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Standard Test Method for Laboratory Measurement of Acoustical Effectiveness of Ship Noise Treatments Laboratory Measurement of Acoustical Effectiveness for Marine Bulkhead and Deck Treatments[1]

This standard is issued under the fixed designation E2963; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

INTRODUCTION

This test method is designed to measure the acoustical effectiveness of treatments that are intended to reduce airborne noise on ships. Such treatments would be applied to compartment structural partitions such as bulkheads, decks, and side shells. To fully characterize the acoustical performance of a treatment, five parameters must be assessed: transmission loss, radiation efficiency, acceptance, absorption, and damping. This test method focuses on the assessment of the first three, and provides for convenient assessments of absorption and damping. Tests discussed in this method are based on the Test Method E90 setup and procedure. This test method is not intended to be a replacement of Test Method E90; conversely, this method builds on the E90 method that is now well established. Similarly, this test method does not replace absorption testing discussed in Test Method C423, nor damping testing discussed in Test Method E756, though for reasons of convenience this method can be used to make approximate assessments of how different treatments may impact these parameters.

1. Scope

1.1 This test method covers the laboratory measurement of the acoustical effectiveness of treatments installed on ship bulkheads, decks, and side shells. Measurements are focused on assessing changes in transmission loss, radiation efficiency, and acceptance that occur when treatments are applied. Measurements of changes to absorption and damping are addressed in Appendix X1 and Appendix X2, respectively.

1.2 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

1.4 Any material that is to be installed on a marine division must meet appropriate fire, combustibility, and other applicable SOLAS, USCG, IMO, Navy, or other required non-acoustical standards and specifications. See Appendix X3 for additional information.

2. Referenced Documents

2.1 *ASTM Standards:*[2]

C423 Test Method for Sound Absorption and Sound Absorption Coefficients by the Reverberation Room Method

E634 Practice for Sampling of Zinc and Zinc Alloys by Spark Atomic Emission Spectrometry

E90 Test Method for Laboratory Measurement of Airborne Sound Transmission Loss of Building Partitions and Elements

E756 Test Method for Measuring Vibration-Damping Properties of Materials

2.2 *ANSI Standards:*[3]

ANSI S1.4-1983 (R2006) Specification for Sound Level Meters

ANSI S1.6-1984 (R2011) Preferred Frequencies, Frequency

[1] This test method is under the jurisdiction of ASTM Committee E33 on Building and Environmental Acoustics and is the direct responsibility of Subcommittee E33.03 on Sound Transmission.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.

Levels, and Band Number for Acoustical Measurements
ANSI S1.8-1989 (R2011) ,Reference Quantities for Acoustical Levels
ANSI S1.11-2004 (R2009) Specification for Octave-Band and Fractional-Octave-Band Analog and Digital Filters
ANSI S1.43-1997 (R2007) Specifications for Integrating-Averaging Sound Level Meters

2.3 *ISO Stadnard:*[4]
ISO 16063-1:1998 , Methods for the Calibration of Vibration and Shock Transducers

3. Terminology

3.1 *Definitions:* The following terms used in this test method have specific meanings that are defined in Terminology E634.

airborne sound
average sound pressure level
background noise
damping
decibel
diffuse sound field
direct sound field
flanking transmission
level
octave band
receiving room
reverberant sound field
reverberation room
sound level
sound pressure
sound pressure level
source room
unit

3.1.1 As defined in Test Method E90 transmission loss is the difference in decibels between the average sound pressure levels in the reverberant source and receiving rooms, plus ten times the common logarithm of the ratio of the area of the common partition to the sound absorption in the receiving room (see Eq 4).

3.1.2 As defined in Test Method E90 sound absorption of a room in a specified frequency band is the hypothetical area of a totally absorbing surface without diffraction effects which, if it were the only absorbing element in the room, would give the same sound decay rate as the room under consideration.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *acceptance, n*—a measure of the vibration velocity level induced in a structure that is exposed to a diffuse sound field composed of one or more frequencies (see Eq 6).

3.2.2 *acoustical effectiveness, n*—a measure of the change in a particular acoustical parameter that is created by the addition of a material to the base structure.

3.2.3 *radiation efficiency, n*—a measure relating the sound pressure level in a diffuse sound field that is produced by a vibrating structural surface, referenced to a specified vibration velocity level, when that surface is moving in an oscillatory motion at one or more frequencies (see Eq 8).

3.2.4 *test or 'base' structure, n*—The structure representing a bulkhead, deck, or shell of a ship.

3.2.4.1 *Discussion*—The base structure is typically constructed with steel or aluminum stiffened plating, though other construction types are possible. This is the structure to which treatments are applied.

3.3 *Symbols:*

A = room constant, m^2
S = area of partition (structure under test), m^2
a = acceleration, m/s^2
c = speed of sound in air, m/s
dB = decibels
f = frequency, Hz
p = pressure, Pa
v = velocity, m/s
L_a = vibration acceleration level, dB re: 10 μm/s^2
L_p = sound pressure level, dB re: 20 μPa. Lv – velocity level, dB re: 10 nm/s (that is, 10^{-8} m/s)
L_Λ = acceptance in decibels referenced to 20 μPa/10 nm/s
L_σ = radiation efficiency in decibels
TL = transmission loss in decibels
ΔX = change in the quantity "X" between treated and non-treated test cases
α = sound absorption coefficient
η = loss factor, (no dimensions)
ρ = density, kg/m^3

3.4 All levels expressed in decibels have a reference quantity. A level expressed in decibels is 10 times the common logarithm of the ratio of a squared quantity divided by a squared reference quantity. For example, the reference quantity for sound pressure level is 20 micropascals. The abbreviated level is written as dB re: 20 μPa

4. Summary of Test Method

4.1 The effectiveness of a given treatment is determined by comparing the acoustical properties of a given structure with and without the treatment applied. Measurements are first performed on a 'baseline' test structure (that is, without the treatment in place). The treatment is then added to the structure and tests are repeated. The differences in acoustical parameters between the treated and non-treated structures determine the acoustical effectiveness of the treatment.

4.2 The general test setup discussed in Test Method E90 shall be used. Two adjacent reverberation rooms are arranged with an opening between them in which a test partition is installed.

4.3 Transmission loss, acceptance, and radiation efficiency (as well as absorption and damping) are all functions of frequency, and measurements are made in a series of frequency bands.

4.4 For measurement of transmission loss, Test Method E90 shall be used to test both the treated and non-treated structures. Fig. 1 presents a schematic diagram of the test setup, for reference purposes.

4.5 For the measurement of acceptance, the same test setup discussed in Test Method E90 is used with accelerometers attached to the test structure. An approximately diffuse sound field is produced in the source room; the space- and time-averaged sound pressure levels are measured in this room. The

[4] Available from International Organization for Standardization (ISO), 1, ch. de la Voie-Creuse, CP 56, CH-1211 Geneva 20, Switzerland, http://www.iso.org.

