Noise Control Roadmap for Significant Noise Hazardous Operations in DoD

17th Annual Systems Engineering Conference
National Defense Industrial Association
October 30, 2014

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Disclosures:
Financial – None
Nonfinancial – None
Views are those of the author and may not reflect the official policy or position of the U.S. Navy or Department of Defense.
Objectives for this Session

• Describe the DoD High Noise Source Reduction Initiative, including methodology used by engineering experts and occupational safety and health professionals, and link to systems engineering.

• Discuss the noise source reduction concept design plans and how they will serve as roadmap for future noise control.

• Inspire you to help implement the roadmap.

Useful Links:

  http://www.public.navy.mil/comnavsafecen/Pages/acquisition/noise_control.aspx
  Scroll down to Noise Control Technology

- Noise Control Poster- “An Investigation of Potential Intervention Strategies Involving High Noise Sources within the Department of Defense (DoD)”:  
Background

• Hazardous Noise is a long standing concern within DoD
  – Is the only known occupational hazard within DoD with exposure levels exceeding protection capability
  – Causes significant negative impact to the quality of life of our Service men and women

• Hearing loss is the most prevalent service-connected disability
  – Over 1.2M veterans received compensation payments in fiscal year 2009
  – Costs to the tax payer is in excess of $1 Billion annually
  – Is ranked #5 for DoD civilian worker compensation payout ($32M) in Chargeback Year 2012
Defense Safety Oversight Council (DSOC)
High Noise Initiative Objectives

- Identify nine significant DoD high noise (steady-state) sources and one promising technology
- Utilize noise control experts and acoustical engineers to develop noise source reduction plans and evaluate projected return on investment that will serve as a roadmap for future noise control in acquisition.
- Evaluate the modular cabin/capsule/pod as a promising noise control technology
# Nine DoD High Noise Sources and One Promising Technology

<table>
<thead>
<tr>
<th>Source</th>
<th>Low Level dB(A)</th>
<th>High Level dB(A)</th>
<th>Allowed Worst Case Unprotected Exposure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shipboard Diesel Driven Systems</td>
<td>98</td>
<td>120</td>
<td>9 seconds</td>
</tr>
<tr>
<td>Shipboard Gas Turbines</td>
<td>85</td>
<td>101</td>
<td>12 minutes</td>
</tr>
<tr>
<td>Ships and High Speed Craft</td>
<td>85</td>
<td>126</td>
<td>2 seconds</td>
</tr>
<tr>
<td>Aircraft Carrier Operations – On-deck</td>
<td>115</td>
<td>167</td>
<td>Less than 1 second</td>
</tr>
<tr>
<td>Aircraft Carrier Operations- Internal Compartments</td>
<td>85</td>
<td>113</td>
<td>45 seconds</td>
</tr>
<tr>
<td>Tracked Vehicles</td>
<td>90</td>
<td>118</td>
<td>14 seconds</td>
</tr>
<tr>
<td>Wheeled Vehicles</td>
<td>85</td>
<td>112</td>
<td>57 seconds</td>
</tr>
<tr>
<td>Cockpit Interior</td>
<td>85</td>
<td>121</td>
<td>7 seconds</td>
</tr>
<tr>
<td>Shipboard Equipment</td>
<td>84</td>
<td>114</td>
<td>36 seconds</td>
</tr>
<tr>
<td>Abrasive Blasting</td>
<td>85</td>
<td>145</td>
<td>Less than 1 second</td>
</tr>
<tr>
<td>Modular Cabin/Capsule/Pod</td>
<td>70</td>
<td>70</td>
<td>Promising Technology</td>
</tr>
</tbody>
</table>
## Basics of Acoustics

**Sound** is produced when a sound source sets the air nearest to it in wave motion. **Noise** is unwanted sound.

<table>
<thead>
<tr>
<th>Physical Properties</th>
<th>Perception</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency- described in Hertz (Hz)</td>
<td>Pitch</td>
<td>For hearing testing and noise control, frequencies are organized into octave bands or 1/3 octave bands and covers from 20 Hz to 20,000 Hz</td>
</tr>
</tbody>
</table>
| Intensity level in Decibels (dB)     | Loudness   | (1) Usually expressed using an A-weighted scale which mimics the ear which hears less of the lower frequencies  
(2) The decibel was named after Alexander Graham Bell and was developed with 0 dB as the threshold of hearing, 85-90 dB as the threshold of discomfort, and 120-140 dB as the threshold of pain  
(3) Decibels are measured on a logarithmic scale |
| Duration as Time Weighted Average (TWA) | Length of time | Usually expressed as an 8 hour TWA of the exposure |
Basics of Acoustics, cont.

