having a continuous spectrum source: ISO/DIS 18405.2, 2.1.3.9	The sound pressure exposure spectral density is a function of positive frequencies. The spectral density so defined is said to be "single-sided".

term	symbol	unit	definition	notes
mean-square sound pressure spectral density	$\overline{p_f^2}$	Pa²/Hz	distribution as a function of frequency of the *mean-square sound pressure* per unit bandwidth of a *sound* having a continuous spectrum source: ISO/DIS 18405.2, 2.1.3.13	The mean-square sound pressure spectral density is a function of positive frequencies. The spectral density so defined is said to be "single-sided". As a consequence of the Wiener-Khinchin theorem, the mean-square sound pressure spectral density of a sound pressure signal is also equal to twice the Fourier transform [ISO 80000-2:2009] of the autocorrelation function of that signal.
root-mean-square sound pressure	p_{rms}	Pa	square root of the *mean-square sound pressure*	

Table 3 Quantities derived from signal sound pressure, applicable to signal only. Compare Table 2, which defines similar quantities applicable to noise and signal plus noise.

term	symbol	unit	definition	notes
signal sound pressure	p_{S}	Pa	contribution to the *sound pressure* from a specified **acoustic signal**	If the sound pressure has sufficiently low amplitude to justify non-linear effects, the signal sound pressure can be calculated as $p_{\mathrm{S}}(t) = p_{\mathrm{S+N}}(t) - p_{\mathrm{N}}(t)$. According to Note 1 to entry 2.1.2.10 of ISO 2016, non-linear effects may be neglected when the magnitude of the sound particle velocity is small compared with the sound speed.

term	symbol	unit	definition	notes
zero-to-peak signal sound pressure	$p_{0-\mathrm{pk,S}}$	Pa	greatest magnitude of the **signal sound pressure**, during a specified time interval	For a continuous sound, the duration of the time interval is specified as a fixed value, in seconds. For a **transient**, the duration of the time interval may be specified as a fixed value, in seconds, or as a percentage energy pressure signal duration, with fixed percentage x.
mean-square signal sound pressure	$\overline{p_{\mathrm{S}}^2}$	Pa^2	integral over a specified time interval of squared **signal sound pressure**, divided by the duration of the time interval, for a specified frequency range	If the signal and noise sound pressures are uncorrelated, the mean-square signal sound pressure for the **signal** may be estimated using $\overline{p_{\mathrm{S}}^2} \approx \overline{p_{\mathrm{S+N}}^2} - \overline{p_{\mathrm{N}}^2}$ For a continuous sound, the duration of the time interval is specified as a fixed value, in seconds. For a **transient**, the duration of the time interval may be specified as a fixed value, in seconds, or as a percentage energy pressure signal duration, with fixed percentage x.

term	symbol	unit	definition	notes
signal sound pressure exposure	$E_{p,T,S}$	Pa^2 s	integral of the square of the **signal sound pressure**, p_S, over a specified time interval or event, for a specified frequency range	If the signal and noise sound pressures are uncorrelated, the signal sound pressure exposure may be estimated using $E_{p,T,\mathrm{S}} \approx E_{p,T,\mathrm{S+N}} - E_{p,T,\mathrm{N}}$ For a continuous sound, the duration of the time interval is specified as a fixed value, in seconds.
signal sound pressure exposure spectral density	$E_{p,f,S}$	Pa^2 s/Hz	distribution as a function of frequency of the **sound pressure exposure** per unit bandwidth of a **signal** having a continuous spectrum	Sound pressure exposure spectral density is a property of a **transient**. The signal sound pressure exposure spectral density is a function of positive frequencies. The spectral density so defined is said to be “single-sided”.
mean-square signal sound pressure spectral density	$\overline{p_{f,S}^2}$	Pa^2/Hz	distribution as a function of frequency of the **mean-square sound pressure** per unit bandwidth of a **signal** having a continuous spectrum	Mean-square signal sound pressure spectral density is a property of a continuous sound. The duration of the time interval is specified as a specified as a fixed value, in seconds. The mean-square signal sound pressure spectral density is a function of positive frequencies. The spectral density so defined is said to be “single-sided”.

term	symbol	unit	definition	notes
percentage energy pressure signal duration	$\tau_{x\%,p}$	s	time during which a specified percentage x of time-integrated squared **signal sound pressure** occurs Based on ISO/DIS 18405.2, 2.5.1.5	Percentage energy pressure signal duration is a property of a transient signal.
signal pressure impulse	J_p	Pa s	*pressure impulse* of a **transient acoustic signal**	

Table 4 Levels of quantities derived from sound pressure, applicable to noise only or signal plus noise, selected where appropriate from Table 2. Compare Table 5, which defines similar quantities applicable to signal only.

term	**symbol**	**unit**	**definition**	**notes**
zero-to-peak sound pressure level	$L_{p,0-\mathrm{pk}}$	dB	level of the **zero to peak sound pressure** In equation form: $L_{p,0-\mathrm{pk}} = 10\log_{10}\frac{p_{0-\mathrm{pk}}^2}{p_0^2}\,\mathrm{dB}$ Reference value: $p_0 = 1\ \mu\mathrm{Pa}$ $p_0^2 = 1\ \mu\mathrm{Pa}^2$ Based on ISO/DIS 18405.2, 2.2.2.1	
mean-square sound pressure level	L_p	dB	level of the **mean-square sound pressure** In equation form: $L_p = 10\log_{10}\frac{\overline{p^2}}{p_0^2}\,\mathrm{dB}$ Reference value: p_0 = 1 μPa p_0^2 = 1 μPa² Based on ISO/DIS 18405.2, 2.2.1.1	
sound pressure exposure level	$L_{E,p}$	dB	level of the **sound pressure exposure** In equation form: $L_{E,p} = 10\log_{10}\frac{E_p}{E_{p,0}}\,\mathrm{dB}$ Reference value: $E_{p,0}^{1/2} = 1\ \mu\mathrm{Pa}\ \ \mathrm{s}^{\frac{1}{2}}$ $E_{p,0} = 1\ \mu\mathrm{Pa}^2\ \mathrm{s}$ Based on ISO/DIS 18405.2, 2.2.1.5	
sound pressure exposure spectral density level	$L_{E,p,f}$	dB	level of the **sound pressure exposure spectral density** In equation form: $L_{E,p,f} = 10\log_{10}\frac{E_{p,f}}{E_{p,f,0}}\,\mathrm{dB}$	

term	symbol	unit	definition	notes
			Reference value: $E_{p,f,0}^{1/2} = 1\ \mu\text{Pa}\ \ \text{s}^{\frac{1}{2}}/\text{Hz}^{\frac{1}{2}}$ $E_{p,f,0} = 1\ \mu\text{Pa}^2\ \text{s/Hz}$ Based on ISO/DIS 18405.2, 2.2.1.9	
mean-square signal sound pressure spectral density level	$L_{p,f}$	dB	level of the **mean-square sound pressure spectral density** In equation form: $L_{p,f} = 10\log_{10}\frac{\overline{p_f^2}}{p_{f,0}^2}\,\text{dB}$ Reference value: $p_{f,0} = 1\ \mu\text{Pa}\ \ /\text{Hz}^{\frac{1}{2}}$ $p_{f,0}^2 = 1\ \mu\text{Pa}^2/\text{Hz}$ Based on ISO/DIS 18405.2, 2.2.1.10	

Table 5 Levels of quantities derived from signal sound pressure, applicable to signal only, selected where appropriate from Table 3. Compare Table 4, which defines similar quantities applicable to noise and signal plus noise.