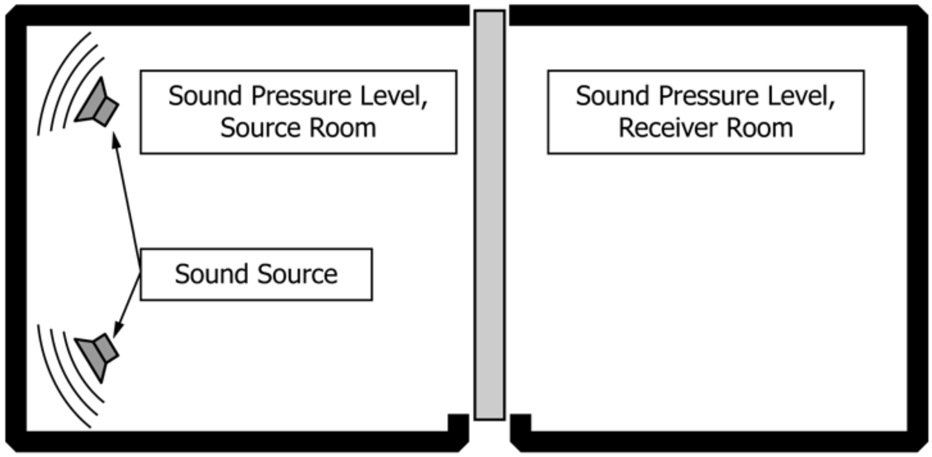

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FIG. 1 Illustration showing the conceptual setup for transmission loss testing (based on Test Method E90)

vibration levels of the test structure are simultaneously measured to produce a space- and time-averaged vibration level of the structure (see Fig. 2). These quantities (sound pressure level and test structure vibration level) are combined to determine the acceptance for the test structure, as shown in Section 13.

4.6 For the measurement of radiation efficiency, the same test setup discussed in Test Method E90 is used. Accelerometers are located on the test structure along with an electromechanical vibration exciter. The vibration exciter drives the structure, which then radiates sound into the receiver room. The sound field produced in this room is considered to be diffuse. The room's space- and time-averaged sound pressure levels are measured, as well as the structure's space- and time-averaged vibration level (see Fig. 3). These quantities, along with the sound absorption in the receiving room and the area of the specimen, are combined to determine the radiation efficiency for the test structure, as shown in Section 13.

4.7 Room absorption measurements are necessary to calculate transmission loss and radiation efficiency. The change in room absorption between the treated and non-treated tests will be directly related to any absorption provided by the treatment. While treatment absorption measurements are formally covered by Test Method C423 it is convenient to use the measured room absorption from transmission loss and radiation efficiency tests to determine the effect of the treatment on absorption. This is discussed in more detail in Appendix X1. These measurements shall not replace measurements described in Test Method C423 as the results would be different. However, they can provide a useful and convenient indication of the absorption of a treatment, which may have sufficient accuracy for engineering applications (see Appendix X1).

4.8 The effect of a treatment on the structure's total damping loss factor formally requires a different test setup than that described in Test Method E90. However, the same structures used for the tests described above can be used to estimate

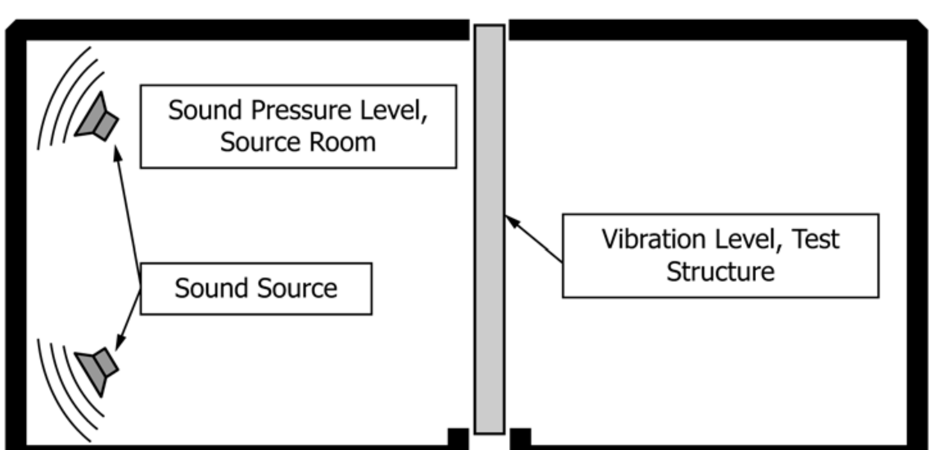

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FIG. 2 Illustration Showing the Conceptual Setup for Acceptance Testing (Note the Similarities to Fig. 1)

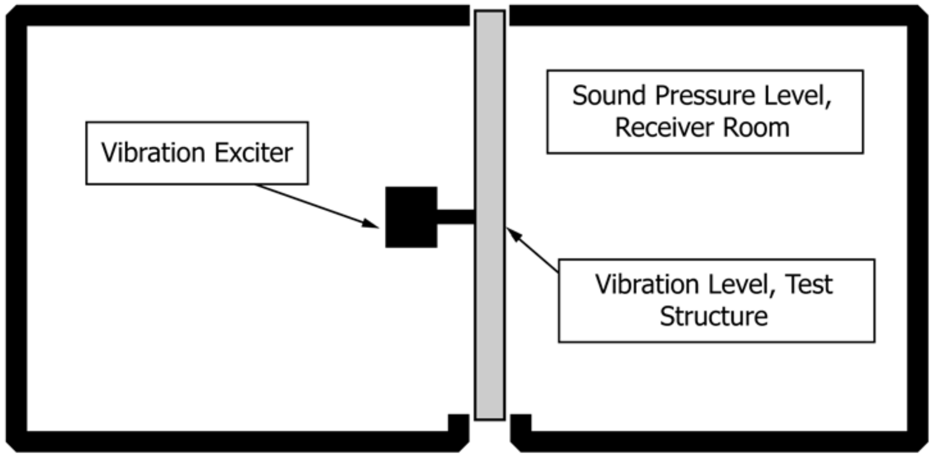

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FIG. 3 Illustration Showing the Conceptual Setup for Acceptance Testing (Note the Similarities to Fig. 1)

damping effectiveness. Options for measuring damping are discussed in more detail in Appendix X2.

5. Significance and Use

5.1 To fully understand the effects of a given treatment, five acoustical factors (transmission loss, acceptance, radiation efficiency, absorption, and damping) must be characterized. For example, only knowing the effect of a given treatment on transmission loss will not allow the acoustical designer or engineer to assess its impacts on propagation of vibration (among other effects), which is an important path to consider for large machinery items and propeller excitation.