Why these basics are important:

• Allowable noise levels are given as an 8 hour TWA
• Noise control is expressed as a reduction in dBs
• A 10 dB increase is subjective doubling of sound heard by the ear
• Two equal sources increase noise by 3 dB
• A dB increase is doubling by sound pressure squared—and halving of the allowed exposure time (See next slide)
• Hearing impairment compensation is determined by hearing reduction in dBs at various frequencies.
Exposure to Noise Without Hearing Protection

Noise Level Exposure Standard based on duration per day*:

<table>
<thead>
<tr>
<th>Allowable Unprotected Sound Level (dBA)</th>
<th>Duration Per Day</th>
<th>Unit of Time Per Day</th>
</tr>
</thead>
<tbody>
<tr>
<td>80</td>
<td>24</td>
<td>Hours</td>
</tr>
<tr>
<td>82</td>
<td>16</td>
<td>Hours</td>
</tr>
<tr>
<td>85</td>
<td>8</td>
<td>Hours</td>
</tr>
<tr>
<td>88</td>
<td>4</td>
<td>Hours</td>
</tr>
<tr>
<td>91</td>
<td>2</td>
<td>Hours</td>
</tr>
<tr>
<td>94</td>
<td>1</td>
<td>Hour</td>
</tr>
<tr>
<td>97</td>
<td>30</td>
<td>Minutes</td>
</tr>
<tr>
<td>100</td>
<td>15</td>
<td>Minutes</td>
</tr>
<tr>
<td>103</td>
<td>7.5</td>
<td>Minutes</td>
</tr>
<tr>
<td>106</td>
<td>3.75</td>
<td>Minutes</td>
</tr>
<tr>
<td>109</td>
<td>1.88</td>
<td>Minutes</td>
</tr>
<tr>
<td>112</td>
<td>0.94</td>
<td>Minute</td>
</tr>
<tr>
<td>115</td>
<td>28.12</td>
<td>Seconds</td>
</tr>
<tr>
<td>118</td>
<td>14.06</td>
<td>Seconds</td>
</tr>
<tr>
<td>121</td>
<td>7.03</td>
<td>Seconds</td>
</tr>
<tr>
<td>124</td>
<td>3.52</td>
<td>Seconds</td>
</tr>
<tr>
<td>127</td>
<td>1.76</td>
<td>Seconds</td>
</tr>
</tbody>
</table>

*This is the DoD Standard which is based on the American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Values for Noise
DoD Criteria for Component Hearing Conservation Programs
DoDI 6055.12, December 3, 2010

Hearing Conservation Programs shall be implemented when:

• Continuous and intermittent noise levels at or above 85 dBA for an 8 hour TWA*
• Impulse noise sound pressure levels of 140 dBp (peak)
• Ultrasonic exposures (special circumstances)

Hearing Conservation Programs mandate engineering noise control as the primary method of achieving noise levels below DoD standards

*This project looked at steady state noise (continuous and intermittent), not impulse noise
### Type of Hearing Protection/Controls at Various dBA Levels

<table>
<thead>
<tr>
<th>Service</th>
<th>Single</th>
<th>Double</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Army</td>
<td>85*-103 dBA</td>
<td>&gt;103-108 dBA</td>
<td>&gt;108 dBA- Refer to DA PAM 40- 501</td>
</tr>
<tr>
<td>Navy</td>
<td>85*- &lt; 96 dBA</td>
<td>≥ 96 dBA</td>
<td>≥ 96 dBA - Refer to BUMEDNOTE 6260 of 24 Apr 2014, that will be integrated into OPNAVINST 5100.23H and OPNAVINST 5100.19F</td>
</tr>
<tr>
<td>Marine Corps</td>
<td>85*- &lt; 96 dBA</td>
<td>≥ 96 dBA</td>
<td>≥ 96 dBA - Refer to BUMEDNOTE 6260 of 24 Apr 2014</td>
</tr>
<tr>
<td>Air Force</td>
<td>85* dBA</td>
<td>Refer to AFOSHSTD48-20</td>
<td>Refer to AFOSHSTD48-20</td>
</tr>
</tbody>
</table>

*DoD Noise Standard for continuous/intermittent noise

**Note:** Military Standard MIL-STD 1474D ‘forbids’ unprotected (i.e., without double hearing protection) exposure above 115 dBA because double hearing protection cannot provide sufficient protection to prevent permanent hearing loss.
Noise and Energy Control are Systems Engineering Issues

- Radiated Noise
- Airborne Path
- 2nd Structureborne Path
- Diesel Engine
- Ship Structure
- U/W Radiated Noise
- First Structureborne Path
- Poorly sized and installed fan
- Inefficient duct design : wasted energy turns to noise!
- No flexible spacer – duct rattles

Inefficient duct design : wasted energy turns to noise!
DoD Criteria for Noise Control in Acquisition
DoDI 6055.12, December 3, 2010

Acquisition Programs shall include implementation of noise assessment and engineering control measures through the systems engineering and system safety process as directed by DoDI 5000.02 when:

• Legacy systems have recognized exposure concerns at or above 85 dBA or 140 dB Peak
• New systems are considered likely to create noise exposures at or above 85 dBA or 140 dB Peak
• Communication is anticipated to be potentially impaired by background noise caused by new equipment
Initiative Evaluation Procedures

- Collected and established noise database for DoD sources, including
  - Physical parameters controlling noise
  - Operating conditions and utilization
- Established commercial off the shelf (COTS) and novel or advanced (non-COTS) noise control approaches
  - Possible noise reduction
  - Non-acoustic impact on space/weight/cost
- Estimated projected noise reductions with various treatments
- Recommended optimal noise reductions
- Estimated lifetime system hearing loss costs
Return on Investment (ROI)

ROI = \[(\text{NIHL Cost Savings}^* - \text{Treatment Implementation Cost}) / \text{Treatment Implementation Cost}\]

Noise Induced Hearing Loss (NIHL) Cost Savings* =

Lifetime System Costs [audiograms, hearing aids, VA NIHL disability, VA tinnitus disability] without treatments —

Lifetime System Cost with treatments.
Noise Induced Hearing Loss (NIHL) Cost Assessment Tool

Based on:

• The “should cost” model (Sachs 2007)* which assumes 100% compliance with the Navy Hearing Conservation Program and VA requirements (more expensive than “actual cost”)


NIHL Cost Assessment Tool Parameters

• Noise Level – Time-Weighted Average (TWA)
  – Representative source levels were established by averaging A-weighted sound pressure levels at various operating conditions across selected DoD platforms
  – Levels were normalized to an 8-hour work day, 5 day work week

• Number of systems

• Number of crew

• Service life of systems and crew

• Effectiveness of hearing protection

• Cost of audiograms, hearing aids & veterans’ disability

• Estimated effectiveness and “cost” of treatments - materials and installation
Other Important Parameters Not Considered (Because Data Was Not Available)

- **Costs related to:**
  - Impact on crew performance and ability to perform
  - Health & social impacts

- **Benefits: Non-acoustic payback**
  - Less chance for “miscommunication" in a lower noise space.
  - Buy Quiet
    - Longer equipment life
    - Lower maintenance
  - Increased efficiency (particularly with Computational Fluid Dynamics (CFD))
  - Reduced weight/space when involved early in design

**Bottom Line:** Both costs and benefits are underestimated, making the ROIs an underestimation.
### Nine DoD High Noise Sources and One Promising Technology

<table>
<thead>
<tr>
<th>Source</th>
<th>Low Level dB(A)</th>
<th>High Level dB(A)</th>
<th>Allowed Worst Case Unprotected Exposure Time</th>
<th>Estimated Exposure Duration With Double Hearing Protection*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shipboard Diesel Driven Systems</td>
<td>98</td>
<td>120</td>
<td>9 seconds</td>
<td>2.5 hours</td>
</tr>
<tr>
<td>Shipboard Gas Turbines</td>
<td>85</td>
<td>101</td>
<td>12 minutes</td>
<td>Unlimited</td>
</tr>
<tr>
<td>Ships and High Speed Craft</td>
<td>85</td>
<td>126</td>
<td>2 seconds</td>
<td>40 minutes</td>
</tr>
<tr>
<td>Aircraft Carrier Operations – On-deck</td>
<td>115</td>
<td>167</td>
<td>Less than 1 second</td>
<td>Less than 1 second</td>
</tr>
<tr>
<td>Aircraft Operations – Internal Compartments</td>
<td>85</td>
<td>113</td>
<td>45 seconds</td>
<td>12 hours</td>
</tr>
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<td>Tracked Vehicles</td>
<td>90</td>
<td>118</td>
<td>14 seconds</td>
<td>4 hours</td>
</tr>
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<td>57 seconds</td>
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<td>7 seconds</td>
<td>2 hours</td>
</tr>
<tr>
<td>Shipboard Equipment</td>
<td>84</td>
<td>114</td>
<td>36 seconds</td>
<td>6 hours</td>
</tr>
<tr>
<td>Abrasive Blasting</td>
<td>85</td>
<td>145</td>
<td>Less than 1 second</td>
<td>28 seconds</td>
</tr>
<tr>
<td>Modular cabin/ Capsule/Pod</td>
<td>70</td>
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<td>Promising Technology</td>
<td>Promising Technology</td>
</tr>
</tbody>
</table>

* This is an estimate using 30 dB reduction for double hearing protection, realizing it may be a conservative best case scenario.
## Typical Treatment Effectiveness

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Airborne Noise Reduction, (dB)</th>
<th>Structureborne Noise Reduction, (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vibration Isolation</td>
<td>0</td>
<td>10-25</td>
</tr>
<tr>
<td>Acoustic Absorption</td>
<td>5-7</td>
<td>0</td>
</tr>
<tr>
<td>High Transmission Loss</td>
<td>5-12</td>
<td>0-7</td>
</tr>
<tr>
<td>Damping</td>
<td>0</td>
<td>5-12</td>
</tr>
<tr>
<td>HVAC Treatments</td>
<td>5-15</td>
<td>0</td>
</tr>
<tr>
<td>Active Control</td>
<td>5-10</td>
<td>10-20</td>
</tr>
<tr>
<td>Pod/Module</td>
<td>10-20</td>
<td>10-15</td>
</tr>
<tr>
<td>Acoustic Design</td>
<td>15-25</td>
<td>15-25</td>
</tr>
<tr>
<td>Computational Fluid Dynamics</td>
<td>5-12</td>
<td>5</td>
</tr>
</tbody>
</table>
Noise Sources: Very high level, broadband noise and vibration sources due to combustion process and lube/cooling subsystems. Diesels tend to induce high noise at low frequencies (below 100 Hz) due to their low rotation rate and firing rate components. Noise levels can exceed the protection capability of ear muffs and ear plugs.