term	symbol	unit	definition	notes
zero to peak signal sound pressure level	$L_{p,0-\text{pk,S}}$	dB	level of the **zero to peak signal sound pressure** In equation form: $L_{p,0-\text{pk,S}} = 10\log_{10}\frac{p_{0-\text{pk,S}}^2}{p_0^2}\,\text{dB}$ Reference value: $p_0 = 1\ \mu\text{Pa}$ $p_0^2 = 1\ \mu\text{Pa}^2$	
mean-square signal sound pressure level	$L_{p,\text{S}}$	dB	level of the **mean-square signal sound pressure** In equation form: $L_{p,\text{S}} = 10\log_{10}\frac{\overline{p_\text{S}^2}}{p_0^2}\,\text{dB}$ Reference value: $p_0 = 1\ \mu\text{Pa}$ $p_0^2 = 1\ \mu\text{Pa}^2$	
signal sound	$L_{E,p,\text{S}}$	dB	level of the **signal sound**	

term	symbol	unit	definition	notes
pressure exposure level			**pressure exposure** In equation form: $L_{E,p,\mathrm{S}} = 10\log_{10}\frac{E_{p,\mathrm{S}}}{E_{p,0}}\,\mathrm{dB}$ Reference value: $E_{p,0}^{1/2} = 1\ \mu\mathrm{Pa}\ \ \mathrm{s}^{\frac{1}{2}}$ $E_{p,0} = 1\ \mu\mathrm{Pa}^2\ \mathrm{s}$	
signal sound pressure exposure spectral density level	$L_{E,p,f,\mathrm{S}}$	dB	level of the **signal sound pressure exposure spectral density** In equation form: $L_{E,p,f,\mathrm{S}} = 10\log_{10}\frac{E_{p,f,\mathrm{S}}}{E_{p,f,0}}\,\mathrm{dB}$ Reference value: $E_{p,f,0}^{1/2} = 1\ \mu\mathrm{Pa}\ \ \mathrm{s}^{\frac{1}{2}}/\mathrm{Hz}^{\frac{1}{2}}$ $E_{p,f,0} = 1\ \mu\mathrm{Pa}^2\ \mathrm{s/Hz}$	
mean-square signal sound pressure spectral density level	$L_{p,f,\mathrm{S}}$	dB	level of the **mean-square signal sound pressure spectral density** In equation form: $L_{p,f,\mathrm{S}} = 10\log_{10}\frac{\overline{p_{f,\mathrm{S}}^2}}{p_{f,0}^2}\,\mathrm{dB}$ Reference value: $p_{f,0} = 1\ \mu\mathrm{Pa}\ \ /\mathrm{Hz}^{\frac{1}{2}}$ $p_{f,0}^2 = 1\ \mu\mathrm{Pa}^2/\mathrm{Hz}$	

To some extent the information contained in Table 2 to Table 5 is generic, in the sense that the definitions are applicable to other scalar quantities. Corresponding definitions are listed in Secs. 5 to 7 for each of sound particle displacement, velocity and acceleration, generalized as needed to cope with the vector nature of these quantities. Some quantities are needed only for sound pressure, and such quantities are defined in Table 6.

Table 6 Quantities derived from signal sound pressure. The quantities listed in this table are needed for the specific reasons described in the notes column. They are not required for particle motion metrics.

term	symbol	unit	definition	notes
90% transient signal sound pressure duration	$\tau_{90\%,p}$	s	**percentage energy pressure signal duration** of a **transient acoustic signal**, with x = 90	needed for Wyatt 2008 (see Table 21)
zero to peak signal sound pressure to pulse duration ratio	p_τ	Pa/s	*zero-to-peak sound pressure* of a **transient acoustic signal** divided by the **90% transient signal sound pressure duration** of that **transient acoustic signal**	this quantity is needed for the draft NOAA guidelines of July 2015 [NOAA 2015]; it is not used in the final guidelines of July 2016 [NOAA 2016]

5 Quantities derived from sound particle displacement

Quantities derived from sound particle displacement are defined in Table 7. In this table, the symbol $\boldsymbol{\delta}(t)$ represents either noise sound particle displacement, $\boldsymbol{\delta}(t) = \boldsymbol{\delta}_{\mathrm{N}}(t)$, if there is no signal, or signal plus noise sound particle displacement, $\boldsymbol{\delta}(t) = \boldsymbol{\delta}_{\mathrm{S+N}}(t)$, if a signal is present. Definitions applicable to signal only can be obtained by first defining the signal sound particle displacement as $\boldsymbol{\delta}_{\mathrm{S}}(t) \equiv \boldsymbol{\delta}_{\mathrm{S+N}}(t) - \boldsymbol{\delta}_{\mathrm{N}}(t)$ and applying the same concepts to a hypothetical sound particle displacement defined as $\boldsymbol{\delta}(t) = \boldsymbol{\delta}_{\mathrm{S}}(t)$, which is the sound particle displacement that would exist if there were no background noise. Definitions obtained in this way are listed in Table 8. In underwater acoustics, quantities are often reported as levels, in decibels. Where applicable, levels of the quantities listed in Table 7 and Table 8 are defined in Table 9 and Table 10, respectively.

Table 7 Quantities derived from sound particle displacement, applicable to noise only or signal plus noise. Compare Table 8, which defines similar quantities applicable to signal only.

term	symbol	unit	definition	notes
zero-to-peak sound particle displacement	$\delta_{0-\mathrm{pk}}$	m	greatest magnitude of the *sound particle displacement* during a specified time interval	
mean-square sound particle displacement	$\overline{\delta^2}$	m^2	integral over a specified time interval of squared magnitude of the *sound particle displacement*, divided by the duration of the time interval, for a specified frequency range source: ISO/DIS 18405.2, 2.1.3.2	
sound particle displacement exposure	$E_{\delta T}$	m^2 s	integral of the square of the magnitude of the *sound particle displacement*, δ, over a specified time interval or event, for a specified frequency range source: ISO/DIS 18405.2, 2.1.3.6	
sound particle displacement exposure spectral density	$E_{\boldsymbol{\delta},f}$	m^2 s/Hz	distribution as a function of frequency of the *sound particle displacement exposure* per unit bandwidth of a *sound* having a continuous spectrum based on: ISO/DIS 18405.2, 2.1.3.9	The sound particle displacement exposure spectral density is a function of positive frequencies. The spectral density so defined is said to be “single-sided”.

term	symbol	unit	definition	notes
mean-square sound particle displacement spectral density	$\overline{\delta_f^2}$	m^2/Hz	distribution as a function of frequency of the *mean-square sound particle displacement* per unit bandwidth of a *sound* having a continuous spectrum based on: ISO/DIS 18405.2, 2.1.3.13	The mean-square sound particle displacement spectral density is a function of positive frequencies. The spectral density so defined is said to be “single-sided”.
root-mean-square sound particle displacement	δ_{rms}	m	square root of the *mean-square sound particle displacement*	

Table 8 Quantities derived from signal sound particle displacement, applicable to signal only. Compare Table 7, which defines similar quantities applicable to noise and signal plus noise.