5.2 It is necessary to have a common definition of acoustical performance and test procedure to determine all five acoustical factors for ship's treatments so that the performance of different treatment types, as well as the same treatment type from different manufacturers, can be compared.

5.3 In some cases, particularly for damping treatments, the effect of the treatment will be dependent on the non-treated structure's material and geometry and other non-acoustic factors such as environmental conditions (that is, temperature). To fully characterize a treatment it may be necessary to test a range of base constructions. For reasons of practicality, convenience, or economy, it may be sufficient to test only one to three constructions to achieve an understanding of the material performance in a range of practical situations. Additional discussion is provided in Annex A1.

6. Test Apparatus

6.1 The room requirements of Test Method E90 shall be used for the testing of transmission loss, acceptance, and radiation efficiency. Special attention may be needed when testing the treated structure to meet the signal-to-noise ratio per Test Method E90.

6.2 Where the test structure is smaller than the opening between the source and receiver rooms, a filler wall shall be constructed as described in Test Method E90. Meeting the transmission loss requirements for this filler wall shall constitute meeting related requirements for acceptance and radiation efficiency.

6.3 The structure shall be constructed to be representative of actual bulkhead, deck, or shell structure to which the treatment will be applied. Often, a single treatment can be applied to many different structures and construction types; therefore, not all constructions can be practically tested. In such cases it is recommended that one to three 'reference' bulkheads be tested, as discussed in Annex A1, to establish a baseline material performance to which other materials can be readily compared. If treatment effectiveness is expected to change significantly with different bulkhead constructions then additional constructions shall be tested to better define the performance of the material.

6.4 Treatments shall be applied to the test structure as they would be in an actual ship installation. This includes the use of special mounting hardware or edge treatments, as applicable.

6.5 *Aging of Specimens*—Treatments that incorporate materials for which there is a curing process shall age for a sufficient interval before testing, as recommended by the manufacturer. In these cases, it may be convenient and practical to use separate test structures of identical construction to test the treated and non-treated conditions.

7. Test Signal Sources

7.1 *Signal Spectrum*—The sound and vibration signals used for these tests shall be random noise having a continuous spectrum within each test frequency band.

7.2 *Sound Sources*—Sound is generated in the rooms using loudspeaker systems. The requirements for sound sources defined in Test Method E90 shall be followed.

7.3 *Vibration Sources*—An electro-mechanical vibration exciter capable of producing vibration in the test frequency band shall be used. Note that multiple vibration exciters may be necessary to cover the entire test frequency range (see 11.2).

Signals can be produced over the entire test frequency range or broken up into multiple frequency ranges as needed to meet the test requirements of this test method.

7.3.1 The vibration exciter must provide enough power to sufficiently excite the test structure to *(a)* generate noise levels in the receiver room that are at least 10 dB above background noise levels and *(b)* generate vibration levels that are at least 10 dB above the background vibration levels of the test structure.

7.3.2 Attach or mount the vibration exciter to a stiffener located away from the edge of the test structure. The closest distance between the vibration exciter and the edge of the structure shall be no smaller than the distance between stiffeners. A location near the middle of the stiffener is preferable for most test structures.

7.3.3 If the 'unstiffened' side of the structure is excited, the vibration exciter should be mounted as close as possible to the location of a stiffener instead of between stiffeners.

7.3.4 Excitation should be oriented normal to the plating. The vibration exciter location must be the same for tests of treated and non-treated structures.

7.3.5 When treatments are applied to only one side, the vibration exciter shall be attached to the non-treated side. When treatments are applied to both sides, the vibration exciter shall be attached directly to the base structure. Minimal movement or removal of treatments should be employed to accommodate vibration exciter attachment.

8. Microphone Requirements

8.1 Microphone requirements and placement described in Test Method E90 shall be followed.

9. Accelerometer Requirements

9.1 Accelerometers are used to measure the vibration of the structure to determine the acceptance, radiation efficiency, and damping properties (discussed in Appendix X2). Systems employing single or multiple accelerometers can be used, though multiple accelerometer systems are recommended.

9.2 *Accelerometer Performance Requirements*—Use accelerometers and data acquisition systems that are stable (as defined in ANSI S1.4, Section 3.10 for a Type 1 measurement system) and have a uniform response in the frequency range of measurement. Where multiple accelerometers are used, they should be of the same model.

9.3 *Accelerometer Mass*—Accelerometers should be as light as possible in order to avoid mass loading effects (**1**).[5] Accelerometers must have a mass of 15 g or less.

9.4 *Calibration*—Each accelerometer shall have been calibrated over the range of test frequencies to ensure the required accuracy per ISO 16063. A record shall be kept of the calibration data and dates of calibration. Field calibration of the entire measurement system for at least one frequency shall be made at least once during each day of testing.

9.5 Field calibration shall be made using a vibration calibrator. The reading of the acceleration level should match the output of the calibrator, adjusted for any gains or sensitivities of the system. Accelerometer sensitivity differences greater than 10 % relative to the nominal manufacturer sensitivity shall not be used.

9.6 *Accelerometer Positions*—Accelerometers shall be mounted to the test structure itself, not to the treatment. When necessary, portions of the treatment can be moved or removed to allow for accelerometer access, as long as such removal does not account for more than 1 % of the total treatment surface area and does not otherwise compromise its effectiveness. When treatments are applied to only one side of a test structure, accelerometers should be applied to the untreated side.

9.6.1 Primary accelerometer positions shall be on plating between stiffeners.

9.6.2 Accelerometer locations may be spaced by approximately the same distance as the smallest distance between adjacent stiffeners. Accelerometers should be located no closer than half the stiffener spacing from the edges of the test structure. For practical bulkhead configurations (see Annex A1), this would result in approximately 10 to 20 locations. An example is shown in Fig. 4.

9.6.3 Alternatively, a pseudo-random placement can be used, as shown in Fig. 5. This involves dividing the test structure into "Accelerometer Placement Areas" and randomly locating one accelerometer within each area. The Accelerometer Placement Areas should have dimensions that are approximately equal to the stiffener spacing; a buffer of at least 10 % of the stiffener spacing shall be provided adjacent to any stiffeners and the edge of the test structure. This will ensure that accelerometers are not placed directly on stiffeners.

9.6.4 Additional accelerometer locations can be used as deemed necessary. Additional locations would be employed if significant variations in vibration levels were seen in any frequency band between adjacent accelerometer locations (that is, variations that would cause deviations to the measured changes that are greater than the expected accuracy discussed in Section 15). In addition, measurement locations on stiffeners can be utilized if deemed to have significant vibration levels relative to plating locations. All accelerometer locations must be identical for tests of treated and non-treated test structures.

