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## LABORATORY TEST REQUIREMENTS FOR MARINE SHOCK ISOLATION SEATS

by

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A	6/22/2018	Introduction section on testing rationale and scope of testing was shortened. Allowable envelopes for recorded acceleration data were simplified. Appendix B was updated with text identifying the relationship between the SRS mitigation ratio and the Dynamic Response Index. Sample plots in Appendix F were updated with the new allowable envelopes. Revised Table 4.

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**SYMBOLS, ABBREVIATIONS, AND ACRONYMS**

A/D.....	analog-to-digital
ASCII.....	American Standard Code for Information Interchange
ATD.....	Anthropomorphic test device
dB.....	decibel
dc.....	direct current
ft.....	feet
g.....	acceleration due to gravity
HSC.....	high speed craft
Hz.....	Hertz (cycles per second)
kg.....	kilogram
m.....	meters
MEMS.....	micro electro-mechanical systems
MR.....	mitigation ratio
msec or ms.....	millisecond
mV.....	millivolt
s/s.....	samples per second
sec.....	second
SDOF.....	single degree-of-freedom
SRS.....	shock response spectrum
SRS <sub>S</sub> .....	shock response spectrum of seat cushion acceleration
SRS <sub>B</sub> .....	shock response spectrum of seat base input acceleration
x, y, z.....	coordinate axes

## **ADMINISTRATIVE INFORMATION**

This report was prepared by the Combatant Craft Division (Code 83) of the Naval Architecture and Engineering Department at the Naval Surface Warfare Center, Carderock Division (NSWCCD) with funding provided by Naval Sea Systems Command (NAVSEA), Program Executive Office Ships, Support Ships, Boats, and Craft Program Office (PMS 325G).

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## **SUMMARY**

This report provides preliminary guidance for laboratory testing of marine shock isolation seats. The purpose of the test is to demonstrate the effectiveness of a passive seat in reducing simulated wave impact loads in a laboratory before installation in a high-speed planing craft. It includes testing procedures, instrumentation system guidance, data processing requirements, test criteria, and test report contents. This guide presents a collection of best practices, preferences, and expectations that will be updated as new criteria or techniques are developed.

## **INTRODUCTION**

### **Background**

Passive shock isolation seats installed in high-speed craft typically use coil springs and dampers (i.e., shock absorbers) or leaf-spring assemblies to reduce the shock forces experienced during severe wave impacts. When the severity of the shock force transmitted through the seat assembly is less than the severity of the impact force at the base of the seat it is referred to as mechanical shock attenuation, or shock mitigation. The word mechanical refers to the excitation of the mechanical spring-damper assembly. Rough water seakeeping trials have shown that improperly designed seats can amplify shock inputs much like an improperly tuned vibration isolator will resonate and amplify input motions. There is therefore a need to demonstrate before installation in a craft that mechanical shock amplification does not occur and that simulated wave impact forces are reduced by the passive spring-damper assembly.

The most severe shock force caused by wave impacts in high-speed craft is always in the vertical direction. Forces in other directions and craft rotations are also important, especially when evaluating human comfort or the potential for adverse health effects. As more data becomes available, and test requirements are refined, forces in the other directions can be included. In the interim, mechanical shock attenuation in the vertical direction remains the focus.

Successful completion of seat laboratory testing and demonstration of shock mitigation is the first step before integration into a craft design. There are many other seat design attributes related to form, fit, function, comfort, and safety that must be considered to determine which seat design is most appropriate for different high-speed craft applications.

### **Scope**

This guide is applicable to testing shock isolation seats to be installed in high-speed planing craft with nominal lengths of 7-meter (22.9 feet) to 30-meter (98.4 feet). The test procedures are intended only for passive seats with no active sensors or mechanisms for real-time adaptation to the dynamic environment.

The impact test severities presented herein are representative of a broad range of wave impact severities observed in different craft with different mission profiles. While it is possible

that higher impact severities might be observed in future trials, there is no intent to test to all possible at-sea scenarios.

The standardized test requirements presented herein do not address the potential for adverse health effects (e.g., extreme discomfort or injury potential). They are merely a simple first step to reduce the risk of installing seats that amplify.

## Normative References

The following references, in whole or in part, provide supplemental information deemed important for successful implementation of the test procedures and performance metrics presented in this guide. Additional relevant information is provided in the list of references.

ISO 18431-4 (2006E): *Mechanical vibration and shock – Signal Processing – Part 4: Shock-response spectrum analysis*, International Organization for Standardization, Geneva, Switzerland, 2006.

ANSI/ASA S2.62-2009: *Shock Test Requirements for Equipment in a Rugged Shock Environment*, American National Standards Institute and Acoustical Society of America, Melville, N.Y., 2009.

*Testing and Evaluation of Life-Saving Appliances*, Maritime Safety Committee Resolution MSC.81(70), Life-Saving Appliances, 2003 Edition, International Maritime Organization, 2003.

## Terms and Definitions

**Acceleration due to gravity.** 9.80665 m/sec<sup>2</sup>, 32.174 ft/sec<sup>2</sup>

**Peak acceleration.** The peak acceleration is the largest instantaneous acceleration (i.e., rate-of-change of velocity) of recorded motions during a transient event.

**Response mode decomposition.** The mathematical separation of a recorded transient response into its different relevant modes of response is called response mode decomposition. The relevant modes of response typically recorded in small craft acceleration data and laboratory test data are rigid body modes and structural vibration modes.

**Payload.** The payload is the additional weight of an inert mass added to the seat assembly to simulate the weight of a seat occupant (with or without carried equipment).

**Rigid body motion.** In this guide rigid body motion is vertical motion recorded on the test platform at the base of a seat, on the seat pan, and on the seat cushion. Low-pass filtering of acceleration data is a response mode decomposition process used to estimate rigid body acceleration. The impulsive load of a wave impact can be quantified by the amplitude and duration of the rigid body acceleration at the base of a seat. The vertical rigid body acceleration recorded during a laboratory test at the base of a seat is a simulation of the heave acceleration experienced in a craft during the impact phase.

**Seat base.** The seat base is the point or points of attachment between the seat assembly and the test platform assembly. In a laboratory test it is the simulated deck of a craft.

**Seat cushion.** The layer or layers of padding material added to an otherwise hard seat assembly for support, comfort and style. The cushion is sometimes referred to as the seat pad.

**Seat pan.** The seat pan is the hard structure above the spring-damper assembly that supports the seat cushion.

**Shock.** The term shock is used to imply mechanical shock, as opposed to electrical shock or chemical shock. Mechanical shock is a transient excitation of a physical system that is characterized by suddenness and severity. The rigid body acceleration pulse recorded during a severe wave slam or laboratory test is referred to as a shock pulse.

**Test platform.** The test platform is the rigid structural assembly to which the test seat is attached.

## TEST DESCRIPTION

### Test Seat

The test seat should be a production-line seat or one that suitably represents seats installed in operating craft. A description of the test seat should be provided that includes physical characteristics such as dimensions, key subassembly parts (e.g., arm rests or foot-rests), cushions and padding, weights, etc., and normal operational characteristics such as adjustment options. The test seat should be attached to the test platform as it would be attached to the deck of a craft. Seats with manual adjustments for occupant weight, or shock absorber damping should be tested in adjustment settings as if an occupant of the specified payload weight were sitting in the seat.

### Payload

The seat payload should be an inert mass secured to the seat cushion using ratchet-type straps to simulate the mass of a human occupant securely fastened with seat belts and/or harness straps. The straps should be positioned to place the center of the payload mass as close as possible to the vertical axis of the motion of the spring-damper assembly. For production-line seats without seat belts or harnesses, the inert mass should be secured by straps that allow approximately 2.5 centimeters (1 inch) of free vertical movement while keeping the center of mass approximately aligned. Straps in horizontal and vertical orientations should be used to prevent the payload from significant rotation or coming adrift during or after each test. Inert masses may include anthropomorphic test devices (ATD) or molded forms to simulate the human buttocks shape if specified. Otherwise, ballast bags or ballast weights may be used as payload.

*Tip: If ballast bags filled with sand are employed it is recommended that several individual tightly-packed bags (e.g., 11.5 kg bags) be placed inside a larger ballast bag (i.e., material made from laminated or coated fabric) with the ballast bag secured to the seat.*

At least three different payload weights should be tested that correspond to the 95<sup>th</sup>, 50<sup>th</sup>, and 5<sup>th</sup> percentile weights of the intended male user population. Seats designated for craft intended for male and female populations should be tested with 95<sup>th</sup> and 50<sup>th</sup> percentile male

population payload weights, and a third weight equal to the 5<sup>th</sup> percentile female population weight.

*Tip: Testing three different payload weights is important. There is currently insufficient evidence for different types of seats to suggest that full protection for the upper, mean, and lower range of occupant weights can be verified by one or two test payloads. As more evidence becomes available it may be reasonable to reduce the number of payload weights to be tested.*

The payload weight may include the additional weight of occupant carried equipment if specified. Payload descriptions, weights, and securing mechanisms should be reported. Appendix A provides guidance for payload weights in the absence of payload specifications. Figure 1 shows example tests of shock isolation seats that used steel plates as payload weight (right side photograph) and an ATD (left side photograph) [1]<sup>1</sup>.