term	symbol	unit	definition	notes
signal sound particle displacement	$\boldsymbol{\delta}_{\mathrm{S}}$	m	contribution to the *sound particle displacement* from a specified **acoustic signal**	Signal sound particle displacement is a vector quantity. If the sound particle displacement has sufficiently low amplitude to justify non-linear effects, the signal sound particle displacement can be calculated as $\boldsymbol{\delta}_{\mathrm{S}}(t) = \boldsymbol{\delta}_{\mathrm{S+N}}(t) - \boldsymbol{\delta}_{\mathrm{N}}(t)$. According to Note 1 to entry 2.1.2.10 of ISO 2016, non-linear effects may be neglected when the magnitude of the sound particle velocity is small compared with the sound speed.
zero-to-peak signal sound particle displacement	$\delta_{0-\mathrm{pk,S}}$	m	greatest magnitude of the **signal sound particle displacement**, during a specified time interval	For a continuous sound, the duration of the time interval is specified as a fixed value, in seconds. For a **transient**, the duration of the time interval may be specified as a fixed value, in seconds, or as a percentage energy

term	symbol	unit	definition	notes
				displacement signal duration, with fixed percentage x.
mean-square signal sound particle displacement	$\overline{\delta_{\mathrm{S}}^2}$	m²	integral over a specified time interval of squared **signal sound particle displacement**, divided by the duration of the time interval, for a specified frequency range	If the signal and noise sound particle displacements are uncorrelated, the mean-square signal sound particle displacement for the **signal** may be estimated using $$\overline{\delta_{\mathrm{S}}^2} \approx \overline{\delta_{\mathrm{S+N}}^2} - \overline{\delta_{\mathrm{N}}^2}$$ For a continuous sound, the duration of the time interval is specified as a fixed value, in seconds. For a **transient**, the duration of the time interval may be specified as a fixed value, in seconds, or as a percentage energy displacement signal duration, with fixed percentage x.
signal sound particle displacement exposure	$E_{\delta,T,S}$	m² s	integral of the square of the magnitude of the **signal sound particle displacement**, $\boldsymbol{\delta}$, over a specified time interval or event, for a specified frequency range	If the signal and noise particle displacements are uncorrelated, the signal sound particle displacement exposure may be estimated using $E_{\delta,T,\mathrm{S}} \approx E_{\delta,T,\mathrm{S+N}} - E_{\delta,T,\mathrm{N}}$ For a continuous sound, the duration of the time interval is specified as a fixed value, in seconds.
signal sound particle displacement exposure spectral density	$E_{\delta,f,S}$	m² s/Hz	distribution as a function of frequency of the **sound particle displacement exposure** per unit bandwidth of a **signal** having a continuous spectrum	Sound particle displacement exposure spectral density is a property of a **transient**. The signal sound particle displacement

term	symbol	unit	definition	notes
				exposure spectral density is a function of positive frequencies. The spectral density so defined is said to be "single-sided".
mean-square signal sound particle displacement spectral density	$\overline{\delta_{f,S}^2}$	m²/Hz	distribution as a function of frequency of the **mean-square sound particle displacement** per unit bandwidth of a **signal** having a continuous spectrum	Mean-square signal sound particle displacement spectral density is a property of a continuous sound. The duration of the time interval is specified as a specified as a fixed value, in seconds. The mean-square signal sound particle displacement spectral density is a function of positive frequencies. The spectral density so defined is said to be "single-sided".
percentage energy displacement signal duration	$\tau_{x\%,\delta}$	s	time during which a specified percentage x of signal sound particle displacement exposure occurs	Percentage energy displacement signal duration is a property of a **transient signal**.
signal displacement impulse	$\boldsymbol{J}_{\delta}$	m s	integral of the **sound particle displacement**, over a specified time interval or event, for a specified frequency range of a **transient acoustic signal**	signal displacement impulse is a vector quantity

Table 9 Levels of quantities derived from sound particle displacement, applicable to noise only or signal plus noise, selected where appropriate from Table 7. Compare Table 10, which defines similar quantities applicable to signal only.

term	symbol	unit	definition	notes
zero-to-peak sound particle displacement level	$L_{\delta,0-\mathrm{pk}}$	dB	level of the **zero to peak sound particle displacement** In equation form: $L_{\delta,0-\mathrm{pk}} = 10\log_{10}\frac{\delta_{0-\mathrm{pk}}^2}{\delta_0^2}\,\mathrm{dB}$ Reference value:	

term	symbol	unit	definition	notes
			$\delta_0 = 1\ \mathrm{pm}$ $\delta_0^2 = 1\ \mathrm{pm}^2$ Based on ISO/DIS 18405.2, 2.2.2.1	
mean-square sound particle displacement level	L_δ	dB	level of the **mean-square sound particle displacement** In equation form: $L_\delta = 10 \log_{10} \frac{\overline{\delta^2}}{\delta_0^2}\ \mathrm{dB}$ Reference value: $\delta_0 = 1\ \mathrm{pm}$ $\delta_0^2 = 1\ \mathrm{pm}^2$ Based on ISO/DIS 18405.2, 2.2.1.1	
sound particle displacement exposure level	$L_{E,\delta}$	dB	level of the **sound particle displacement exposure** In equation form: $L_{E,\delta} = 10 \log_{10} \frac{E_\delta}{E_{\delta,0}}\ \mathrm{dB}$ Reference value: $E_{\delta,0}^{1/2} = 1\ \mathrm{pm\ s}^{\frac{1}{2}}$ $E_{\delta,0} = 1\ \mathrm{pm}^2\ \mathrm{s}$ Based on ISO/DIS 18405.2, 2.2.1.5	
sound particle displacement exposure spectral density level	$L_{E,\delta,f}$	dB	level of the **sound particle displacement exposure spectral density** In equation form: $L_{E,\delta,f} = 10 \log_{10} \frac{E_{\delta,f}}{E_{\delta,f,0}}\ \mathrm{dB}$ Reference value: $E_{\delta,f,0}^{1/2} = 1\ \mathrm{pm\ s}^{\frac{1}{2}}/\mathrm{Hz}^{\frac{1}{2}}$ $E_{\delta,f,0} = 1\ \mathrm{pm}^2\ \mathrm{s/Hz}$ Based on ISO/DIS 18405.2, 2.2.1.9	
mean-square signal sound particle	$L_{\delta,f}$	dB	level of the **mean-square sound particle displacement spectral**	

term	symbol	unit	definition	notes
displacement spectral density level			**density** In equation form: $$L_{\delta,f} = 10\log_{10}\frac{\overline{\delta_f^2}}{\delta_{f,0}^2}\,\mathrm{dB}$$ Reference value: $$\delta_{f,0} = 1\ \mathrm{pm/Hz}^{\frac{1}{2}}$$ $$\delta_{f,0}^2 = 1\ \mathrm{pm^2/Hz}$$ Based on ISO/DIS 18405.2, 2.2.1.10	

Table 10 Levels of quantities derived from signal sound particle displacement, applicable to signal only, selected where appropriate from Table 8. Compare Table 9, which defines similar quantities applicable to noise and signal plus noise.

term	symbol	unit	definition	notes
zero to peak signal sound particle displacement level	$L_{\delta,0-\mathrm{pk,S}}$	dB	level of the **zero to peak signal sound particle displacement** In equation form: $$L_{\delta,0-\mathrm{pk,S}} = 10\log_{10}\frac{\delta_{0-\mathrm{pk,S}}^2}{\delta_0^2}\,\mathrm{dB}$$ Reference value: $$\delta_0 = 1\ \mathrm{pm}$$ $$\delta_0^2 = 1\ \mathrm{pm}^2$$	
mean-square signal sound particle displacement level	$L_{\delta,\mathrm{S}}$	dB	level of the **mean-square signal sound particle displacement** In equation form: $$L_{\delta,\mathrm{S}} = 10\log_{10}\frac{\overline{\delta_\mathrm{S}^2}}{\delta_0^2}\,\mathrm{dB}$$ Reference value: $$\delta_0 = 1\ \mathrm{pm}$$ $$\delta_0^2 = 1\ \mathrm{pm}^2$$	
signal sound particle displacement exposure level	$L_{E,\delta,\mathrm{S}}$	dB	level of the **signal sound particle displacement exposure** In equation form: $$L_{E,\delta,\mathrm{S}} = 10\log_{10}\frac{E_{\delta,\mathrm{S}}}{E_{\delta,0}}\,\mathrm{dB}$$ Reference value: $$E_{\delta,0}^{1/2} = 1\ \mathrm{pm}\ \ \mathrm{s}^{\frac{1}{2}}$$ $$E_{\delta,0} = 1\ \mathrm{pm^2\ s}$$	