Current Noise Range Lower Estimate – Upper Estimate at ear level: 98-120 dBA

Worker Exposure Time Per Day Allowed Unprotected : 9 seconds @ 120 dBA and 24 minutes @ 98 dBA

Noise Controls:

<table>
<thead>
<tr>
<th></th>
<th>Standard Commercial Off The Shelf (COTS) Treatment, Potential dB Reductions</th>
<th>Advanced Treatments, Potential dB Reductions</th>
</tr>
</thead>
</table>
| Airborne Noise Control  | • Walk-in enclosures (15 dB)  
                          • Cladding (2-3 dB)  
                          • Buy Quiet (3-10 dB)  | • Reduce radiation from engine block (3-10 dB)  
                          • Active control of intake/exhaust (low frequency) (10-15 dB) |
| Structureborne Noise Control | • Vibration isolation (10-20 dB)  
                             • Hi-Impedance foundations (5-8 dB)  | • Active Control – low frequency vibration (almost COTS) (15-25 dB)  
                             • Hydraulic mounts (active/passive nonlinear system) (5-10 dB)  
                             • Passive tuned ‘structural’ absorber (5 dB) |
Shipboard Diesel Driven Systems
Pictures of Noise Controls

**Noise Sources:** Diesel casing, turbocharger, intake/exhaust system, sea water cooling & lube systems.

**Noise Controls:**

- Enclosure
- Bulkhead/Deck Cladding
- Vibration Isolators
- Hybrid Electric Drive

[www.propulsionmaine.com](http://www.propulsionmaine.com)
Shipboard Diesel Driven Systems
Summary and Justification

Feasibility: Yes, noise control is feasible.

Estimated Number of DoD Acquisitions (Ships): 1095

Estimated number of workers (Military and Civilians) Exposed: 26,280

Return on Investment (ROI): 0.2:1 to 4:1; NIHL cost reduction = $775 M

Graph showing Noise Before and After:

Range for Sound Levels - Treated Diesel Gensets

Source Level Used - 107 dBA
TWA Source Level Used - 110 dBA
Shipboard Gas Turbines
Noise Source and Controls

Noise Sources: High level, broadband noise and vibration sources due to combustion process. Gas turbines tend to induce high noise at mid- to high frequencies (above 500 Hz) due to high number of compressor blades operating at high rotation rates. Extensive intake/exhaust systems affect multiple spaces. Hearing loss in engine room can be prevented by protection capability of ear muffs and ear plugs; however, high noise at deck stations cannot be abated without special communications.

Current Noise Range Lower Estimate – Upper Estimate at ear level: 85-101 dBA
Worker Exposure Time Per Day Allowed Unprotected : 12 minutes @ 101 dBA and 8 hours @ 85 dBA

Noise Controls:

<table>
<thead>
<tr>
<th></th>
<th>Standard Commercial Off The Shelf (COTS) Treatment, Potential dB Reductions</th>
<th>Advanced Treatments, Potential dB Reductions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Airborne Noise Control</td>
<td>• Enclosure cladding (5-10 dB)</td>
<td>• Active control within enclosure (3-10 dB)</td>
</tr>
<tr>
<td></td>
<td>• Intake/exhaust cladding (10-12 dB)</td>
<td>• Active control of intake/exhaust (low frequency) (5-10 dB)</td>
</tr>
<tr>
<td></td>
<td>• Cooling fan/duct cladding (10-15 dB)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Computational fluid dynamics (CFD)¹ (2-15 dB)</td>
<td></td>
</tr>
<tr>
<td>Structureborne Noise Control</td>
<td>• Vibration isolation (10-15dB)</td>
<td>• Active Control – low frequency vibration (almost COTS) (15-25 dB)</td>
</tr>
<tr>
<td></td>
<td>• Hi-Impedance foundations (5-8 dB)</td>
<td>• Hydraulic mounts (active/passive nonlinear system (5 dB)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Passive tuned ‘structural’ absorber (5 dB)</td>
</tr>
</tbody>
</table>

¹Affecting on-deck stations and internal compartments
Shipboard Gas Turbines
Pictures of Noise Controls

Noise Sources: Gas turbine, cooling air supply fan and duct, intake/exhaust ducting

Noise Controls:

Enclosure

CFD

Example of Active Low Frequency Vibration Mounts

Example of machinery isolation mounts
Feasibility: Yes, noise control is feasible.

Estimated Number of DoD Acquisitions (Ships): 510

Estimated number of workers (Military and Civilians) Exposed: 15,173

Return on Investment (ROI): 0.2:1 to 2:1; NIHL cost reduction = $38.5 M

Graph showing Noise Before and After:
Ships and High Speed Craft
Noise Source and Controls

Noise Sources: Very high level, broadband noise and vibration sources on craft with high power to weight ratios. Unique propulsion systems – fans, water jets, thrusters, etc. Crew in close proximity of high noise and vibration and low transmission loss constructions. Noise levels above 126 dB exceed the protection capability of ear muffs and ear plugs.

Current Noise Range Lower Estimate – Upper Estimate at ear level: 85-126 dBA

Worker Exposure Time Per Day Allowed Unprotected: 2.3 seconds @ 126 dBA and 8 hours @ 85 dBA

Noise Controls:

<table>
<thead>
<tr>
<th></th>
<th>Standard Commercial Off The Shelf (COTS) Treatment, Potential dB Reductions</th>
<th>Advanced Treatments, Potential dB Reductions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Airborne Noise Control</strong></td>
<td>• High transmission loss (TL) Constructions (15 dB)</td>
<td>• Improved light-weight high TL materials (3-10 dB)</td>
</tr>
<tr>
<td></td>
<td>• Buy Quiet (3-7 dB)</td>
<td>• Combination of thermal/fire/acoustic materials (5-10 dB)</td>
</tr>
<tr>
<td></td>
<td>• Damping (2-10 dB)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• CFD fan/thruster design (2-15 dB)</td>
<td></td>
</tr>
<tr>
<td><strong>Structureborne Noise Control</strong></td>
<td>• Vibration isolation (10-15dB)</td>
<td>• Active Control – low freq. vibration (almost COTS) (15-25 dB)</td>
</tr>
<tr>
<td></td>
<td>• Hi-Impedance foundations (5-8 dB)</td>
<td>• Passive tuned ‘structural’ absorber (5 dB)</td>
</tr>
<tr>
<td></td>
<td>• Passive vibration absorbers (10-15 dB)</td>
<td></td>
</tr>
</tbody>
</table>
Ships and High Speed Craft
Pictures of Noise Controls

Noise Sources: Diesel casing, turbocharger, intake/exhaust system, sea water cooling & lube systems.