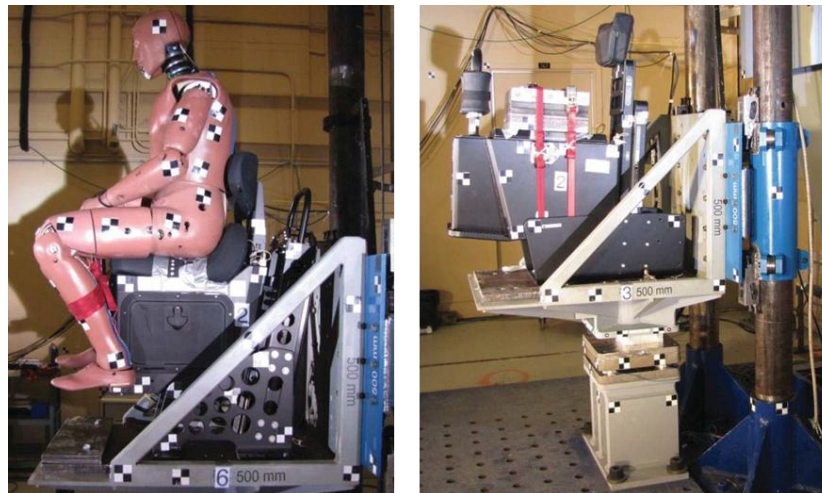


Figure 1. Anthropomorphic test device (ATD) and steel plate payload weights <sup>2</sup>.

*Tip: The use of ATDs as seat payload is desirable, but testing three with different weights may be cost prohibitive. The current preference is to assess seat performance over a range of weights. If one or two ATDs are available ballast weight may be added to the ATD to achieve the desired range of weights, otherwise ballast bags or ballast plates may be used.*

<sup>1</sup> Numbers in brackets are references listed at the end of this guide

<sup>2</sup> Photograph provided courtesy of Defense Research and Development Canada Atlantic

## Protection and Operability Requirements

Protection and operability requirements determine if the test seat meets the specified severity threshold after each test. Both the protection and failure criteria should be specified, including requirements for pre- and post-test operational assessment. The failure criteria should include those listed below.

### *Operability Requirements.*

Following each test the seat should maintain all operational movement and adjustment capabilities, including unimpeded vertical motion of spring-damper assemblies or leaf-springs without binding or stoppage, proper operation of manual adjustments including foot-rest adjustments, or other operational features.

### *Protection Requirements.*

The seat mitigation ratio (MR) is the measure of seat performance. It is the severity of the seat response motion divided by the severity of the base input motion, as given by equation (1).

$$\text{Mitigation Ratio (MR)} = \frac{\text{Seat Response Severity}}{\text{Base Input Severity}} \quad \text{Equation (1)}$$

Mitigation is achieved when the MR value is less than one. A ratio equal to one indicates no mitigation was achieved, and a value greater than one indicates the mechanism amplified the deck input severity. Appendix B presents the method for computing the seat response severity and base input severity to be used in equation (1). Acceleration data processing guidance is provided later in the report.

### *Failure Criteria*

Seat failure criteria should include the following:

- a. Seat structural damage
- b. Components adrift that could be a safety hazard to personnel
- c. Seat operability malfunction
- d.  $MR \geq 1.0$  See equation (1).

## Test Method

### *Drop Test Method*

The seat and payload should be installed on a rigid platform that is dropped from a height to achieve the desired impact severity. Figure 1 showed an example laboratory drop test fixture. The impact surface must be able to deflect or deform to produce the desired impact pulse shape, amplitude, and duration. The duration of the pulse must be relatively long to simulate the unique character of wave impacts. Figure 2 presents another drop test method for simulating the long duration pulse of a wave impact. A rigid wedge attached to the bottom of the platform impacts the sand. The wedge acts as a pulse shaper that can achieve the desired pulse shape, duration and peak acceleration [2]. Appendix C describes the wedge fixture.



Figure 2. Wedge drop test for simulating wave impact pulse<sup>3</sup>

### ***Alternative Methods***

Test methods other than a drop test method may be employed to test passive seats if the method achieves the required test severity thresholds presented later in this report.

### ***Coordinate Axes***

Vertical motion upward is in the positive z direction. The orthogonal x and y directions define the plane of the horizontal test platform and the plane of the seat pan with positive x pointed in the direction of sight by a hypothetical seat occupant. Figure 3 shows example x, y, and z coordinates for a generic shock isolation seat assembly. Location 1 denotes motion below the spring-damper assembly at the base of the seat. Location 2 denotes motion above the spring-damper assembly on the seat pan, and Location 3 denotes motion on the seat cushion.

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<sup>3</sup> United Kingdom Crown copyright photograph with permission

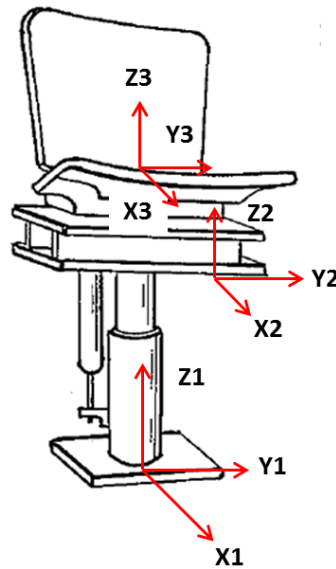


Figure 3. Seat motion coordinates

### ***Angled Drop Test***

Testing seats with an angle insert is optional unless otherwise specified. Wave impact loads in the transverse x and y directions also occur during operations in rough seas depending upon craft pitch, roll, craft heading, speed, and the location of hull impact on a wave (e.g., leading flank, wave crest, or following flank). This can be simulated by using an angle insert between the test platform and the base of the seat [3]. If specified, impact angles with the axis of the seat rotated aft (i.e., minus x direction) 10 degrees and 20 degrees should be tested.

## **INSTRUMENTATION**

### **General Requirements.**

#### ***Data Utilization***

Instrumentation is required for all seat tests prescribed by this guide. Motion at the base of the seat is measured at a rigid location on the test platform to verify that the required impact severity threshold has been achieved. Motion of the seat above the spring-damper assembly is measured and compared to the motion of the seat base to assess the effectiveness of the seat assembly in reducing the impact severity.

#### ***Bandwidth***

The presumption that motions data has been acquired properly cannot be overstated, because improperly collected data will result in meaningless analysis results. Attention must be

paid to sensor mounting, powering, and signal conditioning [4 – 8]. Appropriate anti-aliasing filtering must also be applied as part of the analog-to-digital (A/D) conversion process. Digital data acquisition requires the signal to be band limited to preclude aliased frequency components in the data signal. Sufficient information for evaluating seat mitigation effectiveness can be achieved with a data bandwidth of dc to 100 Hz.

### **Measurement Parameter**

Acceleration is the variable for measurement that defines the severity of the shock input motion at the base of the seat. Acceleration is also the variable for measuring the severity of the response motion measured on the seat above the spring-damper assembly.

Tip: Measuring the relative displacement across the spring-damper assembly is optional but can be helpful for evaluating excursion space limits during higher severity impacts.

### **Data Acquisition System**

#### ***Analog-to-Digital Conversion***

Modern digital data acquisition and measurement systems are self-contained (i.e., they do not need an external computer), relatively inexpensive, highly reliable, and available from a number of sources. Nearly all equipment has a minimum of 16-bit A/D conversion with consequent signal resolution of 65,536 parts (98 dB signal/noise), and many manufacturers offer 24-bit A/D systems. For laboratory drop tests of seats, a data acquisition system should have a minimum of 16-bit A/D, and provisions for assuring alias signal rejection through fixed low-pass hardware pre-filters, oversampling, or a combination of both. A resolution of better than 0.001 g is achievable for a 25-g accelerometer coupled with a 16-bit data acquisition system.

#### ***Sampling Rate***

The minimum sampling rate should be 512 samples per second (s/s).

Tip: Most data acquisition systems are capable of sample rates per channel in the range of 100,000 samples per second or greater. Sampling at 512 s/s or greater is easily achievable.

#### ***Anti-Alias Filter***

A pre-filter should be employed in the hardware prior to A/D conversion to prevent alias frequencies in the data. A 100-Hz low-pass filter with characteristics similar to a 4-pole Butterworth filter is suggested.

#### ***Data Storage***

Data may be stored in a binary form as a matter of efficiency, but it should be converted to a human-readable ASCII (American Standard Code for Information Interchange) format.

Tip: Data saved in ASCII format can be easily reviewed using text editor software like Microsoft<sup>®</sup>'s Notepad and Wordpad, or can be opened using spreadsheet software like Microsoft<sup>®</sup>'s Excel. Likewise, ASCII data can be analyzed using engineering software like DADiSP<sup>®</sup>, MATLAB<sup>®</sup>, or LabVIEW<sup>™</sup>, for example.