term	symbol	unit	definition	notes
signal sound particle displacement exposure spectral density level	$L_{E,\delta,f,\mathrm{S}}$	dB	level of the **signal sound particle displacement exposure spectral density** In equation form: $L_{E,\delta,f,\mathrm{S}} = 10\log_{10}\frac{E_{\delta,f,\mathrm{S}}}{E_{\delta,f,0}}\,\mathrm{dB}$ Reference value: $E_{\delta,f,0}^{1/2} = 1\ \mathrm{pm}\ \ \mathrm{s}^{\frac{1}{2}}/\mathrm{Hz}^{\frac{1}{2}}$ $E_{\delta,f,0} = 1\ \mathrm{pm}^2\ \mathrm{s}/\mathrm{Hz}$	
mean-square signal sound particle displacement spectral density level	$L_{\delta,f,\mathrm{S}}$	dB	level of the **mean-square signal sound particle displacement spectral density** In equation form: $L_{\delta,f,\mathrm{S}} = 10\log_{10}\frac{\overline{\delta_{f,\mathrm{S}}^2}}{\delta_{f,0}^2}\,\mathrm{dB}$ Reference value: $\delta_{f,0} = 1\ \mathrm{pm}/\mathrm{Hz}^{\frac{1}{2}}$ $\delta_{f,0}^2 = 1\ \mathrm{pm}^2/\mathrm{Hz}$	

6 Quantities derived from sound particle velocity

Quantities derived from sound particle velocity are defined in Table 11. In this table, the symbol $\boldsymbol{\delta}(t)$ represents either noise sound particle velocity, $\boldsymbol{u}(t) = \boldsymbol{u}_{\mathrm{N}}(t)$, if there is no signal, or signal plus noise sound particle velocity, $\boldsymbol{u}(t) = \boldsymbol{u}_{\mathrm{S+N}}(t)$, if a signal is present. Definitions applicable to signal only can be obtained by first defining the signal sound particle velocity as $\boldsymbol{u}_{\mathrm{S}}(t) \equiv \boldsymbol{u}_{\mathrm{S+N}}(t) - \boldsymbol{u}_{\mathrm{N}}(t)$ and applying the same concepts to a hypothetical sound particle velocity defined as $\boldsymbol{u}(t) = \boldsymbol{u}_{\mathrm{S}}(t)$, which is the sound particle velocity that would exist if there were no background noise. Definitions obtained in this way are listed in Table 12. In underwater acoustics, quantities are often reported as levels, in decibels. Where applicable, levels of the quantities listed in Table 11 and Table 12 are defined in Table 13 and Table 14, respectively.

Table 11 Quantities derived from sound particle velocity, applicable to noise only or signal plus noise. Compare Table 12, which defines similar quantities applicable to signal only.

term	symbol	unit	definition	notes
zero-to-peak sound particle velocity	$u_{0-\mathrm{pk}}$	m/s	greatest magnitude of the *sound particle velocity* during a specified time interval	
mean-square sound particle velocity	$\overline{u^2}$	$(\mathrm{m/s})^2$	integral over a specified time interval of squared magnitude of the *sound particle velocity*, divided by the duration of the time interval, for a specified frequency range source: ISO/DIS 18405.2, 2.1.3.2	
sound particle velocity exposure	$E_{u,T}$	$(\mathrm{m/s})^2$ s	integral of the square of the magnitude of the *sound particle velocity*, $\boldsymbol{u}$, over a specified time interval or event, for a specified frequency range source: ISO/DIS 18405.2, 2.1.3.6	
sound particle velocity exposure spectral density	$E_{u,f}$	$(\mathrm{m/s})^2$ s/Hz	distribution as a function of frequency of the *sound particle velocity exposure* per unit bandwidth of a *sound* having a continuous spectrum based on: ISO/DIS 18405.2, 2.1.3.9	The sound particle velocity exposure spectral density is a function of positive frequencies. The spectral density so defined is said to be "single-sided".

term	symbol	unit	definition	notes
mean-square sound particle velocity spectral density	$\overline{u_f^2}$	(m/s)²/ Hz	distribution as a function of frequency of the *mean-square sound particle velocity* per unit bandwidth of a *sound* having a continuous spectrum based on: ISO/DIS 18405.2, 2.1.3.13	The mean-square sound particle velocity spectral density is a function of positive frequencies. The spectral density so defined is said to be “single-sided”.
root-mean-square sound particle velocity	u_{rms}	m/s	square root of the *mean-square sound particle velocity*	

Table 12 Quantities derived from signal sound particle velocity, applicable to signal only. Compare Table 11, which defines similar quantities applicable to noise and signal plus noise.

term	symbol	unit	definition	notes
signal sound particle velocity	$\boldsymbol{u}_{\mathrm{S}}$	m/s	contribution to the *sound particle velocity* from a specified **acoustic signal**	Signal sound particle velocity is a vector quantity. If the sound particle velocity has sufficiently low amplitude to justify non-linear effects, the signal sound particle velocity can be calculated as $\boldsymbol{u}_{\mathrm{S}}(t) = \boldsymbol{u}_{\mathrm{S+N}}(t) - \boldsymbol{u}_{\mathrm{N}}(t)$. According to Note 1 to entry 2.1.2.10 of ISO 2016, non-linear effects may be neglected when the magnitude of the sound particle velocity is small compared with the sound speed.
zero-to-peak signal sound particle velocity	$u_{0-\mathrm{pk,S}}$	m/s	greatest magnitude of the **signal sound particle velocity**, during a specified time interval	For a continuous sound, the duration of the time interval is specified as a fixed value, in seconds. For a **transient**, the duration of the time interval may be specified as a fixed value, in seconds, or as a percentage energy velocity signal duration,

term	symbol	unit	definition	notes
				with fixed percentage x.
mean-square signal sound particle velocity	$\overline{u_\mathrm{S}^2}$	$(\mathrm{m/s})^2$	integral over a specified time interval of squared **signal sound particle velocity**, divided by the duration of the time interval, for a specified frequency range	If the signal and noise sound particle velocities are uncorrelated, the mean-square signal sound particle velocity for the **signal** may be estimated using $$\overline{u_\mathrm{S}^2} \approx \overline{u_\mathrm{S+N}^2} - \overline{u_\mathrm{N}^2}$$ For a continuous sound, the duration of the time interval is specified as a fixed value, in seconds. For a **transient**, the duration of the time interval may be specified as a fixed value, in seconds, or as a percentage energy velocity signal duration, with fixed percentage x.
signal sound particle velocity exposure	$E_{u,T,S}$	$(\mathrm{m/s})^2$ s	integral of the square of the magnitude of the **signal sound particle velocity**, $\boldsymbol{u}$, over a specified time interval or event, for a specified frequency range	If the signal and noise particle velocities are uncorrelated, the signal sound particle velocity exposure may be estimated using $$E_{u,T,\mathrm{S}} \approx E_{u,T,\mathrm{S+N}} - E_{u,T,\mathrm{N}}$$ For a continuous sound, the duration of the time interval is specified as a fixed value, in seconds.
signal sound particle velocity exposure spectral density	$E_{u,f,S}$	$(\mathrm{m/s})^2$ s/Hz	distribution as a function of frequency of the **sound particle velocity exposure** per unit bandwidth of a **signal** having a continuous spectrum	Sound particle velocity exposure spectral density is a property of a **transient**. The signal sound particle velocity exposure spectral density is a function of positive frequencies. The spectral density so defined is said to be

term	**symbol**	**unit**	**definition**	**notes**
				"single-sided".
mean-square signal sound particle velocity spectral density	$\overline{u_{f,S}^2}$	(m/s)^2/ Hz	distribution as a function of frequency of the **mean-square sound particle velocity** per unit bandwidth of a **signal** having a continuous spectrum	Mean-square signal sound particle velocity spectral density is a property of a continuous sound. The duration of the time interval is specified as a specified as a fixed value, in seconds. The mean-square signal sound particle velocity spectral density is a function of positive frequencies. The spectral density so defined is said to be "single-sided".
percentage energy velocity signal duration	$\tau_{x\%,u}$	s	time during which a specified percentage x of signal sound particle velocity exposure occurs	Percentage energy velocity signal duration is a property of a **transient signal**.
signal velocity impulse	$\boldsymbol{J_u}$	(m/s) s	integral of the **sound particle velocity**, over a specified time interval or event, for a specified frequency range of a **transient acoustic signal**	signal velocity impulse is a vector quantity