Noise Controls:

- Testing Hi TL Bulkhead
- Testing Spray-on Damping
- Turbo Silencer (Detroit Diesel)
- Example of active noise cancellation system
- Example of machinery isolation mounts
Feasibility: Yes, noise control is feasible.

Estimated Number of DoD Acquisitions (Ships and Craft): 165

Estimated number of workers (Military and Civilians) Exposed: 4,356

Return on Investment (ROI): 1:1 to 3:1; NIHL cost reduction = $49.2M

Graph showing Noise Before and After:

Source level used – 96 dBA
TWA Source Level Used – 97 dBA
Aircraft Carrier Operations--On-Deck
Noise Source and Controls

**Noise Sources:** Extremely high level, broadband noise from the jet engines. Deck crew in close proximity of extremely high noise and only protected by cranial helmets. Noise levels above 167 dB exceed the protection capability of cranial helmets with ear muffs and ear plugs. (Tactical jet noise being addressed separately)

**Current Noise Range Lower Estimate – Upper Estimate at ear level:** 115-167 dBA

**Worker Exposure Time Per Day Allowed Unprotected:** Less than 1 second @ 167 dBA and 28 seconds @ 115 dBA

**Noise Controls:**

<table>
<thead>
<tr>
<th></th>
<th>Standard Commercial Off The Shelf (COTS) Treatment, Potential dB Reductions</th>
<th>Advanced Treatments, Potential dB Reductions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Airborne Noise Control</strong></td>
<td>• Barrier on deck (5-13 dB)</td>
<td>• None</td>
</tr>
<tr>
<td><strong>Structureborne Noise Control</strong></td>
<td>• None</td>
<td>• None</td>
</tr>
</tbody>
</table>
Noise Sources: Jet noise

Noise Controls:

Noise barrier similar to jet blast deflector
Aircraft Carrier Operations--On-Deck
Summary and Justification

Feasibility: Noise control treatments and their installation are difficult to achieve

Estimated Number of DoD Acquisitions (Ships): 11

Estimated number of workers (Military and Civilians) Exposed: 11,000

Return on Investment (ROI): 203:1 to 509:1; NIHL cost reduction = $1.1B

Graph showing Noise Before and After:

Source Level Used – 140 dBA

TWA Source Level Used – 143 dBA
Noise Sources: Very high level, broadband noise-from jet launches, arresting gear, and water brake-is easily transmitted to berthing and living space directly below the flight deck. Noise levels in these compartments reach hazardous levels during flight operations.

Current Noise Range Lower Estimate – Upper Estimate at ear level: 85-113 dBA

Worker Exposure Time Per Day Allowed Unprotected: 45 seconds @ 113 dBA and 8 hours @ 85 dBA

Noise Controls:

<table>
<thead>
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<tbody>
<tr>
<td><strong>Airborne Noise Control</strong></td>
<td>• High transmission loss (TL) Constructions (10-12 dB)</td>
<td>• None</td>
</tr>
<tr>
<td></td>
<td>• Damping (5-7 dB)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Floating Room (Capsule/Pod) (10-15 dB)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Absorptive Materials (3-5 dB)</td>
<td></td>
</tr>
<tr>
<td><strong>Structureborne Noise Control</strong></td>
<td>• None</td>
<td>• None</td>
</tr>
</tbody>
</table>

From [www.navy.mil](http://www.navy.mil)
Noise Sources: Jet noise, catapult and retrieval systems and water brake

Noise Controls:

- Spray on Damping
- Hi – Transmission Loss
- Modular Cabin/Capsule/Pod
Feasibility: Yes, noise control is feasible.

Estimated Number of DoD Acquisitions: 11

Estimated number of workers (Military and Civilians) Exposed: 38,500

Return on Investment (ROI): 37:1 to 44:1; NIHL cost reduction = $565M

Graph showing Noise Before and After:

Source Level Used – 97 dBA
TWA Source Level Used – 100 dBA
**Tracked Vehicles**

**Noise Source and Controls**

**Noise Sources:** Very high level, broadband noise and vibration sources on vehicle due to drive system and track. Crew in highly reverberant compartment and in close proximity to high noise and vibration sources.

**Current Noise Range Lower Estimate – Upper Estimate at ear level:** 90-118 dBA

**Worker Exposure Time Per Day Allowed Unprotected:** 14 seconds @ 118 dBA and 4 hours @ 90 dBA

**Noise Controls:**

<table>
<thead>
<tr>
<th></th>
<th>Standard Commercial Off The Shelf (COTS) Treatment, Potential dB Reductions</th>
<th>Advanced Treatments, Potential dB Reductions</th>
</tr>
</thead>
</table>
| **Airborne Noise Control** | • Cladding (5-10 dB)  
• Buy Quiet (7-12 dB)  
• Fan re-design (10-15 dB) | • Internal modular compartment (capsule/pod) (5-10 dB)  
• Active noise cancellation (5-10 dB) |
| **Structureborne Noise Control** | • Vibration isolation (5-10 dB)  
• Spray on damping (2-10 dB) | • Active control-low frequency vibration (almost COTS) (15-25 dB)  
• Distributed vibration absorber (15-25 dB)  
• Sprocket re-design (10-15 dB) |
Track, sprocket, idler, wheels and cooling fans

Noise Sources: Track, sprocket, idler, wheels and cooling fans

Noise Controls:

Cladding Materials

Testing Spray-on Damping

Passive Distributed Vibration Absorber

Prototype Compliant Idler Wheel
Tracked Vehicles
Summary and Justification

Feasibility: Yes, noise control is feasible.