## Sensors

### *Accelerometers*

Piezoresistive, servo, or micro electro-mechanical systems (MEMS) type accelerometers should be used because they have dc response (i.e., the ability to operate over a frequency range beginning at zero Hz) that can measure -1g during the free-fall phase. They should have a minimum frequency response of dc to 1,000 Hz, a nominal full-scale range of  $\pm 25$  g, and a nominal sensitivity of 50 mV/g or greater.

Tip: Perhaps the most popular, economical, and widely available are MEMS accelerometers, with prices in the range of a few hundreds of dollars each.

Tip: Piezoelectric accelerometers should not be used because they have a lower frequency limit greater than zero Hz.

## Sensor Positioning

### *Vertical Acceleration*

At least two vertically oriented accelerometers should be recorded for drop test fixtures that employ two or more guide rails to maintain a level test platform during free fall. A vertical accelerometer (z1) should be placed on the test platform at the base of the seat at a rigid location as close as possible to the load path. The second vertical accelerometer (z3) should be placed on the seat cushion (i.e., the seat pad) between the cushion and the inert payload as close as possible to the vertical axis of seat motion.

*Tip: Seat pad accelerometers are commercially available from several manufacturers to measure response motions on the seat cushion.*

### *Horizontal Acceleration*

For drop test fixtures that do not have vertical guide rails, tri-axial accelerometers should be positioned on the test platform below the spring-damper assembly and on the seat cushion. The recorded horizontal accelerations (i.e., X1, Y1, X2, and Y2 in Figure 3) are used to ensure the test platform remains horizontal during the test.

***Pan Acceleration***

An optional vertical accelerometer may be installed at a rigid location on the seat pan as close as possible to the load path (i.e., beneath the seat above the spring damper assembly). A comparison of the pan acceleration and the cushion acceleration provides an assessment of the effects of the seat cushion material. Appendix D summarizes lessons learned related to seat cushion comfort and protection in a dynamic environment.

***Relative Displacement***

Optional sensors for measuring relative displacement across the spring-damper assembly include linear and string potentiometers, and electro-optical and laser rangefinders. The linear displacement sensor (if used) should have a nominal full-scale range of 24 inches, minimum accuracy of 2 percent, and a nominal repeatability of 0.1 percent.

**TEST SEVERITY THRESHOLD**

**Pulse Shape**

The test severity threshold defines the required shape, amplitude, and duration of the vertical acceleration applied to the base of the seat to be a valid test. The desired test pulse is a vertical rigid body acceleration curve with a half-sine shape.

**Pulse Amplitude and Duration**

The vertical peak acceleration defines the threshold pulse amplitude. Six peak acceleration thresholds are listed in Table 1. These severity levels simulate impacts for a broad range of operational profiles for different types of planing craft<sup>4</sup>.

Table 1. Test severity thresholds

Threshold Level	Peak Acceleration	Nominal Impact Duration
	g	seconds
6	10.00	0.10
5	8.00	0.10
4	6.00	0.10
3	5.00	0.10
2	4.00	0.10
1	3.00	0.10

The recorded half-sine pulse amplitude should fall within tolerances tabulated below. All craft do not require seats capable of effective performance at Level 6 severity. Appendix E

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<sup>4</sup> This information is contained in a limited distribution U.S. Navy report.

provides guidance for specifying drop test severity for different classes of craft based on generic operational profiles. The desired nominal pulse duration is 0.10 seconds. The pulse duration tolerances are listed below. A digital time history in ASCII format should be included in the impact test report to verify test results.

## Test Severity Tolerance

### *Vertical Acceleration Tolerance*

The recorded vertical acceleration at the base of the seat must fall within tolerance criteria of the threshold pulse to be a valid test. Table 2 lists the tolerances of the allowable envelope for the vertical acceleration recorded at the base of the seat, where (A) is the peak acceleration (low-pass filtered to 20 Hz using a Butterworth filter). These tolerances should be used for drop test methods and alternative test methods.

Table 2. Coordinates for vertical acceleration tolerance envelopes

<b>Upper Envelope</b>	
Time (t) in seconds	Acceleration (g)
-0.075	0
-0.02	1.2 A
0.02	1.2 A
0.06	0.6 A
0.5	0.15
0.6	0.15
<b>Lower Envelope</b>	
Time (t) in seconds	Acceleration (g)
$-0.09 (A + 2) / (2 A)$	-2
0	A
$0.09 (A + 2) / (2 A)$	-2

Figure 4 shows the tolerance envelopes from Table 2 constructed around the Level 4 acceleration threshold. The larger envelope tolerances from approximately 0.05 seconds to 0.3 seconds are intended to envelope the seat base movement that will occur due to spring-damper oscillations after the impact. Appendix F shows the tolerance envelopes for the six severity threshold levels.

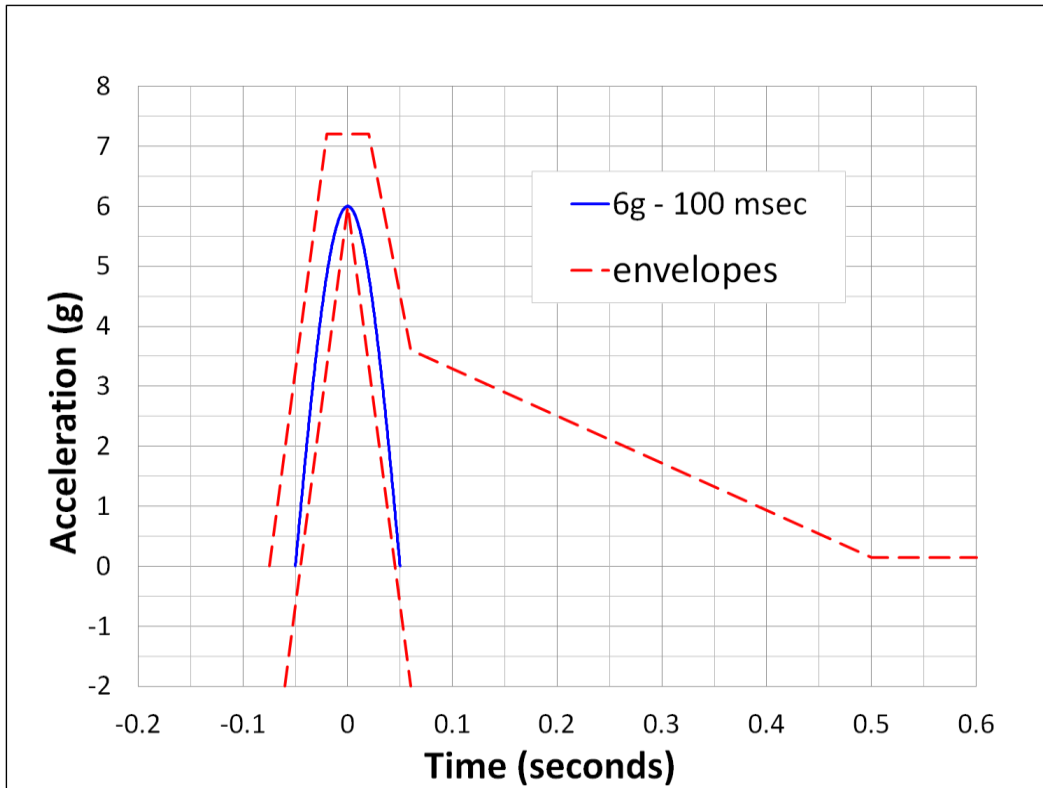


Figure 4. Example envelopes with level 4 threshold acceleration

#### ***Horizontal Acceleration Tolerances for Drop Tests***

Horizontal tolerances apply to drop test fixtures that do not employ guide rails. The purpose of horizontal measurements is to ensure that the test platform is relatively horizontal before and after impact [2]. The magnitudes of accelerations in the horizontal x and y directions should fit within the tolerance envelope listed in Table 3. Figure 5 shows an example plot of the horizontal acceleration envelopes.