Table 13 Levels of quantities derived from sound particle velocity, applicable to noise only or signal plus noise, selected where appropriate from Table 11. Compare Table 12, which defines similar quantities applicable to signal only.

term	**symbol**	**unit**	**definition**	**notes**
zero-to-peak sound particle velocity level	$L_{u,0-\mathrm{pk}}$	dB	level of the **zero to peak sound particle velocity** In equation form: $L_{u,0-\mathrm{pk}} = 10 \log_{10} \frac{u_{0-\mathrm{pk}}^2}{u_0^2} \mathrm{dB}$ Reference value: $u_0 = 1\ \mathrm{nm/s}$ $u_0^2 = 1\ (\mathrm{nm/s})^2$ Based on ISO/DIS 18405.2, 2.2.2.1	
mean-square sound particle velocity level	L_u	dB	level of the **mean-square sound particle velocity**	

term	symbol	unit	definition	notes
			In equation form: $$L_u = 10\log_{10}\frac{\overline{u^2}}{u_0^2}\,\mathrm{dB}$$ Reference value: $$u_0 = 1\ \mathrm{nm/s}$$ $$u_0^2 = 1\ (\mathrm{nm/s})^2$$ Based on ISO/DIS 18405.2, 2.2.1.1	
sound particle velocity exposure level	$L_{E,u}$	dB	level of the **sound particle velocity exposure** In equation form: $$L_{E,u} = 10\log_{10}\frac{E_u}{E_{u,0}}\,\mathrm{dB}$$ Reference value: $$E_{u,0}^{1/2} = 1\ (\mathrm{nm/s})\ \mathrm{s}^{\frac{1}{2}}$$ $$E_{u,0} = 1\ (\mathrm{nm/s})^2\ \mathrm{s}$$ Based on ISO/DIS 18405.2, 2.2.1.5	
sound particle velocity exposure spectral density level	$L_{E,u,f}$	dB	level of the **sound particle velocity exposure spectral density** In equation form: $$L_{E,u,f} = 10\log_{10}\frac{E_{u,f}}{E_{u,f,0}}\,\mathrm{dB}$$ Reference value: $$E_{u,f,0}^{1/2} = 1\ (\mathrm{nm/s})\ \mathrm{s}^{\frac{1}{2}}/\mathrm{Hz}^{\frac{1}{2}}$$ $$E_{u,f,0} = 1\ (\mathrm{nm/s})^2\ \mathrm{s/Hz}$$ Based on ISO/DIS 18405.2, 2.2.1.9	
mean-square signal sound particle velocity spectral density level	$L_{u,f}$	dB	level of the **mean-square sound particle velocity spectral density** In equation form: $$L_{u,f} = 10\log_{10}\frac{\overline{u_f^2}}{u_{f,0}^2}\,\mathrm{dB}$$ Reference value: $$u_{f,0} = 1\ (\mathrm{nm/s})/\mathrm{Hz}^{\frac{1}{2}}$$ $$u_{f,0}^2 = 1\ (\mathrm{nm/s})^2/\mathrm{Hz}$$	

term	symbol	unit	definition	notes
			Based on ISO/DIS 18405.2, 2.2.1.10	

Table 14 Levels of quantities derived from signal sound particle velocity, applicable to signal only, selected where appropriate from Table 12. Compare Table 13, which defines similar quantities applicable to noise and signal plus noise.

term	symbol	unit	definition	notes
zero to peak signal sound particle velocity level	$L_{u,0-\mathrm{pk,S}}$	dB	level of the **zero to peak signal sound particle velocity** In equation form: $L_{u,0-\mathrm{pk,S}} = 10\log_{10}\frac{u_{0-\mathrm{pk,S}}^2}{u_0^2}\,\mathrm{dB}$ Reference value: $u_0 = 1\ \mathrm{nm/s}$ $u_0^2 = 1\ (\mathrm{nm/s})^2$	
mean-square signal sound particle velocity level	$L_{u,\mathrm{S}}$	dB	level of the **mean-square signal sound particle velocity** In equation form: $L_{u,\mathrm{S}} = 10\log_{10}\frac{\overline{u_\mathrm{S}^2}}{u_0^2}\,\mathrm{dB}$ Reference value: $u_0 = 1\ \mathrm{nm/s}$ $u_0^2 = 1\ (\mathrm{nm/s})^2$	
signal sound particle velocity exposure level	$L_{E,u,\mathrm{S}}$	dB	level of the **signal sound particle velocity exposure** In equation form: $L_{E,u,\mathrm{S}} = 10\log_{10}\frac{E_{u,\mathrm{S}}}{E_{u,0}}\,\mathrm{dB}$ Reference value: $E_{u,0}^{1/2} = 1\ (\mathrm{nm/s})\ \ \mathrm{s}^{\frac{1}{2}}$ $E_{u,0} = 1\ (\mathrm{nm/s})^2\ \mathrm{s}$	
signal sound particle velocity exposure spectral density level	$L_{E,u,f,\mathrm{S}}$	dB	level of the **signal sound particle velocity exposure spectral density** In equation form: $L_{E,u,f,\mathrm{S}} = 10\log_{10}\frac{E_{u,f,\mathrm{S}}}{E_{u,f,0}}\,\mathrm{dB}$ Reference value:	

term	symbol	unit	definition	notes
			$E_{u,f,0}^{1/2} = 1\ (\mathrm{nm/s})\ \ \mathrm{s}^{\frac{1}{2}}/\mathrm{Hz}^{\frac{1}{2}}$ $E_{u,f,0} = 1\ (\mathrm{nm/s})^2\ \mathrm{s/Hz}$	
mean-square signal sound particle velocity spectral density level	$L_{u,f,S}$	dB	level of the **mean-square signal sound particle velocity spectral density** In equation form: $L_{u,f,S} = 10 \log_{10} \frac{\overline{u_{f,S}^2}}{u_{f,0}^2}\,\mathrm{dB}$ Reference value: $u_{f,0} = 1\ (\mathrm{nm/s})/\mathrm{Hz}^{\frac{1}{2}}$ $u_{f,0}^2 = 1\ (\mathrm{nm/s})^2/\mathrm{Hz}$	

7 Quantities derived from sound particle acceleration

Quantities derived from sound particle acceleration are defined in Table 15.
In this table, the symbol $\boldsymbol{\delta}(t)$ represents either noise sound particle acceleration, $\boldsymbol{a}(t) = \boldsymbol{a}_{\mathrm{N}}(t)$, if there is no signal, or signal plus noise sound particle acceleration, $\boldsymbol{a}(t) = \boldsymbol{a}_{\mathrm{S+N}}(t)$, if a signal is present. Definitions applicable to signal only can be obtained by first defining the signal sound particle acceleration as $\boldsymbol{a}_{\mathrm{S}}(t) \equiv \boldsymbol{a}_{\mathrm{S+N}}(t) - \boldsymbol{a}_{\mathrm{N}}(t)$ and applying the same concepts to a hypothetical sound particle acceleration defined as $\boldsymbol{a}(t) = \boldsymbol{a}_{\mathrm{S}}(t)$, which is the sound particle acceleration that would exist if there were no background noise. Definitions obtained in this way are listed in Table 16.
In underwater acoustics, quantities are often reported as levels, in decibels. Where applicable, levels of the quantities listed in Table 15 and Table 16 are defined in Table 17 and Table 18, respectively.

