An Investigation of Potential Intervention Strategies Involving High Noise Sources within the Department of Defense (DoD)

R. Fischer and C. Page, Noise Control Engineering, Inc.
J. Erdman, Naval Safety Center Liaison Office-Pentagon
L. Byrnes and G. Burdge, Concurrent Technologies Corporation

Disclaimer: The views expressed in this technical poster are those of the authors and do not reflect the official policy of the Department of Defense

THE INITIATIVE

EXECUTIVE SUMMARY

Under a DoD Defense Safety Oversight Council Initiative, safety and occupational health professionals, and noise control experts and acoustical engineers evaluated nine steady-state high noise sources and one promising technology.

For each source, current noise ranges were obtained from a variety of existing data sources and noise controls were identified. The combined noise treatment costs for each noise source were evaluated across selected DoD platforms. Noise Induced Hearing Loss (NIHL) cost savings were calculated using an Excel-based tool developed by Noise Control Engineering, Inc. (NCE). Returns on investment were estimated. Two distinct applications for the modular cabin/capsule/pod were identified for military ships.

BACKGROUND

Hazardous noise is a long standing concern across the Department of Defense (DoD)

- Is the only known occupational hazard with exposure levels exceeding protection capability
- Causes significant negative impact to the quality of life of 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 taxpayer is in excess of $1 Billion annually
- Is ranked #5 for DoD civilian worker compensation payout ($32M) in Chargeback Year 2012

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

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
- Determined Return on Investments - ROIs

NCE NOISE INDUCED HEARING LOSS (NIHL) COST ASSESSMENT TOOL

Based on:

- American National Standards Institute-ANSI S3.44 & International Standards Organization-ISO 1990:1999
- The "should cost" model (Sachs 2007)* which assumes 100% compliance with the Navy Hearing Conservation Program and VA requirements (more expensive than "actual cost")

*Sachs, F.Z., Weathersby, P.K., Marshall, L., and Tufts, J., 2007, "Model for Estimating Life-Cycle Costs Associated with Noise Induced Hearing Loss," NSMRL Technical Report 1248, Naval Submarine Medical Research Laboratory, Groton, CT http://www.dtic.mil/cgibin/GetTRDoc?Location=U2&doc=GetTRDoc.pdf&AD=ADA461439

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
  - 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.

RETURN ON INVESTMENT

$$ROI = \frac{\text{(NIHL Cost Savings* – Treatment Implementation Cost)}}{\text{Treatment Implementation Cost}}$$

NIHL Cost Savings/Reduction* =
Lifetime System Costs [audiograms, hearing aids, VA NIHL disability, VA tinnitus disability] without treatments —Lifetime System Cost with treatments.

NOISE SOURCE REDUCTION CONCEPT DESIGN PLANS

Shipboard Diesel Driven Systems
Noise Source and Controls

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

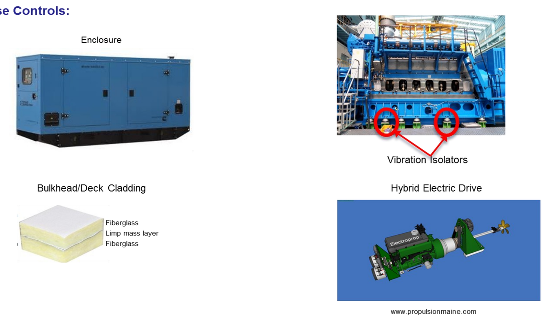
Worker Exposure Time Per Day Allowed Unprotected: 9 seconds @ 120 dBA and 24 minutes @ 98 dBA

Noise Controls:

	Standard Commercial Off The Shelf (COTS) Treatment, Potential dB Reductions	Advanced Treatments, Potential dB Reductions
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)

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

Noise Controls:



Feasibility: Yes, noise control is feasible.