Table 3. Coordinates for horizontal acceleration envelopes

Time (seconds)	Acceleration ( g )	
	Upper envelope	Lower envelope
-0.2	0.2	-0.2
-0.1	0.2	-0.2
-0.09	2	-2
0.49	2	-2
0.5	1	-1
1	0.2	-0.2
1.5	0.2	-0.2

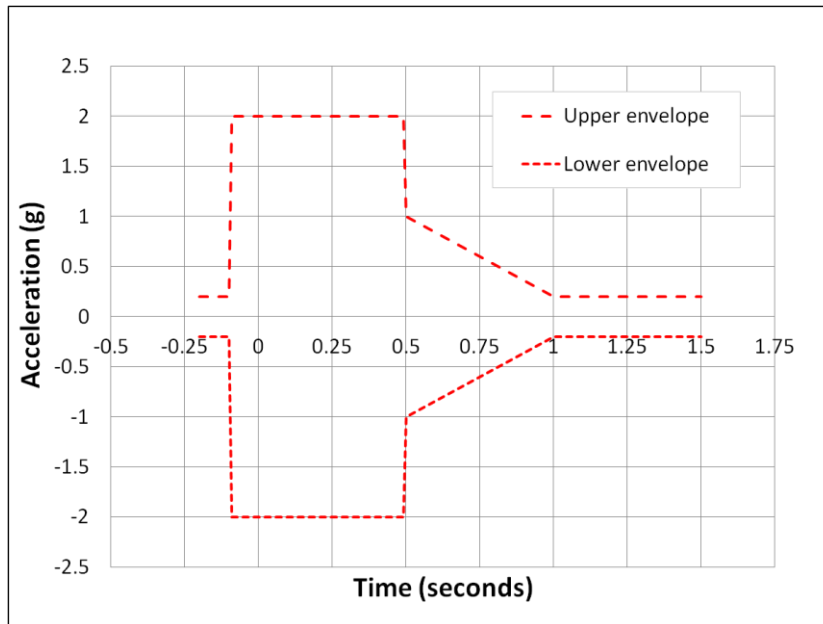


Figure 5. Horizontal acceleration envelopes

## TEST PROCEDURE

### Test Specification

This guide can be referenced by procurement documents if a test specification is also cited. The test specification should include the following: the maximum test severity threshold to be achieved during the sequence of tests (see Appendix E), the payload weights to be tested (nominally 2 or 3, see Appendix A), and the total number of tests to be performed (nominally three tests for each payload weight). If different from guidance presented herein, the test

specification should also include seat operational requirements, protection requirements or goals in terms of mitigation ratios, failure criteria, sensor locations, and test report content.

### **Test Sequence**

A test sequence is a series of drop tests for one payload weight. The test sequence for each payload weight should start with drop tests at Level 1 and proceed through the successive higher levels up to the most severe level specified. Each level of valid testing should be repeated three times. A valid test is achieved when the 20-Hz low-pass filtered acceleration curve for the seat base accelerometer falls within the tolerance envelopes.

### **Seat Configuration**

Seats with manual adjustments for changing stiffness or damping characteristics should be set or configured for the payload weight being tested. Manual adjustments should not be made during a sequence of tests.

### **Test Completion**

#### ***Maximum Threshold Achieved***

A test sequence for a given payload is completed when 3 valid tests have been conducted at all threshold levels up to the specified maximum threshold level.

#### ***Exceeding Failure Criteria***

The test sequence for a given payload is completed if a failure criterion is exceeded. The mitigation ratio criterion is exceeded when the computed MR is greater than or equal to 1.0 (see Appendix B). In some instances a mild bottom impact may result in a mitigation ratio less than 1.0. Testing after a mild bottom impact with MR less than 1.0 may be continued at the discretion of the test director to evaluate repeatability of the mild bottom impact or to evaluate seat performance at the next higher threshold level. Continued testing after a severe bottom impact is not recommended because the mitigation ratio will likely have exceeded 1.0.

#### ***All Payloads Tested***

A testing program is completed when all specified payload weights and severity thresholds have been tested.

## **DATA PROCESSING**

### **Vertical Zero Axis**

The zero axes for all recorded vertical acceleration data should be calibrated so that zero means at rest and -1 g corresponds to acceleration due to earth's gravity (i.e., free-fall).

### **Low-pass Filter**

All recorded acceleration data should be post-processed using a low-pass 4-pole Butterworth filter with a 20-Hz cut-off frequency [11, 12]. Time history plots of low-pass filtered

acceleration data recorded at the seat base (with tolerance envelopes) and on the seat cushion should be included in the test report. Other data plots may be provided as appropriate.

**Mitigation Ratio**

The mitigation ratio (MR) should be computed using the 20-Hz low-pass filtered acceleration data for each drop test. Appendix B summarizes how shock response spectra (SRS) are used to compute the ratio. The use of shock response spectra (SRS) is documented in ISO 18431-4: 2006E Mechanical vibration and shock – Signal Processing – Part 4. All results should be tabulated as shown in Table 4.

Table 4. Example test results: severity threshold level 4<sup>5</sup>

184 Pound Payload Weight				
Drop test Number	Severity Threshold Level	Seat Base Peak Acceleration (g)	MR Value	Average MR Value
1	1	3.5	0.75	0.73
2	1	3.6	0.73	
3	1	3.4	0.71	
4	2	4.4	0.68	0.66
5	2	4.4	0.66	
6	2	4.5	0.64	
7	3	5.2	0.65	0.65
8	3	5.3	0.65	
9	3	5.1	0.66	
10	4	6.5	0.59	0.58
11	4	6.4	0.57	
12	4	6.5	0.58	
Overall Average MR Value				0.66

**TEST REPORT**

**General Requirement**

Unless otherwise specified, the test report should present text, photographs, sketches, acceleration data plots, and data tables that summarize test conduct and results.

**Report Contents**

The report should include, but not be limited to the following:

- a. Seat manufacturer, model, description, manual adjustment positions (as tested if present)

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<sup>5</sup> Not actual drop test data

- b. Test date, test laboratory
- c. Maximum threshold severity level
- d. Payload weight(s), description, tie-down method
- e. Description of the data acquisition system and sensors
- f. Description and photograph of seat/payload assembly on drop test fixture
- g. Description of test execution sequence
- h. Tabulated MR test results for all tests
- i. Certification statement

## **Test Certification**

### ***Certification Statement***

The following certification statement should be included in the test report. “I certify that these tests were conducted on a production line seat in accordance with NSWCCD-80-TR-2015/010, and that the test data presented are from actual tests.

### ***Certification Signature***

The certification statement should be followed by the printed name, signature, and the signature date.

## REFERENCES

1. Gannon, Dr. Liam, *Single Impact Testing of Suspension Seats for High-Speed Craft*, Ocean Engineering Journal 141, pp. 116 – 124, 2017.
2. *Maritime Whole Body Vibration, Shock Mitigating Seat Test Protocol 1*, PQQ Reference JK6KHJ8427, Ministry of Defense, Defense Equipment and Support Organization, United Kingdom, 1 August 2014.
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12. Riley, Michael R., Coats, Dr. Timothy W., *Quantifying Mitigation Characteristics of Shock Isolation Seats in a Wave Impact Environment*, Naval Surface Warfare Center Carderock Division Report NSWCCD-TR-80-2015/001, January 2015.

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## APPENDIX A. PAYLOAD WEIGHT GUIDANCE

Reference A1 provides a variety of anthropometric measurements for service members. Since its publication a recent study by the U.S. Army Readiness Command reported a weight increase in the general male population between 1988 and 2007. Table A1 provides a list of updated estimates of 5<sup>th</sup>, 50<sup>th</sup>, and 95<sup>th</sup> percentile male and female weights based on the U.S. Army findings. These payload weights may be used unless weights for specific populations are specified.

Added weight of foul weather clothing or equipment worn by seat occupants should be added to Table A1 weights if specified.

Table A1. Interim Payload Weight Guidance

Population Percentile	Male		Female	
	lbs	kg	lbs	kg
95 th	248.6	112.8	195.3	88.6
50 th	184.0	83.5	145.2	65.9
5 th	135.8	61.6	109.3	49.6

### Appendix A Reference

A1. DOD HDBK 743A, *Military Handbook Anthropometry of U.S. Military Personnel*, U.S. Department of Defense, 13 February 1991.

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## APPENDIX B. SHOCK SEVERITY

The shock response spectrum (SRS) is a computational tool used internationally to compare the severity of different shock motions [B1 to B10]. It is also referred to as a maximum response spectrum that can be used to analyze any dynamic event. It is especially useful for evaluating and comparing two different shock pulses (i.e., at the deck and on the seat cushion) that have different pulse shapes, peak amplitude, jerk, and pulse duration. It is used as a measure of shock isolation seat mitigation performance by comparing the deck input acceleration SRS with the seat pad response acceleration SRS for individual wave impacts.

The SRS uses a model of the single-degree-of-freedom (SDOF) system shown in Figure B1 to compute the effects of an input motion  $X(t)$  on the SDOF system. The system has a base attached to a mass ( $m$ ) by a spring with stiffness  $k$  and a damper with damping coefficient  $c$ . For a prescribed time varying shock input motion  $X(t)$  at the base of the system the resulting response of the mass ( $m$ ) is  $Y(t)$ . The relative displacement  $Z(t)$  between the base and the mass is  $X(t)$  minus  $Y(t)$ . The equation of motion of the system given by equation B1 is obtained by summing the inertial force of the mass and the forces within the spring and damper.