Estimated Number of DoD Acquisitions: 97,109

Estimated number of workers (Military and Civilians) Exposed: 485,545

Return on Investment (ROI): 0.1:1 to 1:1; NIHL cost reduction = $8.1B

Graph showing Noise Before and After:

Source level used – 111 dBA
TWA Source level used – 113 dBA
Wheeled Vehicles
Noise Source and Controls

**Noise Sources:** Very high level, broadband noise and vibration sources on vehicle due to drive system and tires. Crew in highly reverberant compartment and in close proximity to high noise and vibration sources.

**Current Noise Range Lower Estimate – Upper Estimate at ear level:** 85-112 dBA

**Worker Exposure Time Per Day Allowed Unprotected:** 56 seconds @ 112 dBA and 8 hours @ 85 dBA

**Noise Controls:**

<table>
<thead>
<tr>
<th></th>
<th>Standard Commercial Off The Shelf (COTS) Treatment, Potential dB Reductions</th>
<th>Advanced Treatments, Potential dB Reductions</th>
</tr>
</thead>
</table>
| **Airborne Noise Control** | • Cladding (5-8 dB)  
• Buy Quiet (7-12 dB)  
• Fan re-design (10-15 dB) | • Internal modular compartment (capsule/pod) (5-10 dB)  
• Active noise cancellation (5-10 dB)  
• Tire tread re-design (5-10 dB) |
| **Structureborne Noise Control** | • Vibration isolation (5-10 dB)  
• Spray on damping (2-10 dB) | • Active control-low frequency vibration (almost COTS) (15-25 dB)  
• Distributed vibration absorber (15-25 dB) |
Wheeled Vehicles
Pictures of Noise Controls

Noise Sources: Diesel/gearbox, cooling fan and tire noise

Noise Controls:

Top - Baseline OASPL's
(No Noise Control Measures Applied)

A. Noise Levels After ACS
   Evaporator Fans Replaced

B. Noise Levels After A. +
   Curb-side ACS Noise
   Reducing Plenum Installed

C. Noise Levels After B. +
   Road-side ACS Ventilation Duct
   Silencing Treatments Installed

- Operator #1 Location
  - 108 dBA
    A. 103 dBA
    B. 95 dBA
    C. 93 dBA

- Operator #2 Location
  - 110 dBA
    A. 104 dBA
    B. 100 dBA
    C. 92 dBA

- Driver Location
  - 99 dBA
    A. 99 dBA
    B. 99 dBA
    C. 99 dBA

- Supervisor Location
  - 103 dBA
    A. 98 dBA
    B. 95 dBA
    C. 92 dBA
Wheeled Vehicles
Summary and Justification

Feasibility: Yes, noise control is feasible.

Estimated Number of DoD Acquisitions: 440,792

Estimated number of workers (Military and Civilians) Exposed: 1,322,376

Return on Investment (ROI): 2:1 to 5:1; NIHL cost reduction = $7.9B

Graph showing Noise Before and After:

Source level used – 88 dBA
TWA Source Level – 90 dBA
Noise Sources: Very high level, broadband noise and vibration sources distributed throughout vessel. Noise easily transmitted to operations, topside and accommodations. Crew in highly reverberant compartment and in close proximity to high noise and vibration sources. HVAC and fluid system also contribute to high noise levels. Jet operations on CVN and amphibian ships.

Current Shipboard Noise Range Lower Estimate – Upper Estimate at ear level: 85-121 dBA

Modular Cabin/Capsule/Pod as Promising Technology: There are 2 distinct applications of this technology on ships: (1) Berthing-to make quiet areas quieter to allow ears to ‘recover’ and (2) Isolation booths in high noise work areas to physically separate the worker from the noise.

<table>
<thead>
<tr>
<th>Benefit of Standard Commercial Off The Shelf (COTS) Modular Cabins and Berthing Capsules/Pods</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Navy</strong></td>
</tr>
<tr>
<td>• Has high potential to control noise and vibration. This “room in a room” concept has been tested on a Navy carrier and was found to provide a 10 dB noise reduction. For shipboard machinery reduction on order of 15-20 dB expected.</td>
</tr>
<tr>
<td><strong>Cruise Industry</strong></td>
</tr>
<tr>
<td>• Standard on many cruise ships to provide guests cabins with quiet spaces [Noise standard for cruise industry 49 – 55 dB(A)]</td>
</tr>
</tbody>
</table>
Modular Cabin/Capsule/Pod—Promising Technology
Pictures of Some Types of Modular Cabins/Capsules/Pods

Noise Sources: Shipboard equipment and machinery for surface ship; aircraft.