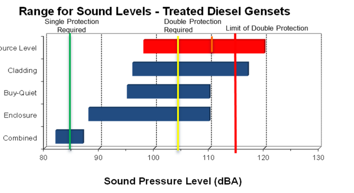
Estimated Number of DoD Acquisitions (Ships): 1095

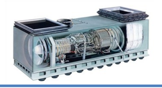
Estimated number of workers (Military and Civilians) Exposed: 26,280

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

Graph showing Noise Before and After:

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

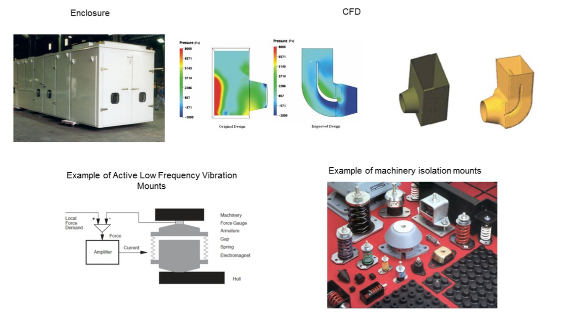
Noise Controls:

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

[1]Affecting on-deck stations and internal compartments

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

Noise Controls:



Feasibility: Yes, noise control is feasible.

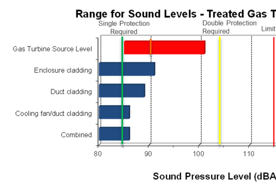
Estimated Number of DoD Acquisitions (Ships): 510

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:

Source level used – 87 dBA
TWA Source Level Used – 90 dBA



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

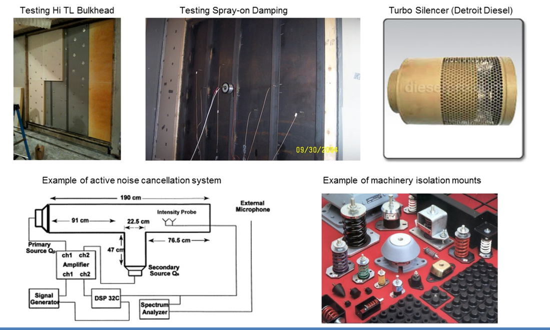
Noise Controls:

	Standard Commercial Off The Shelf (COTS) Treatment, Potential dB Reductions	Advanced Treatments, Potential dB Reductions
Airborne Noise Control	• High transmission loss (TL) Constructions (15 dB) • Buy Quiet (3-7 dB) • Damping (2-10 dB) • CFD fan/thruster design (2-15 dB)	• Improved light-weight high TL materials (3-10 dB) • Combination of thermal/fire/acoustic materials (5-10 dB)
Structureborne Noise Control	• Vibration isolation (10-15dB) • Hi-Impedance foundations (5-8 dB) • Passive vibration absorbers (10-15 dB)	• Active Control – low freq. vibration (almost COTS) (15-25 dB) • Passive tuned 'structural' absorber (5 dB)

Landing Craft Air Cushion (LCAC) fan from militaryfactory.com

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

Noise Controls:



Feasibility: Yes, noise control is feasible.

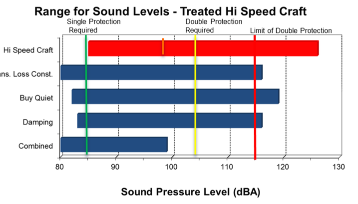
Estimated Number of DoD Acquisitions (Ships and Craft): 165

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:

	Standard Commercial Off The Shelf (COTS) Treatment, Potential dB Reductions	Advanced Treatments, Potential dB Reductions
Airborne Noise Control	• Barrier on deck (5-13 dB)	• None
Structureborne Noise Control	• None	• None

Noise Sources: Jet noise

Noise Controls:

Noise barrier similar to jet blast deflector

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

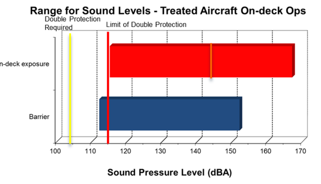
Estimated Number of DoD Acquisitions (Ships): 11

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



Aircraft Carrier Operations-Internal Compartments
Noise Source and Controls

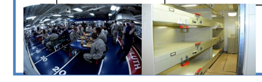
Noise Sources: Very high level, broadband noise-from jet launches, arresting gear, and water brake-is easily transmitted to berthing and living space directly below the flight deck. Noise levels in these compartments reach hazardous levels during flight operations.