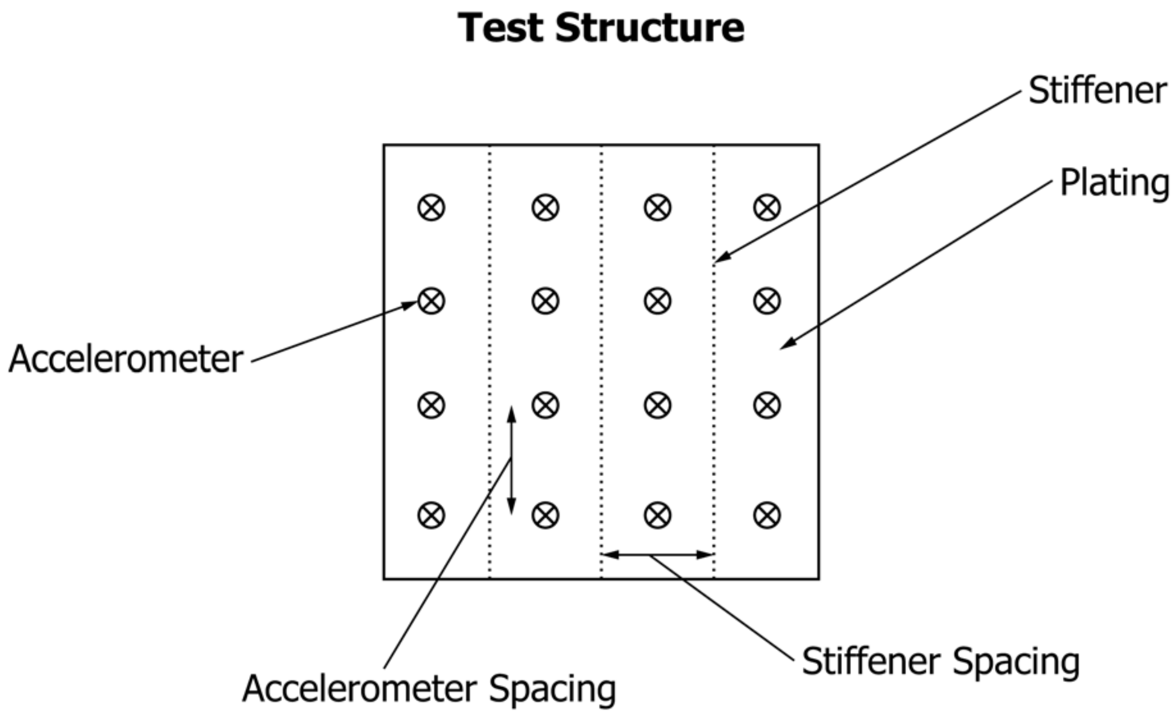
9.6.5 During radiation efficiency testing, measurements shall not be performed directly at or immediately adjacent to the vibration exciter position. Accelerometers should be located at least ½ of the stiffener spacing away from the vibration exciter.

9.7 *Accelerometer Measurement Direction*—Accelerometers should be applied to the structure so that they measure vibration in the direction normal to the plate surface (that is, out-of-plane direction).

10. Hazards

10.1 Test structures will be heavy. Care must be taken when assembling, moving, and installing test structures. Proper mechanical lifting equipment shall be used at all times when moving test structures. All personnel shall maintain a safe distance from test structures while they are being moved. When stationary, test structures must be properly secured in place.

[5] The boldface numbers in parentheses refer to a list of references at the end of this standard.



Note that stiffener spacing is approximately the same as the accelerometer spacing.

FIG. 4 Example of accelerometer measurement locations

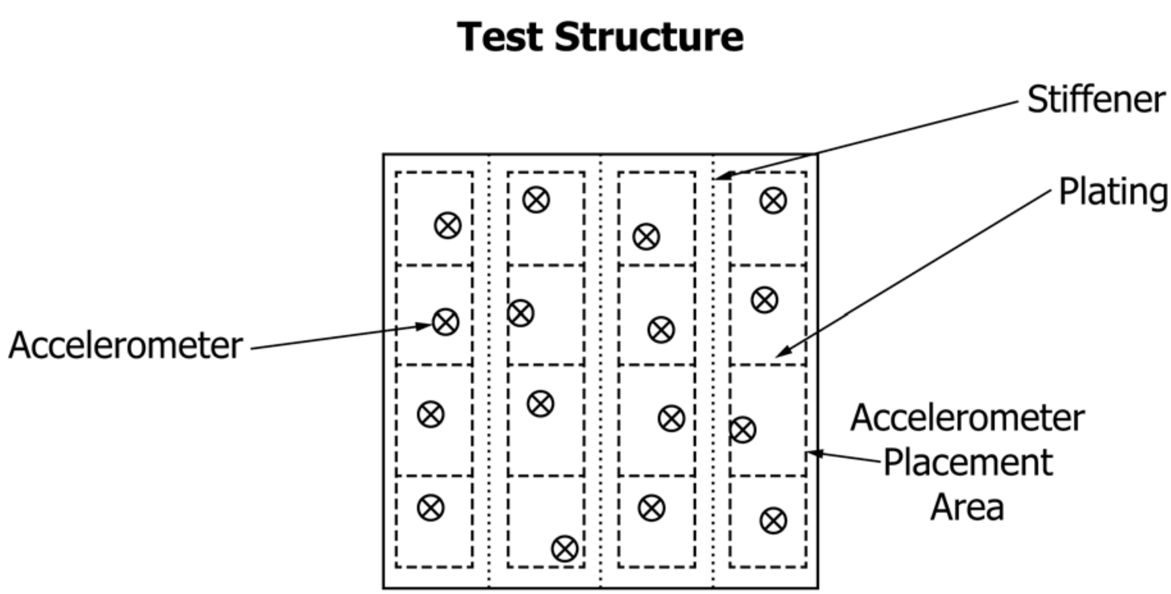


FIG. 5 Example of pseudo-random accelerometer measurement locations

11. Frequency Range and Bandwidth for Analysis

11.1 The frequency range and bandwidth for all tests shall be the same as that specified in Test Method E90, except as specified below.

11.2 *Standard Test Frequencies*—Measurements shall be made in one-third-octave bands with mid-band frequencies specified in ANSI S1.6 from 100 to 10 000 Hz. It is often desirable that the frequency range be extended to include bands below 100 Hz. Many applications require information on low frequency acoustical performance and laboratory operators are encouraged to collect and report information down to at least 63 Hz where feasible. Note that larger room volumes are recommended when measuring at lower frequencies (see Test Method E90).

12. Procedure

12.1 *Measurement Overview*—Measurements of transmission loss and acceptance can be performed simultaneously. Measurements of radiation efficiency must be performed separately. Measurements of sound absorption and damping are performed separately, as discussed in Appendix X1 and Appendix X2, respectively. Sound sources and vibration exciters must not be used at the same time during a test.

12.1.1 Measurements of transmission loss are performed in accordance with Test Method E90.

12.1.2 Measurements of acceptance are performed by generating an acoustic signal in the source room and measuring the resulting sound pressure level in the source room as well as the vibration of the test structure. Note that when performing a measurement of acceptance of the treated test structure, the treated side is typically in the source room.