Table 15 – Quantities derived from sound particle acceleration, applicable to noise only or signal plus noise. Compare Table 16, which defines similar quantities applicable to signal only.

term	symbol	unit	definition	notes
zero-to-peak sound particle acceleration	$a_{0-\mathrm{pk}}$	m/s^2	greatest magnitude of the *sound particle acceleration* during a specified time interval	
mean-square sound particle acceleration	$\overline{a^2}$	(m/s^2)^2	integral over a specified time interval of squared magnitude of the *sound particle acceleration*, divided by the duration of the time interval, for a specified frequency range source: ISO/DIS 18405.2, 2.1.3.2	
sound particle acceleration exposure	$E_{a,T}$	(m/s^2)^2 s	integral of the square of the magnitude of the *sound particle acceleration*, $\boldsymbol{a}$, over a specified time interval or event, for a specified frequency range source: ISO/DIS 18405.2, 2.1.3.6	
sound particle acceleration exposure spectral density	$E_{a,f}$	(m/s^2)^2 s/Hz	distribution as a function of frequency of the *sound particle acceleration exposure* per unit bandwidth of a *sound* having a continuous spectrum	The sound particle acceleration exposure spectral density is a function of positive frequencies. The spectral density so defined is said to be

term	symbol	unit	definition	notes
			based on: ISO/DIS 18405.2, 2.1.3.9	“single-sided”.
mean-square sound particle acceleration spectral density	$\overline{a_f^2}$	$(m/s^2)^2$/ Hz	distribution as a function of frequency of the *mean-square sound particle acceleration* per unit bandwidth of a *sound* having a continuous spectrum based on: ISO/DIS 18405.2, 2.1.3.13	The mean-square sound particle acceleration spectral density is a function of positive frequencies. The spectral density so defined is said to be “single-sided”.
root-mean-square sound particle acceleration	a_{rms}	m/s^2	square root of the *mean-square sound particle acceleration*	

Table 16 Quantities derived from signal sound particle acceleration, applicable to signal only. Compare Table 15, which defines similar quantities applicable to noise and signal plus noise.

term	symbol	unit	definition	notes
signal sound particle acceleration	$\boldsymbol{a}_{\mathrm{S}}$	m/s^2	contribution to the *sound particle acceleration* from a specified **acoustic signal**	Signal sound particle acceleration is a vector quantity. If the sound particle acceleration has sufficiently low amplitude to justify non-linear effects, the signal sound particle acceleration can be calculated as $\boldsymbol{a}_{\mathrm{S}}(t) = \boldsymbol{a}_{\mathrm{S+N}}(t) - \boldsymbol{a}_{\mathrm{N}}(t).$ According to Note 1 to entry 2.1.2.10 of ISO 2016, non-linear effects may be neglected when the magnitude of the sound particle velocity is small compared with the sound speed.
zero-to-peak signal sound particle acceleration	$a_{0-\mathrm{pk,S}}$	m/s^2	greatest magnitude of the **signal sound particle acceleration**, during a specified time interval	For a continuous sound, the duration of the time interval is specified as a fixed value, in seconds. For a **transient**, the duration of the time interval may be specified as a fixed value, in seconds, or as a percentage energy acceleration signal

term	**symbol**	**unit**	**definition**	**notes**
				duration, with fixed percentage x.
mean-square signal sound particle acceleration	$\overline{a_{\mathrm{S}}^2}$	(m/s²)²	integral over a specified time interval of squared **signal sound particle acceleration**, divided by the duration of the time interval, for a specified frequency range	If the signal and noise sound particle accelerations are uncorrelated, the mean-square signal sound particle acceleration for the **signal** may be estimated using $\overline{u_{\mathrm{S}}^2} \approx \overline{u_{\mathrm{S+N}}^2} - \overline{u_{\mathrm{N}}^2}$ For a continuous sound, the duration of the time interval is specified as a fixed value, in seconds. For a **transient**, the duration of the time interval may be specified as a fixed value, in seconds, or as a percentage energy acceleration signal duration, with fixed percentage x.
signal sound particle acceleration exposure	$E_{a,T,\mathrm{S}}$	(m/s²)² s	integral of the square of the magnitude of the **signal sound particle acceleration**, $\boldsymbol{a}$, over a specified time interval or event, for a specified frequency range	If the signal and noise particle accelerations are uncorrelated, the signal sound particle acceleration exposure may be estimated using $E_{u,T,\mathrm{S}} \approx E_{u,T,\mathrm{S+N}} - E_{u,T,\mathrm{N}}$ For a continuous sound, the duration of the time interval is specified as a fixed value, in seconds.
signal sound particle acceleration exposure spectral density	$E_{a,f,\mathrm{S}}$	(m/s²)² s/Hz	distribution as a function of frequency of the **sound particle acceleration exposure** per unit bandwidth of a **signal** having a continuous spectrum	Sound particle acceleration exposure spectral density is a property of a **transient**. The signal sound particle acceleration exposure spectral density is a function of positive frequencies. The spectral density so defined is said to

term	symbol	unit	definition	notes
				be “single-sided”.
mean-square signal sound particle acceleration spectral density	$\overline{a^2_{f,S}}$	$(m/s^2)^2$/ Hz	distribution as a function of frequency of the **mean-square sound particle acceleration** per unit bandwidth of a **signal** having a continuous spectrum	Mean-square signal sound particle acceleration spectral density is a property of a continuous sound. The duration of the time interval is specified as a specified as a fixed value, in seconds. The mean-square signal sound particle acceleration spectral density is a function of positive frequencies. The spectral density so defined is said to be “single-sided”.
percentage energy acceleration signal duration	$\tau_{x\%,a}$	s	time during which a specified percentage x of signal sound particle acceleration exposure occurs	Percentage energy acceleration signal duration is a property of a **transient signal**.
signal acceleration impulse	$\boldsymbol{J_a}$	(m/s^2) s	integral of the **sound particle acceleration**, over a specified time interval or event, for a specified frequency range of a **transient acoustic signal**	signal acceleration impulse is a vector quantity

Table 17 Levels of quantities derived from sound particle acceleration, applicable to noise only or signal plus noise, selected where appropriate from Table 15. Compare Table 18, which defines similar quantities applicable to signal only.

term	symbol	unit	definition	notes
zero-to-peak sound particle acceleration level	$L_{a,0-\mathrm{pk}}$	dB	level of the **zero to peak sound particle acceleration** In equation form: $L_{a,0-\mathrm{pk}} = 10\log_{10}\frac{a^2_{0-\mathrm{pk}}}{a_0^2}\,\mathrm{dB}$ Reference value: $a_0 = 1\ \mu\mathrm{m/s^2}$ $a_0^2 = 1\ (\mu\mathrm{m/s^2})^2$ Based on ISO/DIS 18405.2, 2.2.2.1	
mean-square sound particle acceleration level	L_a	dB	level of the **mean-square sound particle acceleration**	