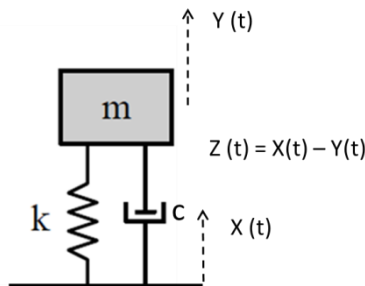


Figure B1. Single-degree-of-freedom Mathematical Model

$$m \ddot{y}(t) = -k z(t) - c \dot{z}(t) \quad (\text{B1})$$

Where  $t$  is time and:

$$\omega = \sqrt{\frac{k}{m}} \quad (\text{B2})$$

The undamped natural frequency ( $f$ ) in Hertz (Hz) of the SDOF system is given by equation B3.

$$f = \frac{\omega}{2\pi} = \left(\frac{1}{2\pi}\right)\sqrt{\frac{k}{m}} \text{ Hz} \quad (\text{B3})$$

The solution of equation B1 provides the predicted response motion of the mass (m) caused by the base input motion either in terms of the absolute motion of the mass  $Y(t)$  or the relative displacement  $Z(t)$  between the base and the mass.

An SRS is the maximum response of a set of single-degree-of-freedom (SDOF), spring-mass-damper oscillators to an input motion. The input motion is applied to the base of all oscillators, and the calculated maximum response of each oscillator versus the natural frequency make up the spectrum [B7].

The relative displacement SRS is often used as a parameter to compare shock severity when two input shock motions are being compared. It is an intuitive engineering measure of severity because the relative displacement is proportional to the strain in the spring in Figure B1. The shock pulse that causes the larger strain, and therefore the largest damage potential, is judged to be the more severe of the two shock pulses. Figure B2 shows three vertical acceleration time histories recorded at different locations on a craft. The plot on the right is the computed maximum relative displacement SRS (DSRS) for each acceleration shock pulse. Visual inspection of the time histories on the left indicate that the red bow shock pulse is the most severe because of its higher amplitude. The DSRS curves on the right quantify the differences in severity. The key feature of the SRS approach is that it quantifies shock severity based on its effect on SDOF oscillators with varying natural frequencies. It characterizes the shock severity in the response domain, so that the effects of shock pulse shape, peak amplitude, jerk, and pulse duration can be taken into account for systems across a broad range of natural frequencies.

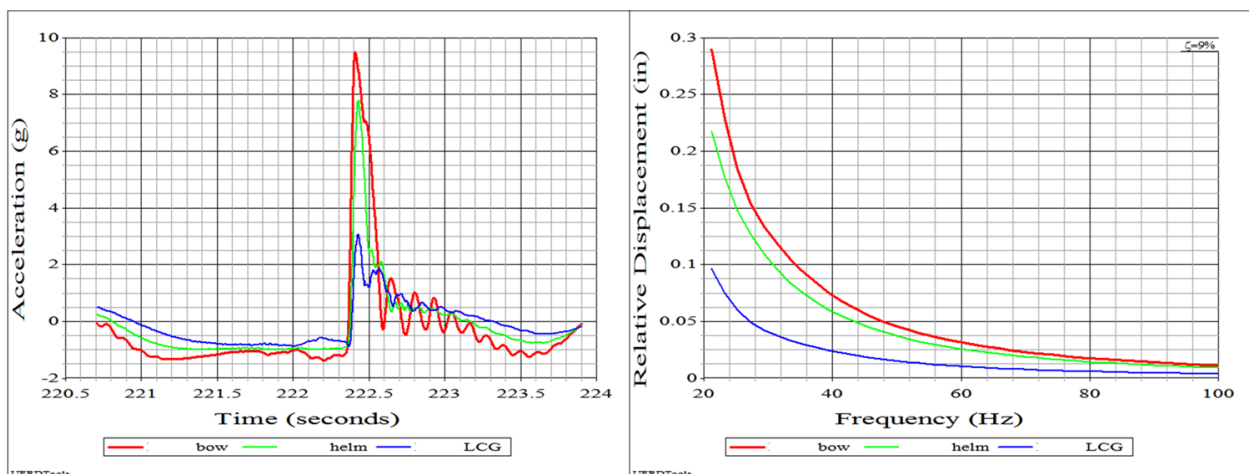


Figure B2. Three Wave Slam Shocks and Relative Displacement SRS

### Mitigation Ratio Using SRS

The universal approach to quantifying shock transmissibility is by dividing the severity of the shock response pulse above the mounts by the severity of the base input shock pulse [B1]. In

this appendix the term shock mitigation ratio is the same as shock transmissibility. Many engineering texts define the mitigation ratio (or transmissibility) as the ratio of the peak response acceleration above the mounts divided by the peak acceleration of the shock input. This is appropriate for short duration pulses (i.e., < 10 milliseconds) or as long as the shock input pulse and the shock response pulse above the mounts have similar shape and pulse duration. For long duration pulses and when pulse shapes, jerk values, and pulse durations are not similar the preferred method of quantifying shock mitigation is to use the shock response spectra ratio given by equation B4. This is because the SRS ratio inherently accounts for differences in the important shock parameters, including pulse shape, peak amplitude, pulse duration, and jerk.

$$\text{Mitigation Ratio} = \frac{\text{SRS}_{\text{Response}}}{\text{SRS}_{\text{Input}}} \quad (\text{B4})$$

If the ratio is greater than 1.0, the shock pulse for the response is more severe than the shock pulse for the base input. This called dynamic amplification. If the ratio is less than 1.0, the shock pulse for the response is less severe than the shock pulse for the base input. As an example, Figure B4 shows relative displacement SRS (DSRS) for two hypothetical half-sine pulses, 7 g – 100 msec base input acceleration and 5 g – 210 msec above-mount response acceleration. The question is how much less severe or more severe is the above-mount response pulse compared to the base input pulse?

Figure B5 was constructed to answer this question by dividing the DSRS for the 5 g – 210 msec pulse by the DSRS for the 7 g – 100 msec pulse. A damping ratio of 22 percent was assumed for the calculations. It shows that over a broad frequency range the 5 g – 210 msec shock pulse is less severe than the 7 g – 100 msec pulse (i.e., the ratio is less than 1.0). For natural frequencies from approximately 45 Hz to 500 Hz the mitigation ratio is approximately 0.71 (i.e., the 5-g pulse is 29 percent less severe than the 7-g pulse). Between 4 Hz and 30 Hz the mitigation ratio varies from 0.55 to 0.7 (i.e., 30 percent to 45 percent less severe).

The mitigation ratio based on relative displacement shock response spectra (DSRS) is a convenient relative measure of shock input severity because (1) it takes into account the effects of acceleration magnitude, pulse duration, and the rate of acceleration application (i.e., jerk), and (2) because of its relationship to compressive strain or stress in the SDOF mathematical model [B11]. The concept of stress as a measure of shock severity is not new. The early NASA studies concluded that magnitude (i.e., peak acceleration) alone does not define shock severity, nor does acceleration cause damage in a system. Stress (or strain, i.e., relative displacement), a result of acceleration, causes damage [B12].