12.1.3 Measurements of radiation efficiency are performed by energizing the vibration exciter and measuring the resulting vibration of the test structure as well as the sound pressure level in the receiver room. Note that when performing a measurement of radiation efficiency of the treated test structure, the treated side is typically in the receiver room unless significant changes to damping loss factor are expected. The vibration exciter must not be located in the receiver room, as noise from the vibration exciter itself may adversely impact the test results.

12.1.4 Given the above test descriptions, it will be advantageous to allow both test rooms to be used interchangeably as the source and receiver room. For example, if a treatment is applied to one side of a test structure, the treated side should be in the source room for the acceptance test and the receiver room for the radiation efficiency test. This can be accomplished by applying the treatment on the side of the test structure facing the room containing the sound source and using microphones in both rooms. In these tests, the vibration exciter and accelerometers would be located on the non-treated side of the test structure. It may be convenient to install sound sources in both rooms, as room absorption measurements would need to be performed in both spaces.

12.2 *Measurement of Average Sound Pressure Levels* $<L_1>$ *and* $<L_2>$—Measurements of sound pressure levels within the source room ,$<L_1>$ and $<L_2>$ room shall be performed in accordance with Test Standard E90.

12.3 *Measurement of Time Average Vibration Acceleration Levels,* L_a—Acceleration levels at all positions shall be measured and averaged over the same minimum averaging time used for stationary microphone measurements, as described in Test Method E90. This shall be done for both acceptance and radiation efficiency measurements.

12.4 *Background Noise and Vibration*—Background noise shall be measured in the source and receiver rooms in accordance with Test Method E90. Background vibration levels shall be measured using a similar procedure. It is important that background noise be measured using the same gain or 'range' settings in the data acquisition system as is used during measurements with sound or vibration sources operational, as this will include any electrical noise in the system.

12.4.1 Noise and vibration levels measured with the sound or vibration sources operational must be corrected for background noise if the measured levels are less than 10 dB above background. All measurements should be at least 5 dB above background. Corrections for sound levels within 5 to 10 dB of background shall use the following formula:

$$L_s = 10Log\left[10^{L_{sb}/10} - 10^{L_b/10}\right] \quad (1)$$

where:

L_b = background level, dB
L_{sb} = level of signal and background combined, dB, and
L_s = adjusted signal level, dB.

12.4.2 If the output of the sound sources cannot be increased so the combined level is at least 5 dB above the background level, then subtract 2 dB from the combined level and use this as the corrected signal level. In this case, the measurements can be used only to provide an estimate of the lower limit of the measured acoustical parameter. Identify such measurements in the test report.

12.5 *Determination of Room Absorption, A*—The room absorption in the receiver room must be measured to calculate transmission loss and radiation efficiency. As noted in 4.7, a measurement of absorption can be used to assist with the definition of the acoustical performance of a treatment. The measurement of room absorption shall follow Test Method E90. The receiver room may be different for tests of transmission loss and radiation efficiency. In either case, it will be desirable to measure the room constant in the room containing the treatment (see Appendix X1).

13. Calculation

13.1 All calculations shall be performed for each one-third-octave band test frequency.

13.2 For each measurement of airborne noise, the space and time averaged sound pressure level shall be calculated in accordance with Test Method E90.

13.3 For each measurement of vibration, the measured acceleration level shall be converted to velocity using the equation:

$$L_v = L_a - 20*Log(2\pi f) + 60 \quad (2)$$

where:

L_v = the vibration velocity level in dB re: 10 nm/s,
L_a = the vibration acceleration level in dB re: 10 μm/s^2, and
f = the one-third-octave band center frequency.

The space and time averaged vibration velocity level shall be calculated in each one-third-octave band using:

$$\langle L_v \rangle = 10\ Log\left[\frac{1}{n}\sum_{i=1}^{n} 10^{L_i/10}\right] \quad (3)$$

where:

$<L_v>$ = the space and time average vibration velocity level, dB re: 10 nm/s,
n = the number of accelerometer locations, and
Li = the time average vibration velocity level of measurement position i, dB re: 10 nm/s.

13.4 *Transmission Loss*—As per Test Method E90, the calculation of transmission loss for a structure under test uses the equation:

$$TL = \langle L_i \rangle - \langle L_2 \rangle + 10Log\left[\frac{S}{A_2}\right] \quad (4)$$

where:

TL = the transmission loss of the structure, dB,
$<L_1>$ = the time and space average sound pressure level in the source room, dB re: 20 µPa,
$<L_2>$ = the time and space average sound pressure level in the receiver room, dB re: 20 µPa,
S = the surface area of the test structure (plating only, not including stiffener areas), m^2, and
A_2 = the room constant for the receiver room, m^2.

13.4.1 To calculate the effect of the treatment on transmission loss, use the equation:

$$\Delta TL = TL_{Treat} - TL_{Non-Treat} \quad (5)$$

where:

ΔTL = the change in transmission loss due to the application of the treatment, dB,
TL_{Treat} = the transmission loss calculated for the test structure with the treatment, dB, and
$TL_{Non\text{-}Treat}$ = the transmission loss calculated for the test structure without the treatment, dB.

13.5 *Acceptance*—The acceptance of a structure under test is defined here as (based on **(2)** assuming a reverberant receiver room):

$$L_\Lambda = \langle L_1 \rangle - \langle L_v \rangle \quad (6)$$

where:

L_Λ = the acceptance of the structure, dB re: 20 µPa/10 nm/s,
$<L_1>$ = the time and space average sound pressure level in the source room, dB re: 20 µPa, and
$<L_v>$ = the time and space average vibration velocity level on the test structure, dB re: 10 nm/s.

13.5.1 To calculate the effect of the treatment on acceptance, use the equation:

$$\Delta L_\Lambda = L_{\Lambda,\,Treat} - L_{\Lambda,\,Non-Treat} \quad (7)$$

where:

$\Delta_{L\Lambda}$ = the change in acceptance due to the application of the treatment, dB,
$L_{\Lambda,Treat}$ = the acceptance calculated for the test structure with the treatment, and
$L_{\Lambda,Non\text{-}Treat}$ = the acceptance calculated for the test structure without the treatment.