term	**symbol**	**unit**	**definition**	**notes**
			In equation form: $$L_a = 10\log_{10}\frac{\overline{a^2}}{a_0^2}\,\mathrm{dB}$$ Reference value: $a_0 = 1\ \mu\mathrm{m/s^2}$ $a_0^2 = 1\ (\mu\mathrm{m/s^2})^2$ Based on ISO/DIS 18405.2, 2.2.1.1	
sound particle acceleration exposure level	$L_{E,a}$	dB	level of the **sound particle acceleration exposure** In equation form: $$L_{E,a} = 10\log_{10}\frac{E_a}{E_{a,0}}\,\mathrm{dB}$$ Reference value: $E_{a,0}^{1/2} = 1\ (\mu\mathrm{m/s^2})\ \mathrm{s}^{\frac{1}{2}}$ $E_{a,0} = 1\ (\mu\mathrm{m/s^2})^2\ \mathrm{s}$ Based on ISO/DIS 18405.2, 2.2.1.5	
sound particle acceleration exposure spectral density level	$L_{E,a,f}$	dB	level of the **sound particle acceleration exposure spectral density** In equation form: $$L_{E,a,f} = 10\log_{10}\frac{E_{a,f}}{E_{a,f,0}}\,\mathrm{dB}$$ Reference value: $E_{a,f,0}^{1/2} = 1\ (\mu\mathrm{m/s^2})\ \mathrm{s}^{\frac{1}{2}}/\mathrm{Hz}^{\frac{1}{2}}$ $E_{a,f,0} = 1\ (\mu\mathrm{m/s^2})^2\ \mathrm{s/Hz}$ Based on ISO/DIS 18405.2, 2.2.1.9	
mean-square signal sound particle acceleration spectral density level	$L_{a,f}$	dB	level of the **mean-square sound particle acceleration spectral density** In equation form: $$L_{a,f} = 10\log_{10}\frac{\overline{a_f^2}}{a_{f,0}^2}\,\mathrm{dB}$$ Reference value: $a_{f,0} = 1\ (\mu\mathrm{m/s^2})/\mathrm{Hz}^{\frac{1}{2}}$ $a_{f,0}^2 = 1\ (\mu\mathrm{m/s^2})^2/\mathrm{Hz}$	

term	symbol	unit	definition	notes
			Based on ISO/DIS 18405.2, 2.2.1.10	

Table 18 Levels of quantities derived from signal sound particle acceleration, applicable to signal only, selected where appropriate from Table 16. Compare Table 17, which defines similar quantities applicable to noise and signal plus noise.

term	symbol	unit	definition	notes
zero to peak signal sound particle acceleration level	$L_{a,0-\mathrm{pk,S}}$	dB	level of the **zero to peak signal sound particle acceleration** In equation form: $L_{a,0-\mathrm{pk,S}} = 10\log_{10}\frac{a_{0-\mathrm{pk,S}}^2}{a_0^2}\,\mathrm{dB}$ Reference value: $a_0 = 1\ \mu\mathrm{m/s^2}$ $a_0^2 = 1\ (\mu\mathrm{m/s^2})^2$	
mean-square signal sound particle acceleration level	$L_{a,\mathrm{S}}$	dB	level of the **mean-square signal sound particle acceleration** In equation form: $L_{a,\mathrm{S}} = 10\log_{10}\frac{\overline{a_\mathrm{S}^2}}{a_0^2}\,\mathrm{dB}$ Reference value: $a_0 = 1\ \mu\mathrm{m/s^2}$ $a_0^2 = 1\ (\mu\mathrm{m/s^2})^2$	
signal sound particle acceleration exposure level	$L_{E,a,\mathrm{S}}$	dB	level of the **signal sound particle acceleration exposure** In equation form: $L_{E,a,\mathrm{S}} = 10\log_{10}\frac{E_{a,\mathrm{S}}}{E_{a,0}}\,\mathrm{dB}$ Reference value: $E_{a,0}^{1/2} = 1\ (\mu\mathrm{m/s^2})\ \ \mathrm{s}^{\frac{1}{2}}$ $E_{a,0} = 1\ (\mu\mathrm{m/s^2})^2\ \mathrm{s}$	
signal sound particle acceleration exposure spectral density level	$L_{E,a,f,\mathrm{S}}$	dB	level of the **signal sound particle acceleration exposure spectral density** In equation form: $L_{E,a,f,\mathrm{S}} = 10\log_{10}\frac{E_{a,f,\mathrm{S}}}{E_{a,f,0}}\,\mathrm{dB}$ Reference value: $E_{a,f,0}^{1/2} = 1\ (\mu\mathrm{m/s^2})\ \ \mathrm{s}^{\frac{1}{2}}/\mathrm{Hz}^{\frac{1}{2}}$	

term	symbol	unit	definition	notes
			$E_{a,f,0} = 1\ (\mu\text{m/s}^2)^2\ \text{s/Hz}$	
mean-square signal sound particle acceleration spectral density level	$L_{a,f,\text{S}}$	dB	level of the **mean-square signal sound particle acceleration spectral density** In equation form: $L_{a,f,\text{S}} = 10\log_{10}\frac{\overline{a_{f,\text{S}}^2}}{a_{f,0}^2}\,\text{dB}$ Reference value: $a_{f,0} = 1\ (\mu\text{m/s}^2)/\text{Hz}^{\frac{1}{2}}$ $a_{f,0}^2 = 1\ (\mu\text{m/s}^2)^2/\text{Hz}$	

8 Correspondence with terminology used in selected publications

Prior to ISO 18405 (ISO, 2016) there was no recognized formal standardization in underwater acoustical terminology. As a result, different publications have employed different terms for the same concepts, and in some cases different meanings for the same terms. Interpretation of any publication is facilitated by relating its terminology to a standard terminology. In this section the terminology of selected key or frequently referenced publications is related to the standard Project Terminology of this report. In particular, two influential review papers have been selected, namely Southall et al. 2007 and Popper et al. 2014. Each was written by a team of acknowledged experts, one on the impact of sound on aquatic mammals (Southall et al. 2007 – henceforth abbreviated S2007), and the second on the impact of sound on fishes and turtles (Popper et al. 2014 – henceforth abbreviated P2014). The terminology used by these two review publications is related to the Project Terminology in Table 19 and Table 20. The authors of the present report include one co-author of each of S2007 (DRK) and P2014 (MBH). To ensure accurate representation of S2007 and P2014 terminology, DRK and MBH have reviewed Table 19 and Table 20 respectively, in consultation where appropriate with their original co-authors.

In addition to the two peer-reviewed papers, a third publication (Wyatt 2008) was selected as being of special interest to the JIP because it described sources of relevance to the oil and gas industry. See Table 21.

Table 19 List of terms from Southall et al. 2007 (S2007), related to the Project Terminology.

standard name, including standard synonyms, symbols and abbreviations	**S2007 name, including synonyms, symbols and abbreviations, where relevant**	**notes**
2.1.2.1 **sound pressure** p	instantaneous sound pressure $P(t)$	
2.1.2.3 **zero-to-peak sound pressure** **peak sound pressure** p_{pk} $p_{\text{0-pk}}$	peak sound pressure P_{max}	
2.1.2.8 **peak-to-peak sound pressure** $p_{\text{pk-pk}}$	peak-to-peak sound pressure	
2.1.3.1 **mean-square sound pressure** $\overline{p^2}$	mean-squared pressure	
2.1.3.5 **sound pressure exposure** **time-integrated squared sound pressure** **sound exposure**	sound exposure $E(t)$	Sound exposure is defined on p499 of S2007 as an unweighted quantity synonymous with *time-integrated squared sound pressure*.

standard name, including standard synonyms, symbols and abbreviations	**S2007 name, including synonyms, symbols and abbreviations, where relevant**	**notes**
$E_{p,T}$		In addition the term "sound exposure" is also used throughout S2007 in the alternative sense of "exposure to sound". We emphasize the need to clarify whether the sound exposure is evaluated at a specified fixed receiver position or at a moving receiver, for specified receiver motion. In principle the "receiver" might be an animal, a man-made receiver, or an animat.
2.2.1.1 **mean-square sound pressure level** **sound pressure level** **SPL** $L_{p,\mathrm{rms}}$ L_p	root-mean-square (RMS) SPL	The shorthand "dB SPL" is used by S2007 to indicate a value of *mean-square sound pressure level*, expressed in decibels; i.e., to the mean pressure over a defined duration. The use of "mean-square SPL" as an abbreviation for *mean-square sound pressure level* is deprecated by ISO (2016). If one wishes to avoid spelling out the name "mean-square sound pressure level" in full, correct alternatives given by ISO (2016) are "sound pressure level" and "SPL", all of which are synonymous.
2.2.1.5 **time-integrated squared sound pressure level** **sound exposure level** **sound pressure exposure level** SEL $L_{E,p}$	sound exposure level SEL	Most commonly, sound exposure level (abbreviated SEL) in S2007 refers to the total received sound exposure, in principle unweighted, and expressed as a level in dB re 1 μPa^2 s. However, it is used in S2007 to refer to both weighted and unweighted quantities.