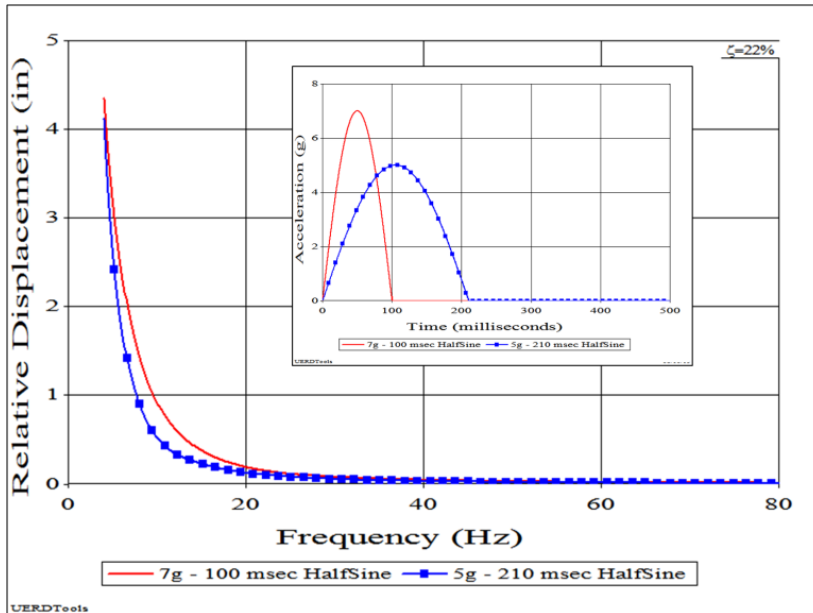


Figure B4. Comparison of Hypothetical DSRS

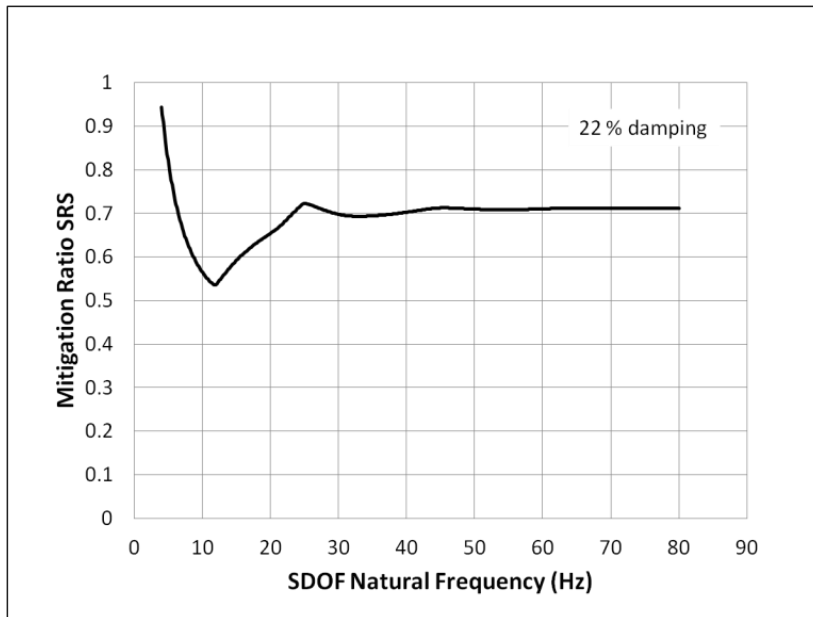


Figure B5. Mitigation Ratio for 5 g and 7 g Half-sine Pulses

### SRS Frequency of Interest

Numerous studies of the effects of a vertical shock load on a seated human have used an analogous, lumped-mass model of the human body consisting of a mass, a spring, and a damper. The lumped-mass model (i.e., single-degree-of-freedom model) was first studied in 1957 [B13] and applied in 1969 [B14] to describe the impact of jet aircraft ejection seats to the human body.

It was reported to be a simple model that was well validated for the risk of spinal injury based on ejection seat data and able to account for shock pulse duration dependency [B15]. The model, called the Dynamic Response Index (DRI) computes the maximum relative displacement of the lumped mass model assuming a natural frequency of 8.4 Hz and 22.4% damping ratio. The maximum relative displacement is determined by solving equation B1. Since it is a single degree of freedom model as shown in Figure B1 it is identical to an SRS calculation for specific frequency and damping values (i.e., 8.4 Hz and 22.4% damping). These values represent the natural frequency and damping ratio to be used for SRS mitigation ratio calculations.

Initial calculations of the SRS mitigation ratio for marine seats in high-speed craft used a natural frequency of 8 Hz and a 9-percent damping ratio. The 9-percent value was selected because it provided a broader range of ratio values over which to evaluate seat mitigation performance [B9, B10]. The 22.4 percent damping ratio was subsequently adopted to be consistent with reference B16. For single shocks the SRS mitigation ratio computed using 8.4 Hz and 22.4 percent critical damping is equivalent to the ratio of the Dynamic Response Index (DRI) for the seat cushion response acceleration divided by the DRI for the deck acceleration input.

Table 1 lists numerous applications where the DRI has been used in testing standards and investigations of the effects of different types of single shock pulses on seated humans. It is specified by the International Maritime Organization as the criterion for evaluating seat occupant safety during ship lifeboat drop tests [B16]. It is specified by the North Atlantic Treaty Organization (NATO) as the criterion for evaluating the risk of spinal injury to seat occupants in armored vehicles [B17, B18]. It has been used as a shock isolation seat design criterion for individual severe wave impacts in a high speed craft [B19], and it has been used to quantify the severity of different individual wave impacts recorded during high-speed craft tests [B20].

The DRI is the only metric currently available that is applicable to single impacts on seated humans able to quantify the severity of different shock pulses that have different shapes, different peak amplitudes, different jerk values, and different pulse durations. As a relative measure of impact severity (i.e., especially when used in a mathematical ratio) the SRS mitigation ratio provides a consistent mathematical tool for determining the severity of a seat cushion acceleration pulse compared to the deck input acceleration pulse. For this application the DRI ratio (i.e., the SRS mitigation ratio) is not a measure of the potential for adverse health effects. It is a measure solely of mechanical shock attenuation.

Table B1. Use of DRI Load Criterion for Single Shocks

Document Type	Seat Occupant Application	Document Title	Organization	Reference
Test Standards and Criteria	Ship lifeboat freefall water impact	Testing and Evaluation of Life Saving Appliances, Lifeboat Drop Tests	International Maritime Organization (IMO)	IMO-MSC.81(70), 2003
	Land vehicle mine effects	Procedure for Evaluating the Protection Level of Armored Vehicles	North Atlantic Treaty Organization (NATO)	NATO-AEP-55, Volume 2 (Edition 2), 2011
	Land vehicle mine effects	Test Methodology for Protection of Vehicular Occupants Against Anti-Vehicular Landmine Effects	North Atlantic Treaty Organization (NATO) Human Factors and Medicine Panel	NATO-RTO-TR-HFM-090, 2007
Engineering Handbook / Guide	Fixed and rotary wing aircraft crash protection	Crew Systems Crash Protection Handbook	US Department of Defense	JSSG-2010-7
	General vertical shock load applications	Effects of Shock and Vibration on Humans, Chapter 41	McGraw-Hill publication	Harris' Shock and Vibration Handbook, 2010
Technical reports and papers	Seated anthropomorphic test device shock load response comparison	Comparative Analysis of THOR-NT-ATD and Hybrid-III ATD in Laboratory Vertical Shock Testing	US Army	ARL-TR-6648, 2013
	Aircraft ejection seat cushion study	Seat Interfaces for Aircrew Performance and Safety	US Air Force	AFRL-RH-WP-TR-2010-0083, 2010
	High speed craft shock isolated seat design study	Analysis, Optimization, and Development of a Specialized Passive Shock Isolation System for High Speed Planing Boats	Taylor Devices, Inc, and Tayco Developments, Inc.	A. Klembezyk, M. Mosher, 2003
	High speed craft shock isolated seat single impact injury parameter	The Modeling and Measurement of Humans in High Speed Planing Boats Under Repeated Vertical Impacts	University of Virginia and US Navy	C. Bass, R. Salzar, A. Ziemba, S. Lucas, R. Peterson, 2005

## Appendix B References

- B1. Harris, Cecil M., editor-in-chief, *Shock and Vibration Handbook, Fourth Edition*, McGraw-Hill Companies, Inc., New York, New York, 1995.
- B2. ANSI/ASA S2.62-2009, *Shock Test Requirements for Equipment in a Rugged Shock Environment*, American National Standards Institute and Acoustical Society of America, Melville, N.Y., 2009.
- B3. Department of Defense Test Method Standard, *Environmental Engineering Considerations and Laboratory Tests*, Military Standard, MIL-S-810G, change 1, Method 516.7, Shock, 15 April 2014.
- B4. STANAG 4559, *Testing of Surface Ship Equipment on Shock Testing Machines*, NATO Standardized Agreement, 13 May 2008.
- B5. Alexander, J. Edward, *The Shock Response Spectrum – A Primer*, Society of Experimental Mechanics Inc., Proceedings of the IMAC XXVII, Orlando, Florida, USA, 9 – 12 February 2009.

- B6. Gaberson, Howard A., *Shock Severity Estimation*, Sound and Vibration Magazine, Volume 46 Number 1, January 2012.
- B7. ISO-18431-4: 2007, *Mechanical vibration and shock – Signal processing – Part 4: Shock response spectrum analysis*, International Organization for Standardization, Geneva, Switzerland, 2007.
- B8. Riley, Michael R., Coats, Timothy W., “The Simulation of Wave Slam Impulses to Evaluate Shock Mitigation Seats for High-Speed Planing Craft”, Naval Surface Warfare Center Carderock Division Report NSWCCD-23-TM-2013/26, May 2013.
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- B10. Riley, Michael R., Coats, Timothy W., *Quantifying Mitigation Characteristics of Shock Isolation Seats in a Wave Impact Environment*, Naval Surface Warfare Center Carderock Division Report NSWCCD-80-TR-2015/001, January 2015.
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- B18. *Test Methodology for Protection of Vehicular Occupants against Anti-Vehicular Landmine Effects*, North Atlantic Treaty Organization Research and Technology Organization Publication NATO-RTO-TR-HFM-090, 2007.

- B19. Klembezyk, A., Mosher, M., *Analysis, Optimization, and Development of a Specialized Passive Shock isolation System for High Speed Planing Boats*, SAVIAC 2003, 74<sup>th</sup> Shock and Vibration Symposium, San Diego, CA, October 2003.
- B20. Bass, C., Salzar, R., Ziemba, A., Lucas, S., Petersen, R., *The Modeling and Measurement of Humans in High Speed Planing Boats Under Repeated Vertical Impacts*, International Research Council on Bio-dynamics of Impact Conference, Prague, Czech Republic, September 2005.

## APPENDIX C. WEDGE TEST FIXTURE

### Wedge Description

Figure C1 shows a wedge test fixture used to achieve nominal 100-msec half-sine pulses. The dimensions of the wedge are shown in Figure C2. All dimensions are in millimeters. The wedge was constructed using 6mm thick steel plate and was attached to the base of the test platform. The apex of the wedge was formed from a piano hinge.