Noise Controls: Modular Cabin or ‘Capsule’/‘Pod’

Berthing capsule/pod

From Wikipedia

Modular cabins for work or berthing

From rm-group.com

From grainger.com

From Nauticexpo.com
Effectiveness of Modular Cabin

Figure 38. Performance of Modular Cabin Treatment for F-18 on Catapult 2 (10 dBA reduction)

Note: With modular cabin, noise level is below 85 dBA

Cockpit Interior
Noise Source and Controls

Noise Sources: Very high level, broadband noise with some high frequency tonal components due to jet/turbo prop and ventilation systems. Crew in highly reverberant compartment and in close proximity to high noise and vibration sources.

Current Noise Range Lower Estimate – Upper Estimate at ear level: 85-121 dBA

Worker Exposure Time Per Day Allowed Unprotected: 7.2 seconds @ 121 dBA and 8 hours @ 85 dBA

Noise Controls:

<table>
<thead>
<tr>
<th></th>
<th>Standard Commercial Off The Shelf (COTS) Treatment, Potential dB Reductions</th>
<th>Advanced Treatments, Potential dB Reductions</th>
</tr>
</thead>
</table>
| **Airborne Noise Control** | • Cladding (5-8 dB)  
• Buy Quiet (3-7 dB)  
• Ventilation Design (CFD) (5-12 dB)  
• Damping (2-10 dB) | • Active Noise Cancellation (5-10 dB) |
| **Structureborne Noise Control** | • Passive tuned vibration absorbers (5-10 dB) | • None |
Cockpit Interior
Pictures of Noise Controls

Noise Sources: Jet, compressor, cockpit HVAC, prop blade rate, flow noise

Noise Controls:

Cladding materials

BYU Active Cancellation Test on Cooling Fan

600 Hz - ANC on (kd = 0.5)
Mean-square reduction: 13.8 dB

Compact cooling system

A cutaway view of Hewlett-Packard's new electric-ducted server cooling fan, which was adapted from model jet airplane engines. (Image courtesy of Hewlett-Packard.)
Cockpit Interior
Summary and Justification

Feasibility: Yes, noise control is feasible.

Estimated Number of DoD Acquisitions: 9,613

Estimated number of workers (Military and Civilians) Exposed: 16,823

Return on Investment (ROI): 0.8:1 to 4:1; NIHL cost reduction = $246 M

Graph showing Noise Before and After:

Source Level Used – 106 dBA
TWA Source Level Used – 98 dBA
Shipboard Equipment
Noise Source and Controls

Noise Sources: Very high level, broadband noise and vibration sources distributed throughout vessel. Noise easily transmitted to operations, topside and accommodations. Crew in highly reverberant compartments and in close proximity to high noise and vibration sources. Noise sources include: pumps, hydraulic systems, HVAC fans/air handlers/fan coil assemblies/etc., and all other (non-diesel, non-gas turbine) “auxiliary” equipment present and used in ship environments.

Current Noise Range Lower Estimate – Upper Estimate at ear level: 85-121 dBA
Worker Exposure Time Per Day Allowed Unprotected: 7 seconds @ 121 dBA and 8 hours @ 85 dBA
Noise Controls:

<table>
<thead>
<tr>
<th>Standard Commercial Off The Shelf (COTS) Treatment, Potential dB Reductions</th>
<th>Advanced Treatments, Potential dB Reductions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Airborne Noise Control</strong></td>
<td>• Improved light-weight high transmission loss materials (5-10 dB) • Active noise control (HVAC) (12 dB)</td>
</tr>
<tr>
<td>• Buy Quiet (5-15 dB) • Computational Fluid Dynamics (CFD)propulsor design (10-20 dB) • *Heating, Ventilation and Air-Conditioning (HVAC) design (5-15 dB) • Damping (2-10 dB) • Acoustic insulation (3-5 dB) • Hydraulic silencer (5-10 dB)</td>
<td></td>
</tr>
<tr>
<td><strong>Structureborne Noise Control</strong></td>
<td>• Active Control – low frequency vibration (almost COTS) (15-25 dB)</td>
</tr>
<tr>
<td>• Vibration isolation (10-15 dB) • Hi-Impedance foundations (5-8 dB)</td>
<td></td>
</tr>
</tbody>
</table>
Shipboard Equipment
Pictures of Noise Controls

Noise Sources: HVAC systems, propulsors, compressors and pumps

Noise Controls:
- Hydraulic Silencer
- Quiet Propeller Design
- Acoustic Insulation
- Duct ANC
  Engineering noise control

Figure 10.30(a). Configuration of a feedforward active noise control system to attenuate noise propagation along a duct (after Eriksson and Allie, 1989).
Shipboard Equipment
Summary and Justification

Feasibility: Yes, noise control is feasible.

Estimated Number of DoD Acquisitions (Ships): 602

Estimated number of workers (Military and Civilians) Exposed: 463,540

Return on Investment (ROI): 11:1 to 40:1; NIHL cost reduction = $3.9B

Graph showing Noise Before and After:

Source Level Used – 92 dBA TWA
Source Level Used – 95 dBA
**Abrasive Blasting**

**Noise Source and Controls**

**Noise Source:** High level broadband noise defined by the nozzle and delivery system, size and composition of item being blasted, blasting area and work piece angle. Critical components are air blaster nozzle, air supply to hood, air compressors, exhaust ventilation and air releases during grit pot blow-down. Dust exhaust fans and waste separation systems also create high noise.