13.6 *Radiation Efficiency*—The calculation of radiation efficiency for a structure under test (based on **(3)**) uses the equation:

$$L_\sigma = \langle L_2 \rangle - \langle L_v \rangle - 10Log\left(\frac{4S}{A_2}\right) + 14 \quad (8)$$

where:

L_σ = the radiation efficiency of the structure, dB,
$<L_2>$ = the time and space average sound pressure level in the receiver room, dB re: 20 µPa,
$<L_v>$ = the time and space average vibration velocity level on the test structure, dB re: 10 nm/s,
S = is the surface area of the test structure (plating only, not including stiffener areas), m^2, and
A_2 = the room constant for the receiver room, m^2

13.6.1 To calculate the effect of the treatment on radiation efficiency, use the equation:

$$\Delta L_\sigma = L_{\sigma,\,Non-Treat} - L_{\sigma,\,Treat} \quad (9)$$

where:

$\Delta_{L\sigma}$ = the change in radiation efficiency due to the application of the treatment, dB,
$L_{\sigma,Treat}$ = the radiation efficiency calculated for the test structure with the treatment, dB, and
$L_{\sigma,Non\text{-}Treat}$ = the radiation efficiency calculated for the test structure without the treatment, dB.

14. Report

14.1 Include the following information in the test report:

14.1.1 A statement that the tests were conducted according to this test method and that data for flanking limit tests and reference specimen tests (per Test Method E90) are available on request. Exceptions should be noted. Conformance to the relevant sections of Annex A1 of Test Method E90 shall be reported when applicable.

14.1.2 A description of the size of the test rooms including overall dimensions, volume, and presence and location of any acoustically diffusive elements located in the rooms.

14.1.3 A description of the test structure (bulkhead, deck, or shell structure). The description must be sufficiently detailed to identify the specimen, at least for those elements affecting test parameters. This includes overall test structure height and width, materials of the plating and stiffeners (including densities of materials), plating and stiffener dimensions, and stiffener spacing. A sketch of the test structure indicating stiffener locations is required. Pictures of the test structure are recommended. If the test structure is not one of the recommended test structures listed in Annex A1, an explanation of the rationale for the selection of the base structure used for testing shall be provided (for example, the treatment is only meant to work on structures similar to those used for testing which are not representative of those listed in Annex A1, or the test structure is a variant of those listed in Annex A1 for a certain reason).

14.1.4 A description of the methods used to attach stiffeners to the plating, including weld lengths if applicable. If details of the specimen construction are withheld at the sponsor's request, the report shall state this. Any unique features of the structure that may affect the test results shall be reported.

14.1.5 A description of the treatment. The description must be sufficiently detailed to identify the specimen, at least for those elements that may affect the test parameters. The report should include, at a minimum, the treatment name, coverage area (including a sketch as needed to identify non-uniform or irregular coverage areas), identification of which side of the test structure the treatment was applied (that is, stiffened or unstiffened side, or both), material description, density, and thickness. If multiple layers of materials are used, this information shall be provided for all layers along with a description of the order of the layers as they have been applied. Descriptions of all fastening elements used, (pins, screws, nails, glue, etc.) and the spacing between them should be given. Any spacing or gap between the treatment and the test structure must be provided. A designation and description furnished by the sponsor of the test may be included in the report provided that they are attributed to the sponsor. If some details of the specimen construction are withheld at the sponsor's request, the report shall state this. The curing period of the treatment, if any, and the condition of the specimen as tested (shrinkage, cracks, etc.) shall be reported.

14.1.6 A description of the method of installation of the specimen in the test opening, including the location of framing members relative to the edges, and the treatment of the junction with the test opening. The use and type of caulking, gaskets, tape, or other sealant on perimeter or interior joints shall be carefully described.

14.1.7 The dates of construction and testing.

14.1.8 Calculated effectiveness of treatment on transmission loss, radiation efficiency, and acceptance, rounded to the nearest decibel for the test frequency bands (see Eq 5, Eq 7, and Eq 9).

14.1.9 Calculated transmission loss, acceptance, and radiation efficiency for non-treated and treated test structures (see Eq 4, Eq 6, and Eq 8).

14.1.10 Identify data affected by flanking transmission or background noise.

14.1.11 Measured room constants for treated and non-treated tests.

14.1.12 Include a description of the method of vibration exciter attachment to the test structure.

14.1.13 Include a description of the location of the treatment (that is, source or receiver room) for each test.

14.1.14 The temperature and humidity in the rooms during the measurements.

14.1.15 The confidence limits found for the laboratory as described in Test Method E90, Annex A2, either during the actual test or in separate measurements.

14.1.16 *Treatment absorption coefficients*—provide either *(1)* the calculated absorption coefficients using the measurements of room constants from testing described in Appendix X1, *(2)* the measured absorption coefficients from separate testing of the treatments using Test Method C423, or *(3)* reference to the test report where results from testing of absorption coefficients per Test Method C423 can be found.

14.1.17 *Damping Loss Factors*—for materials where significant changes to damping loss factors are expected, provide one of the following: *(1)* the calculated damping loss factors for the treated and non-treated test structures using the measurement approach discussed in Appendix X2, along with the change in loss factor due to the applied treatment, *(2)* the measured damping loss factors from separate testing of the treatments using Test Method E756, or *(3)* reference to the test report where results from testing of damping loss factors per Test Method E756 can be found.

14.1.18 All data shall be provided in an electronic spreadsheet format.

15. Precision and Bias

15.1 *Precision and Bias*—This test method makes extensive use of the methods described in Test Method E90, and therefore the precision and bias discussed in Test Method E90 should carry over to this Test Method for measurements of transmission loss. Two measurements of a 9 mm thick aluminum bulkhead treated with mineral wool treatments performed at a single laboratory on different days with a complete rebuild show an average variation in transmission loss effectiveness of 1.0 dB with a maximum variation of 3.2 dB and a standard deviation of 0.8 dB in the frequency range of 50 to 6300 Hz. The same set of tests show an average variation in acceptance effectiveness of 1.1 dB with a maximum variation of 4.2 dB and a standard deviation of 1.0 dB over the same frequency range (50 to 6300 Hz). Similar tests performed on an identical bulkhead treated with a damping treatment show an average variation in radiation efficiency effectiveness of 2.4 dB with a maximum variation of 6.3 dB and a standard deviation of 1.9 dB in the frequency range of 50 to 6300 Hz. Similar tests performed on a 6 mm aluminum bulkhead at two different test facilities with a layered treatment consisting of a barium sulfate 'limp barrier' sandwiched between two layers of fiberglass show an average variation in transmission loss effectiveness of 2.4 dB with a maximum variation of 8.3 dB and a standard deviation of 2.2 dB over the frequency range of 50 to 6300 Hz. Note that the same data shows reduced variation over the frequency range of 50 to 3150 Hz, with an average variation in transmission loss effectiveness of 1.7 dB with a maximum variation of 4.0 dB and a standard deviation of 1.2 dB.

16. Keywords

16.1 acoustic acceptance; acoustic radiation efficiency; acoustic treatment effectiveness; airborne sound transmission loss; absorption; acceptance; bulkhead; damping; deck; radiation efficiency; ship structure; side shell; sound transmission loss; transmission loss

ANNEX

(Mandatory Information)

A1. TEST STRUCTURES

A1.1 Scope

A1.1.1 This annex discusses the possibilities for 'base' test structure configurations. Any given treatment may have different impacts when applied to different base structures. The fundamental construction of base structures can range significantly in plating thickness, stiffener sizes and stiffener layouts. Testing all possible variations is not practical, and in many cases is not necessary.