standard name, including standard synonyms, symbols and abbreviations	**S2007 name, including synonyms, symbols and abbreviations, where relevant**	**notes**
2.2.2.1 **peak sound pressure level** **zero-to-peak sound pressure level** $L_{p,\mathrm{pk}}$ $L_{p,\mathrm{0\text{-}pk}}$	peak SPL	In Tables 3 (p443) and 5 (p452), the shorthand "dB re: 1 μPa (peak) (flat)" is used by S2007 to indicate a value of *zero-to-peak sound pressure level*, expressed in decibels. This is the level of the maximum magnitude of the sound pressure, specifically applicable for intense signals of short rise time and short duration, such as impulse sounds. The use of "peak SPL" as an abbreviation for *peak sound pressure level* is deprecated by ISO (2016). To avoid confusion between peak sound pressure level (level of the peak sound pressure) and maximum sound pressure level (peak value of SPL), it is preferable to spell out the name "peak sound pressure level" in full.
2.7.1.4 **weighted sound exposure level** **weighted sound pressure exposure level** $\mathbf{SEL_w}$ $L_{E,p,\mathrm{w}}$	sound exposure level SEL	In S2007, SEL is sometimes used as a synonym of the unweighted quantity *time-integrated squared sound pressure level* (see 2.2.1.5 above). On other occasions it is used as a weighted quantity. See for example the remark on p444: "As for the single pulse criteria, peak pressures are unweighted (i.e., "flat-weighted"), but SEL should be weighted by the appropriate M-weighting function (Figure 1)." When used in this way, the weighted quantity is sometimes referred to as "weighted SEL", or similar (e.g. p442, 445, and 451). When not stated explicitly in this way (see e.g., Tables 3 (p443) and 5 (p452), specifying

standard name, including standard synonyms, symbols and abbreviations	**S2007 name, including synonyms, symbols and abbreviations, where relevant**	**notes**
		the risk thresholds for injury and behavioral response, as proposed by S2007), it is instead indicated by the notation "dB re: 1 μPa²-s (<Mxx>)", where <Mxx> indicates one of the M-weighting functions M_{lf}, M_{mf}, M_{hf}, M_{pw}, as described by S2007. More specifically, for weighted sound exposure, the *frequency weighting function* used in S2007 is given by $w(f) = w_{\mathrm{aud}}(f) = 10^{\frac{M(f)}{10\ \mathrm{dB}}}$, where $M(f)$ is given by Eqs. (7) and (8) of S2007.

Table 20 List of terms from Popper et al. 2014 (P2014), related to the Project Terminology.

standard name, including standard synonyms, symbols and abbreviations	**P2014 name, including synonyms, symbols and abbreviations, where relevant**	**notes**
2.1.2.3 **zero-to-peak sound pressure** **peak sound pressure** p_{pk} $p_{0\text{-pk}}$	peak sound pressure	
2.1.2.9 **sound particle displacement** ***δ***	particle displacement	
2.1.2.10 **sound particle velocity** ***u***	particle velocity	
2.1.2.11 **sound particle acceleration** ***a***	particle acceleration	
2.2.1.1 **mean-square sound pressure level** **sound pressure level** **SPL** $L_{p,\mathrm{rms}}$ L_p	rms sound pressure level	The shorthand “dB rms” is used by P2014 in Tables 7.5 ff to indicate a value of this quantity, expressed in decibels. The use of “mean-square SPL” as an abbreviation for *mean-square sound pressure level* is deprecated by ISO (2016). In the y-axis label of Figs 3.2 and 3.3, the hearing threshold for rms sound pressure level is abbreviated as “Sound Pressure Threshold”
2.2.1.5 **time-integrated squared sound pressure level** **sound exposure level** **sound pressure exposure level** SEL $L_{E,p}$	sound exposure level SEL	In P2014, sound exposure level (SEL) is an unweighted quantity, synonymous with 2.2.1.5 *time-integrated squared sound pressure level*. The shorthand “dB $\mathrm{SEL_{cum}}$” is used by P2014 in Tables 7.3 ff to indicate a value of **cumulative sound exposure level**, expressed in decibels.

standard name, including standard synonyms, symbols and abbreviations	**P2014 name, including synonyms, symbols and abbreviations, where relevant**	**notes**
2.2.2.1 **peak sound pressure level** **zero-to-peak sound pressure level** $L_{p,\mathrm{pk}}$ $L_{p,0\text{-}\mathrm{pk}}$	peak sound pressure level $\mathrm{SPL}_{\mathrm{peak}}$	In Tables 7.2, 7.3 and 7.4 of P2014, the shorthand “dB peak” is used to indicate a value of *zero-to-peak sound pressure level*, expressed in decibels. The use of “peak SPL” as an abbreviation for *peak sound pressure level* is deprecated by ISO (2016).
root-mean-square sound pressure	root-mean-square (rms) sound pressure	**root-mean-square sound pressure** is defined in Table 2
zero-to-peak sound particle velocity	peak particle velocity peak velocity	**zero-to-peak sound particle velocity** is defined in Table 11

Table 21 List of terms from Wyatt 2008 (W2008), related to the Project Terminology.

standard name, including standard synonyms, symbols and abbreviations	**W2008 name, including synonyms, symbols and abbreviations, where relevant**	**notes**
2.1.2.3 **zero-to-peak sound pressure** **peak sound pressure** p_{pk} $p_{\text{0-pk}}$	peak pressure	On pp 40-43, W2008 uses the term “peak pressure” as a synonym of 2.1.2.3 *zero-to-peak sound pressure* The same term is also used by W2008 as a level, synonymous with *zero-to-peak sound pressure level* (see 2.2.2.1 below).
2.2.1.1 **mean-square sound pressure level** **sound pressure level** **SPL** $L_{p,\text{rms}}$ L_p	equivalent continuous sound level L_{eq} or sound pressure level SPL	The term “equivalent continuous sound level” is used by W2008 as a synonym of unweighted sound pressure level. The use of “mean-square SPL” as an abbreviation for *mean-square sound pressure level* is deprecated by ISO (2016).
2.2.1.5 **time-integrated squared sound pressure level** **sound exposure level** **sound pressure exposure level** **SEL** $L_{E,p}$	sound exposure level SEL	This term is used by W2008 to indicate an unweighted quantity, i.e., with the *frequency weighting function* given by $w(f) = 1$.
2.2.2.1 **peak sound pressure level** **zero-to-peak sound pressure level** $L_{p,\text{pk}}$ $L_{p,\text{0-pk}}$ DEPRECATED: peak SPL	peak pressure	W2008 defines the term “peak pressure” on p82 as “the instantaneous maximum of the absolute sound pressure, in dB re 1 μPa” synonymous with *peak sound pressure level*. It is used in this sense on p19 (Table 3.2.) and p45. The same term is also used by W2008 as to mean *zero-to-peak sound pressure* (see 2.1.2.3 above).
90% transient signal sound pressure duration	pulse duration	W2008 defines “pulse duration” as “the time interval between the arrival of 5% and 95% of the total pulse energy measured in seconds.” We assume that “energy” in this definition refers to the sound pressure exposure, making it consistent with the requirements of July 2016 US criteria (NOAA 2016).

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