**Current Noise Range Lower Estimate – Upper Estimate at ear level:** 85-145 dBA

**Worker Exposure Time Per Day Allowed Unprotected:** < 1 second @ 145 dBA and 8 hours @ 85 dBA

**Noise Controls:**

<table>
<thead>
<tr>
<th></th>
<th>Standard Commercial Off The Shelf (COTS) Treatment, Potential dB Reductions</th>
<th>Advanced Treatment, Potential dB Reductions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Airborne Noise Control</strong></td>
<td>• Nozzle redesign-computational fluid dynamics (CFD) (2-4 dB)</td>
<td>• Partial nozzle barrier (2-4 dB)</td>
</tr>
<tr>
<td><strong>Structureborne Noise Control</strong></td>
<td>• None</td>
<td>• None</td>
</tr>
</tbody>
</table>
Abrasive Blasting
Pictures of Noise Controls

Noise Sources: Nozzle, air compressors and exhaust ventilation systems

Noise Controls:

Nozzle Re-Design (CFD)
Abrasive Blasting
Pictures of Noise Controls

**Noise Sources:** Nozzle, air compressors and exhaust ventilation systems

**Interim Noise Controls:**

- CAVCom
- Sensear
Abrasive Blasting
Summary and Justification

Feasibility: Noise control will require research and development.

Estimated Number of DoD Acquisitions: 500

Estimated number of workers (Military and Civilians) Exposed: 1,250

Return on Investment (ROI): 2:1 to 5:1; NIHL cost reduction = $12M

Graph showing Noise Before and After:

Source level used – 97 dBA TWA
Source level used – 94 dBA
# Return on Investment

<table>
<thead>
<tr>
<th>DoD Source</th>
<th>Return on Investment</th>
<th>Potential NIHLCost Reduction</th>
<th>Untreated TWA</th>
<th>dB(A) Reduction</th>
<th>Service Years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shipboard Diesel Driven Systems</td>
<td>0.2:1 – 4:1</td>
<td>$774,708,120</td>
<td>110 dB(A)</td>
<td>33</td>
<td>40</td>
</tr>
<tr>
<td>Shipboard Gas Turbines</td>
<td>0.2:1 - 2:1</td>
<td>$38,509,074</td>
<td>90 dB(A)</td>
<td>8</td>
<td>35</td>
</tr>
<tr>
<td>Ships/High Speed Craft</td>
<td>1:1 – 3:1</td>
<td>$49,218,444</td>
<td>97 dB(A)</td>
<td>17</td>
<td>22</td>
</tr>
<tr>
<td>Aircraft Carrier Operations-On-Deck</td>
<td>203:1 – 509:1</td>
<td>$1,121,310,000</td>
<td>143 dB(A)</td>
<td>13</td>
<td>50</td>
</tr>
<tr>
<td>Aircraft Carrier Operations-Internal Compartments</td>
<td>37:1 – 44:1</td>
<td>$565,873,000</td>
<td>100 dB(A)</td>
<td>21</td>
<td>50</td>
</tr>
<tr>
<td>Tracked Vehicles</td>
<td>0.1:1 – 1:1</td>
<td>$8,125,110,030</td>
<td>113 dB(A)</td>
<td>16</td>
<td>50</td>
</tr>
<tr>
<td>Wheeled Vehicles</td>
<td>2:1 – 5:1</td>
<td>$7,958,058,768</td>
<td>90 dB(A)</td>
<td>7</td>
<td>30</td>
</tr>
<tr>
<td>Cockpit Noise</td>
<td>0.8:1 – 4:1</td>
<td>$246,473,773</td>
<td>98 dB(A)</td>
<td>12</td>
<td>35</td>
</tr>
<tr>
<td>Shipboard Equipment</td>
<td>11:1 – 40:1</td>
<td>$3,889,987,680</td>
<td>95 dB(A)</td>
<td>7</td>
<td>40</td>
</tr>
<tr>
<td>Abrasive Blasting</td>
<td>2:1 – 5:1</td>
<td>$12,317,500</td>
<td>94 dB(A)</td>
<td>6</td>
<td>50</td>
</tr>
</tbody>
</table>
Noise Control Successes Outside of DoD, cont.

MSHA maintains a list of “technologically and administratively achievable” and “promising” noise controls that is updated and provided to the mining industry as new controls are developed.

Noise Control Successes Outside of DoD

Major strides have been made in noise control technology in the areas of:

- Mining
- Commercial aviation
- Aerospace

Technology has improved and costs have come down.
Noise Control Successes Outside of DoD, cont.

**Technologically and administratively achievable noise controls**

- Shown to reduce sound levels and noise exposure
- Used either singly or as part of a suite of controls
- Proven to work via widespread use or scientific study
- Reduce noise exposure (*not sound level*) by 3 dB(A)
- Have a realistic basis in present technology (can be made or bought)
Next Steps

- Engage Service Acquisition Leads and brief initiative results
- Incorporate existing noise control requirements and detailed guidance into joint capabilities (requirements) documents
- Update MIL-STD 1474 (Design Criteria Standard-Noise Limits) to better address impulse noise, ship and aircraft noise control
- Implement noise control guidance once MIL-STD 882E is revised to provide more guidance for risk evaluations
- Partner to use the systems engineering approach to manage for efficiency in energy consumption and noise
- Design systems for sustainability
- Work to develop a DoD list of “technologically achievable” and “promising” noise controls
- Apply existing acoustic modeling methods and further develop these tools to allow for optimizing noise control approaches
- Document noise control successes in future acquisitions
- Monitor the effectiveness of noise mitigation in the system safety process and external program reviews to support risk management, accountability, and life-cycle cost mitigation
Questions?

Special Thanks to:

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