A1.1.2 For example, absorption materials (such as fiberglass and mineral wool) and joiner facings tend to have acoustical effects that are largely independent of the details of the base structure for a wide range of conventional ship constructions (that is, steel or aluminum stiffened plating). Conversely, conventional damping materials will show strong variations in effectiveness when applied to different plate types and thicknesses. Other treatments (or application of treatments) may or may not have a dependence on the test structure.

A1.1.3 For this reason, tests of new treatments should be performed for a range of base structure constructions unless it can be shown (either by similarity to other treatments or by previous direct testing) that the effectiveness of such treatments is independent of the base structure construction.

A1.1.4 The following sections provide guidance on possible base structure constructions, which should provide a reasonable range of structures that may be representative of many actual ship constructions. Other options are recommended if it is believed that a specific treatment will perform differently for such structures. Again, the intent is not to attempt to test all possible ship constructions/treatments, but rather to provide a reasonable range of constructions so that the acoustic effects can be estimated in other applications.

A1.2 Test Structure Construction Overview

A1.2.1 A representative arrangement of common ship bulkhead constructions is shown in Fig. A1.1. In this arrangement, vertically oriented stiffeners are spaced at regular intervals. These stiffeners are welded across their entire length to a plate. While this layout is one of many possible constructions, it is representative of structures used on ships. Overall dimensions, plating thicknesses, stiffener types, and stiffener spacing can be

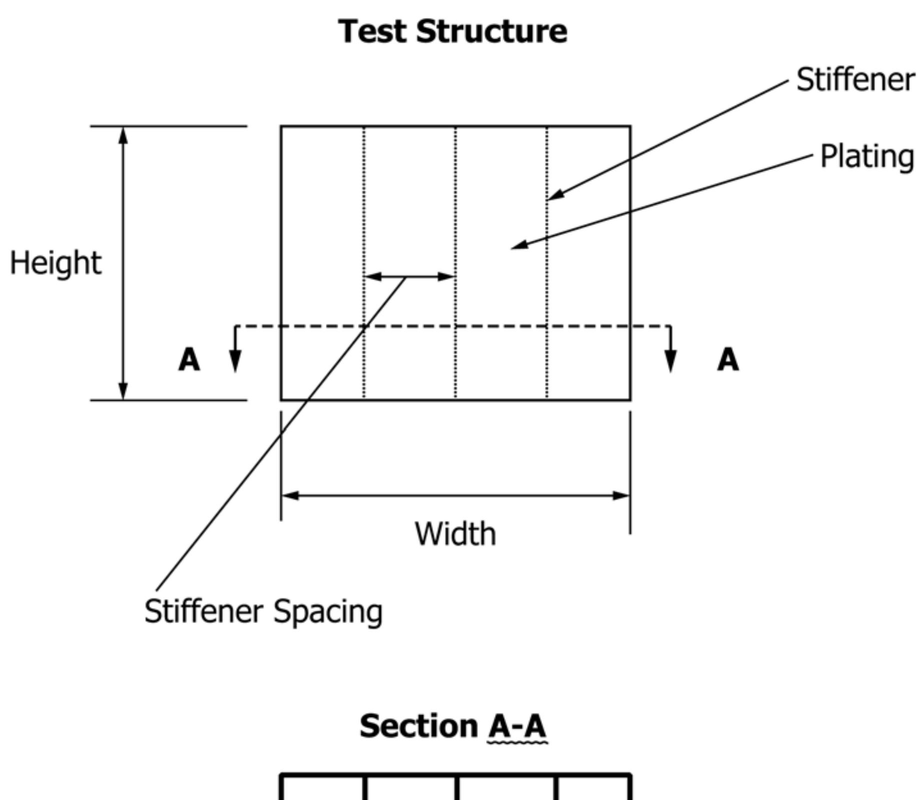


FIG. A1.1 General Layout of Suggested Test Structure varied as deemed necessary. Note that the number of stiffeners can increase or decrease as appropriate for a given test structure size and stiffener spacing.

A1.2.2 It is recommended that the minimum dimensions of the test structure be 2.4 by 2.4 m. This size is representative of bulkheads located in living spaces. Larger test structures may be desirable, though such structures would become increasingly difficult to manage. As discussed in Test Method E90, if the test structure size is smaller than the opening between the source and receiver rooms then a filler wall will need to be constructed to support the test structure; the filler wall must meet the requirements of Test Method E90.

A1.2.3 Plating materials most common to shipbuilding are steel and aluminum. It is expected that most tests will use these materials. Other materials may be appropriate, particularly for measurements with damping materials. Similarly, other construction types such as extruded aluminum and 'honeycomb' structures may be appropriate materials for base structures if these are used for a particular vessel.

A1.2.4 Plating thicknesses (assuming steel and aluminum construction) commonly range from 4 mm to 20 mm, though thicknesses outside of this range certainly may be used in many applications.

A1.2.5 Stiffener spacing typically varies from ship to ship, though commonly ranges from 0.3 to 0.8 m. Stiffener types vary widely, and can include, for example, flat bar, angle, T shapes, and 'bulbs'.

A1.2.6 The construction in Fig. A1.1 shows flat bar along the entire perimeter of the test structure. It is recommended that stiffeners of some type be used along the perimeter of the test structure to help ensure repeatable boundary conditions. This may facilitate the installation of the test structure in the test space.

A1.3 Recommended Test Structures

A1.3.1 When testing general purpose treatments (that is, those that are not meant to be specifically applied to a particular structure or construction type), the constructions listed in Table A1.1 are strongly recommended and should provide a reasonable baseline for treatment effectiveness. These constructions reference the layout shown in Fig. A1.1, and should use flat bar stiffeners along the perimeter. The plating surface density for the structures listed in Table A1.1 cover a large range (approximately 8 to 70 kg/m^2); plating surface density is directly related to treatment performance for many treatments, particularly damping materials, and is the reason for the selection of constructions given here.

A1.3.2 For convenience, the stiffener type and spacing has not been modified for these constructions. Changing stiffener spacing and type will play a role in the transmission loss, acceptance, and radiation efficiency of the test structure, though these factors may be more influential on the absolute value of these parameters and less important for measurements of the relative change of these parameters.

A1.3.3 Additional structures should be tested if a treatment is to be used on structures that differ significantly from those listed in Table A1.1.

A1.3.4 For those treatments that have been shown to be independent of base structure construction, or if only one test structure is to be used for any reason, Test Structure #2 must be used for testing.

A1.3.5 A rationale should be provided in the test report for the selection of the base structure used during testing if none of the structures listed in Table A1.1 are used.