The test platform consisted of mild steel plates with a combined thickness of approximately 60mm and dimensions of 510mm x 510mm.

The wedge was dropped into sand held in place by a box with dimensions of 0.82m x 0.82m x 0.5m. The sand box was filled with dry sand to a depth of at least 0.36m. The sand was levelled prior to each test.



Figure C1. Test Platform including Wedge End View<sup>C1</sup>

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<sup>C1</sup> United Kingdom Crown copyright photograph with permission

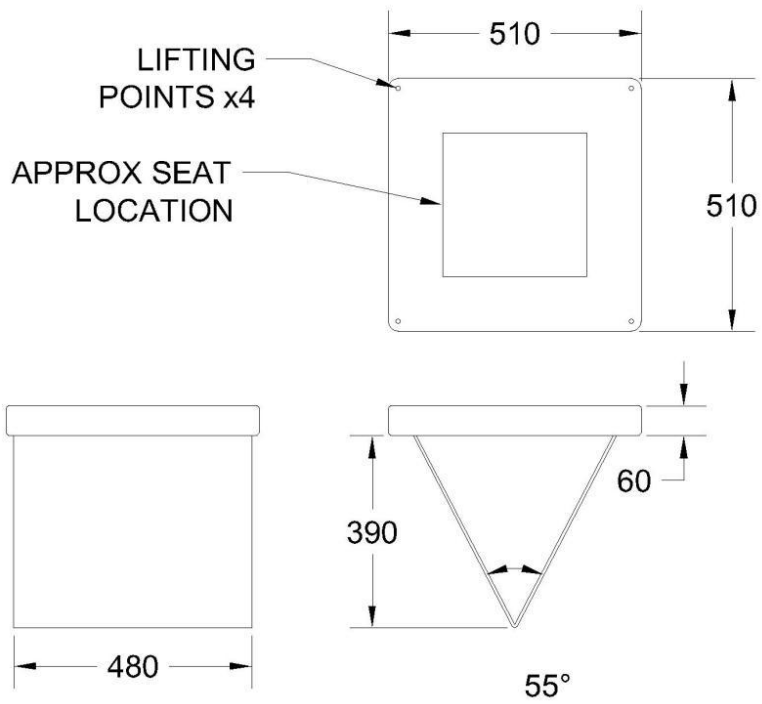


Figure C2 Dimensions of Test Platform and Wedge (all dimensions in mm)<sup>C2</sup>

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<sup>C2</sup> United Kingdom Crown copyright drawing with permission

## APPENDIX D. SEAT CUSHION DYNAMICS

Acceleration data recorded during seakeeping trials of high-speed planing craft demonstrates that the same lessons learned in the aviation industry for airplane ejection and crash impacts also apply for wave impacts [D1, D2]. The lessons are summarized below.

The compliance of soft seat cushion material results in relative displacements between the seat pan and the top of the cushion that can cause load amplification in a severe wave impact environment. The total change in impulse will be the same for cushioned seat or hard seat conditions, but a higher load will be applied for a shorter period of time on a soft cushion. The selection of seat cushion materials is therefore a compromise between soft-compliant materials that provide comfort and harder seat materials that prevent or limit impact load amplification.

Seat cushions are primarily designed for comfort. Their form fitting characteristic spreads the occupant load over the largest possible area in non-impact environments thereby decreasing high pressure points and preventing restriction of blood flow.

Every effort should be made to design a cushion that acts as a shock damper between the occupant and the mass of the seat and minimizes relative motion between the occupant and the seat. Otherwise impact force (or acceleration) amplification can occur.

Relative motions can be minimized by increased foam density and/or reduced foam thickness.

Different layers of viscoelastic and loading-rate-sensitive materials can be used to achieve these goals.

Cushion comfort is of primary concern and must not be unduly compromised to achieve crash (i.e., impact) safety.

### Appendix D References

- D1. Olivares, Dr. Gerardo, *Dynamic Seat Certification by Analysis: Volume III – Comparison of Hybrid II versus Hybrid III ATD Dynamic Evaluation NIAR Test Series*, NIAR Technical Report FAA-003D, Wichita, KS, September 2009.
- D2. Riley, Michael R., Murphy, Heidi, Coats, Dr. Timothy, *Initial Investigation of Wave Impact Load Transfer Through Shock Mitigation Seats in High-Speed Planing Craft*, Naval Surface Warfare Center Carderock Division Report NSWCCD-23-TM-2013/35, August 2013.

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## APPENDIX E. TEST SEVERITY GUIDANCE

Four suggested craft classifications provide a framework for specifying test severities for shock isolation seats [E1]: Class 1 Low Speed Commercial/Leisure, Class 2 High Speed Commercial / Leisure, Class 3 Search and Rescue, and Class 4 Military. This class rating scale was developed from experience of trials on commercial, leisure, search and rescue, and military rigid hull inflatable boats in the UK with vessel lengths from 5 to 10 meters. Generic descriptions of Class 1, 2, 3, and 4 are provided below.

### **Class 1: Low Speed Commercial / Leisure**

Class 1 describes small high speed craft carrying passengers of various ages and physical conditions, possibly including children and the elderly. Typical applications include ferry craft and sightseeing tours. Class 1 craft will typically operate at low speeds except in extremely calm conditions. Wave impacts are avoided. Class 1 vessels generally do not operate in poor weather. Class 1 corresponds to craft with operational environments not typically requiring personnel protection in the form of shock isolation seats.

### **Class 2: High Speed Commercial / Leisure**

Class 2 describes small high speed craft similar to Class 1 vessels, where the Class 2 vessel operator may choose to operate at higher speeds, as limited by their own tolerance.

Typical applications include commercial operators offering *thrill rides* and marine wildlife tour boats that are capable of high speed transits. Some applications, such as maritime wind farm maintenance boats, may require operations in poor weather. Crew and passengers of Class 2 vessels are often required to meet physical fitness standards. Engines on Class 2 vessels are typically more powerful than on Class 1 vessels, and so speeds are typically higher, perhaps in excess of 20 knots when conditions allow. Wave impacts are more common on Class 2 vessels than on Class 1 vessels.

### **Class 3: Search and Rescue**

Class 3 describes small high speed craft used for search and rescue (SAR), which often requires operations at high speed in poor weather, and in relatively high sea states. Class 3 vessel personnel are highly motivated, and well trained. They are experienced at operating in severe conditions, and are generally physically fit and healthy. Engines on Class 3 vessels often provide sufficient power to exceed 30 knots when conditions allow. Severe wave impact slamming events are typical for normal operation on Class 3 vessels.

### **Class 4: Military**

Class 4 describes high-speed craft used for military operations. Personnel in Class 4 vessels are usually physically fit and very highly motivated. As a result of their training and experience

they are more accustomed to sustained, extreme motions and wave impacts during high-speed operations.

Table E1 lists suggested test levels for classes 2, 3, and 4 if not otherwise specified. The upper box of each gray shaded region in the table corresponds to the suggested maximum test severity for each class. Three levels for Military Class 4 are provided for acquisition program flexibility<sup>E1</sup>.

The class definitions identify broad applications across leisure, commercial, and military craft where there is potential for operating in successively more severe wave impact environments. It is understood that the definitions may or may not fit a specific commercial, search and rescue, or military craft. It is therefore important that craft owners, program managers, or operators develop seat test requirements that identify the maximum exposure severity for specific craft applications.

Table E1. Recommended Testing Levels for Military and Commercial Craft

Test Severity					Craft Class				
Threshold Level	Peak Acceleration	Nominal Impact Duration	Nominal Drop Height		Class 4			Class 3	Class 2
	g	sec	m	ft	Military 4-3	Military 4-2	Military 4-1	Search and Rescue	High Speed Commercial or Leisure
6	10.00	0.10	2.07	6.78					
5	8.00	0.10	1.32	4.34					
4	6.00	0.10	0.74	2.44					
3	5.00	0.10	0.51	1.69					
2	4.00	0.10	0.33	1.08					
1	3.00	0.10	0.18	0.61					

Actual drop test heights needed to achieve acceleration thresholds will be different from the nominal drop heights listed in Table E1. The values listed are for initial calibration testing.

## Appendix E References

E1. Colwell, J.L., Gannon, L., Gunston, T., Langlois, R.G., Riley, M.R., Coats, T.W., *Shock Mitigation Seat Test and Evaluation*, The Royal Institute of Naval Architects, 2011-288.

<sup>E1</sup> Further guidance provided in a limited distribution U. S. Navy report.

**APPENDIX F. THRESHOLD LEVEL TOLERANCE ENVELOPES**

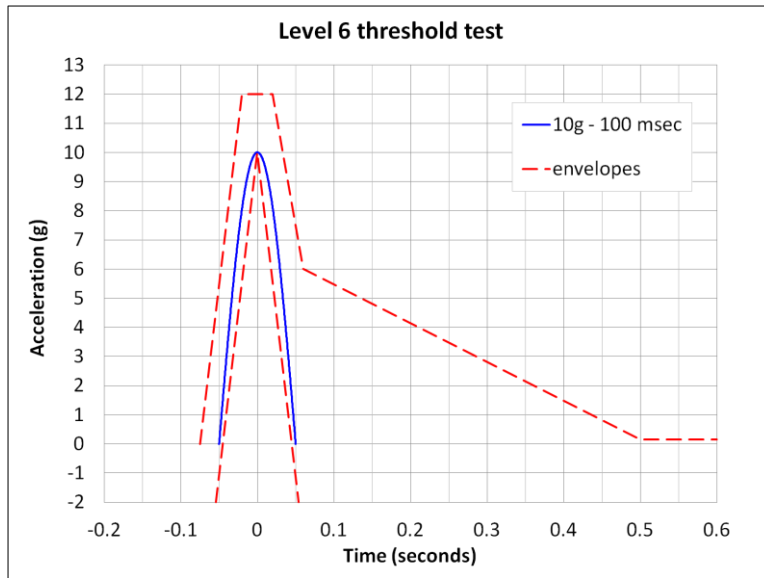


Figure F1. Level 6 Threshold and Tolerance Envelopes

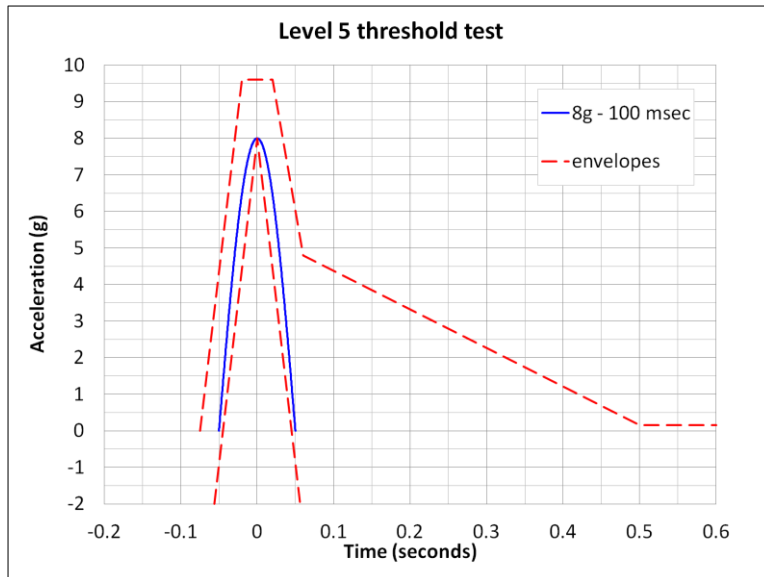


Figure F2. Level 5 Threshold and Tolerance Envelopes

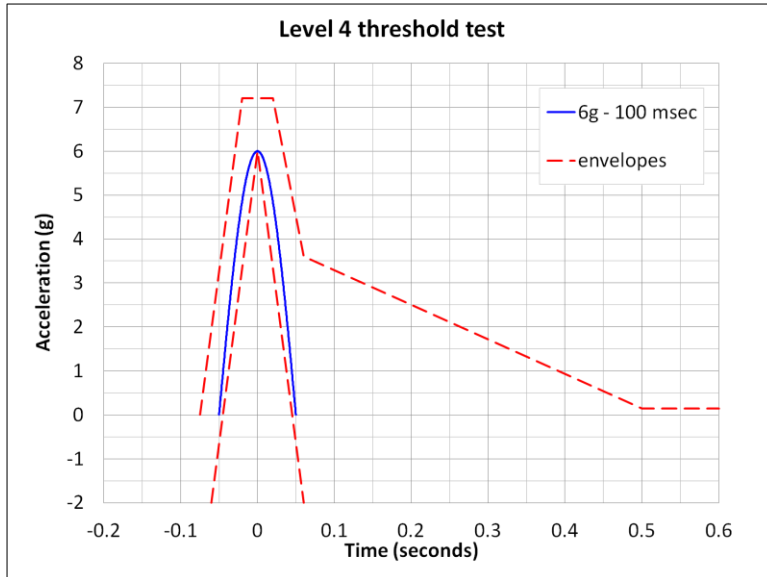


Figure F3. Level 4 Threshold and Tolerance Envelopes

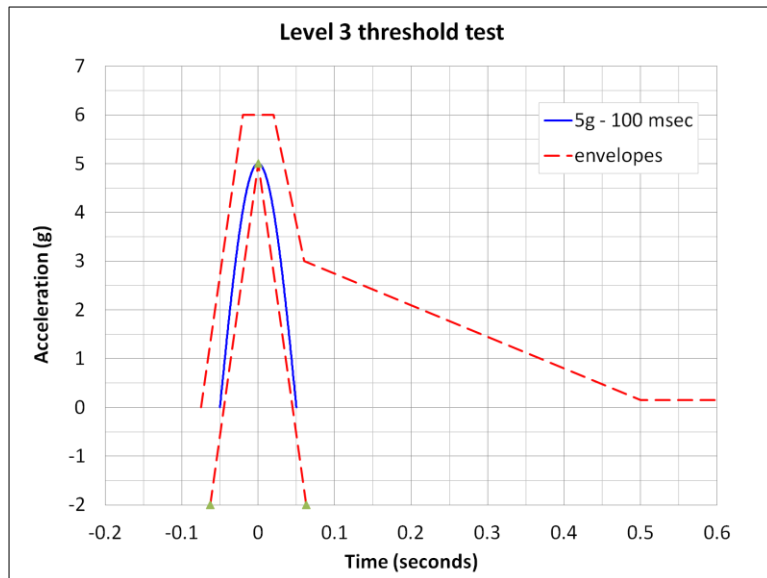


Figure F4. Level 3 Threshold and Tolerance Envelopes

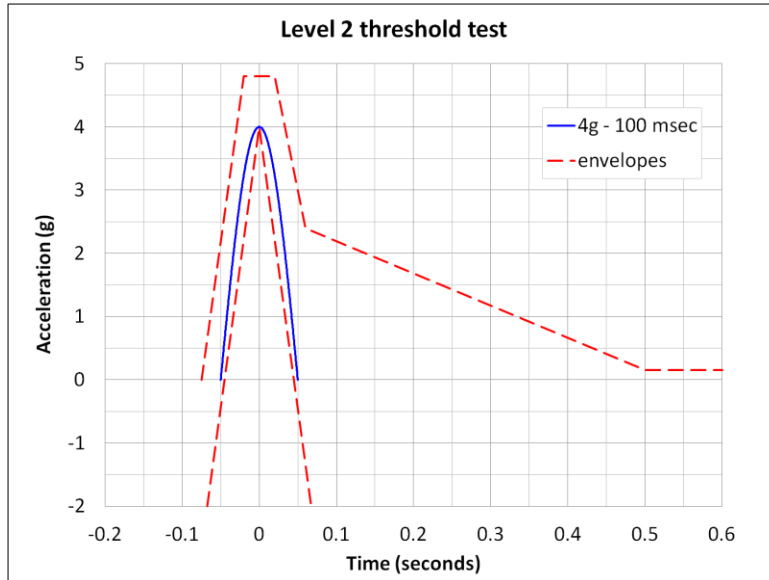


Figure F5. Level 2 Threshold and Tolerance Envelopes

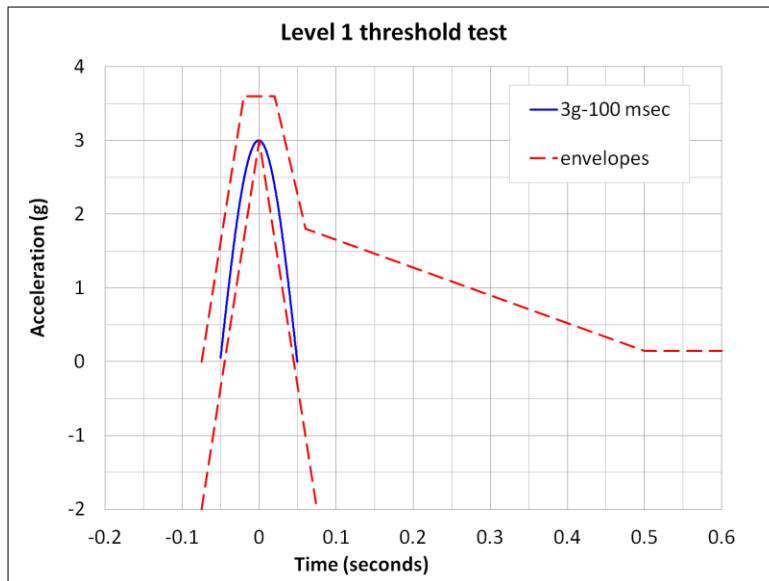


Figure F6. Level 1 Threshold and Tolerance Envelopes

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