TABLE A1.1 Recommended Test Structure

Test Structure number	Height	Width	Plating material	Plating Thickness	Stiffener Spacing	Stiffener Type
1	2.4 m	2.4 m	Aluminum	3 mm	0.6 m	50 × 25 mm angle
2	2.4 m	2.4 m	Aluminum	9 mm	0.6 m	50 × 25 mm angle
3	2.4 m	2.4 m	Steel	9 mm	0.6 m	50 × 25 mm angle

APPENDIXES

(Nonmandatory Information)

X1. ASSESSMENT OF ACOUSTICAL ABSORPTION

X1.1 Scope

X1.1.1 The testing of acoustical absorption is an important step in completing its acoustical characterization. Test Method C423 provides a method by which absorption can be measured. The current test method is not a replacement for Test Method C423 testing. However, as discussed in the main sections of this test method, a measurement of room constants (which is directly related to treatment absorption) is required to perform transmission loss, radiation efficiency, and acceptance testing. Therefore, it is convenient to calculate and report the absorption provided by a given treatment based on the measurements taken as discussed in the test method.

X1.1.2 Note that if acoustical absorption is the primary function of any treatment tested using this test method, then it is recommended that additional testing per Test Method C423 be performed. The results of the method given here will not be directly comparable to results obtained though tests performed in accordance with Test Method C423 tests. However, in many practical ship applications the differences in test results may lead to only small errors in predicted noise for a given space; such errors may be considered acceptable by application engineers. This is particularly true for materials whose primary function is not absorption

X1.2 Calculation

X1.2.1 The calculation of treatment absorption uses the room constant measurements performed before and after installation of the treatment. All other aspects of the test room and test setup shall be identical for both measurements.

X1.2.2 The absorption coefficients are a function of frequency. The following calculation must be performed for each one-third-octave band in the test frequency range.

X1.2.3 The calculation of treatment absorption is performed using the following equation:

$$\alpha = \frac{A_{Treat} - A_{No\ treat}}{S_{Treat}} \quad (X1.1)$$

where:

A_{treat} = the room constant for the test room containing the treatment after the treatment has been applied (m^2),
$A_{NoTreat}$ = the room constant in the same room prior to application of the treatment (m^2), and
S_{Treat} = the surface area of the test structure, excluding stiffeners (that is, plating only) (m^2)

X2. ASSESSMENT OF DAMPING LOSS FACTORS

X2.1 Scope

X2.1.1 Damping is an important aspect of many treatments, and a full characterization in accordance with Test Method E756 is strongly recommended for any treatment that is expected to provide a significant increase to the damping loss factor of a given ship structure. However, if a full assessment has not been made, the structures used for the testing described in this Test Method provide a convenient opportunity to make a partial assessment of the treatment's damping effectiveness.

X2.1.2 The primary difference between this test and the other tests described in this test method is the test structure is not located between two test rooms. Rather, it must be removed from all previously described supporting structures and hung freely. It is important to minimize the number of supports contacting the structure, as well as the contact area, as extraneous connections will provide additional damping making the results difficult to interpret.

X2.1.3 Testing involves one of several methods of modal testing. The specific method to be used is not prescribed here, as many methods exist that can provide similar results (see X2.3.2).

X2.1.4 Note that this test would be performed at one temperature (room temperature), though in some cases more than one temperature could be tested by moving the test structure to a different environment (outside, for example). If significant variations in performance with temperature are expected, then testing in accordance with Test Method E756 is recommended. However, note that in many cases environments in ships where treatments would be applied are climate controlled and may not see a large variation in temperature.

X2.2 Test Setup

X2.2.1 Tests will be performed separately for the treated and non-treated bulkheads.

X2.2.2 The bulkhead shall be suspended from a crane or other structure so that it is hanging above the floor, and is not in contact with any other structure except that which is being used to suspend it.

X2.2.3 For practical reasons, the bulkhead shall be suspended using a chain and/or hook assembly, attached at one to two points. A 'soft' mounting will in nearly all cases be impractical due to the weight of the test structure.

X2.3 Test Procedure

X2.3.1 The test structure shall be tested using either a modal impact hammer or a vibration exciter to excite the structure. Accelerometers shall be used to measure the resulting vibration. The requirements for the vibration exciter and accelerometer are provided in Sections 7 and 9. If an impact hammer is used, similar requirements apply.

X2.3.2 The hammer or vibration exciter shall be used to excite the test structure, either via transient signal, steady state single frequency signals, broadband noise, or other means. Locations for excitation and vibration measurement may be varied as needed to obtain clear, repeatable results. Such locations should be maintained for both treated and non-treated structures.

X2.3.3 Natural frequencies and damping loss factors of the test structure shall be determined using any valid modal testing approach. The 'half-power' method, described in Test Method E756, may be used here if modes are well spaced; however, given the larger modal density of plates relative to beams, other methods such as modal curve fitting (**4**), Nyquist Plots (**5**), dynamic stiffness methods (**6**), or the Power Injection Method (**7**) may produce better results. Commercially available modal testing packages exist which use these and other methods to determine natural frequencies and damping loss factors.

X2.3.4 Note that the type of signal used and processing of excitation and response signals may be different for different modal test methods. Appropriate processing methods shall be used for the selected approach.

X2.3.5 The results of this testing will be loss factor values at specific frequencies for both the treated and non-treated structures.

X2.4 Calculation

X2.4.1 The change in loss factor due to the applied treatment is the difference in the loss factor between the treated and non-treated test structures. However, the presence of a given treatment may change the natural frequencies of the system, potentially complicating analysis.

X2.4.2 A least squares curve fit shall be applied to the damping loss versus frequency data for the treated and non-treated structures.

X2.4.3 The change in damping loss shall be computed using the equation

$$\Delta\eta = \eta_{treated} - \eta_{non-treated} \tag{X2.1}$$

where:

η = the damping loss factor. This will be a function of frequency.

X2.4.4 The analysis shall be performed using 'narrrow-bands' (that is, 1 Hz frequency bandwidth) rather than one-third-octave bands. This is necessary due to the discrete frequency nature of the modal analysis. Additional information can be found in Test Method E756.

X3. ADDITIONAL INFORMATION ON NON-ACOUSTIC REQUIREMENTS FOR MATERIALS

X3.1 Overview

X3.1.1 Per SOLAS consolidated edition 2009, Chapter II-2, Regulation 5 Paragraph 3.1.1, Insulation material requirements: "Insulation materials shall be non-combustible materials." This includes fire, thermal, and acoustic treatments. The interior surface finish, if applied to the insulation, shall be an approved interior finish material which has low-flame spread characteristics. The interior finish cannot be installed as an integral layer within the insulation system. Non-combustible materials are approved under USCG EU Approval series 164.109 and interior finishes are approval series 164.112. In general, all insulation installed on any SOLAS ship must meet the above requirements.

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