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:

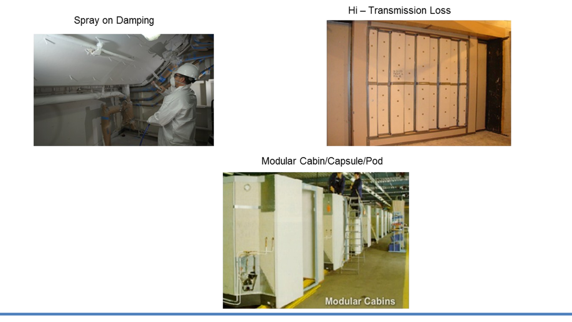
	Standard Commercial Off The Shelf (COTS) Treatment, Potential dB Reductions	Advanced Treatments, Potential dB Reductions
Airborne Noise Control	• High transmission loss (TL) Constructions (10-12 dB) • Damping (5-7 dB) • Floating Room (Capsule/Pod) (10-15 dB) • Absorptive Materials (3-5 dB)	• None
Structureborne Noise Control	• None	• None



From www.navy.mil

Noise Sources: Jet noise, catapult and retrieval systems and water brake

Noise Controls:



Feasibility: Yes, noise control is feasible.

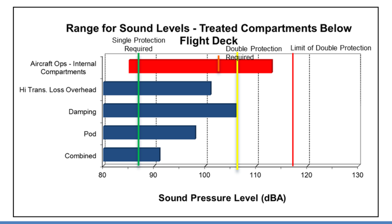
Estimated Number of DoD Acquisitions: 11

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

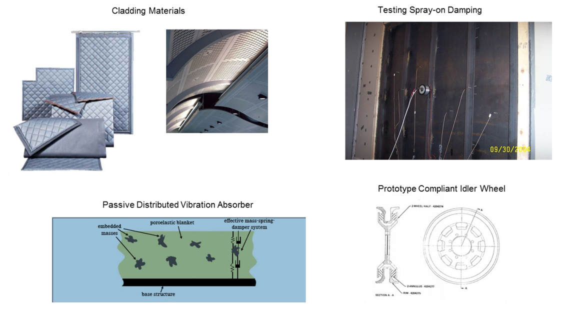
Worker Exposure Time Per Day Allowed Unprotected: 14 seconds @ 118 dBA and 4 hours @ 90 dBA

Noise Controls:

	Standard Commercial Off The Shelf (COTS) Treatment, Potential dB Reductions	Advanced Treatments, Potential dB Reductions
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)

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

Noise Controls:



Feasibility: Yes, noise control is feasible.

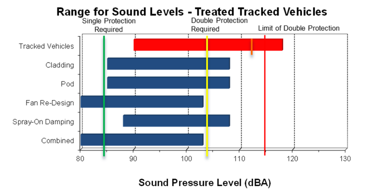
Estimated Number of DoD Acquisitions: 97,109

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

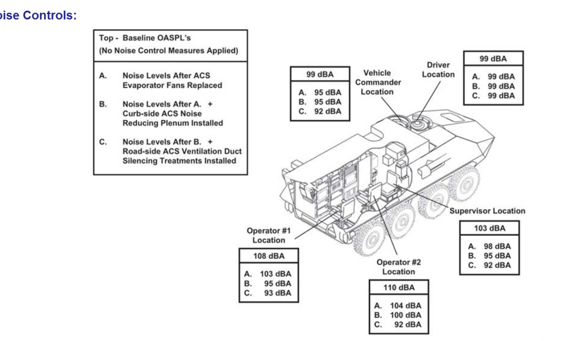
Worker Exposure Time Per Day Allowed Unprotected: 56 seconds @ 112 dBA and 8 hours @ 85 dBA

Noise Controls:

	Standard Commercial Off The Shelf (COTS) Treatment, Potential dB Reductions	Advanced Treatments, Potential dB Reductions
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)

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

Noise Controls:



Feasibility: Yes, noise control is feasible.

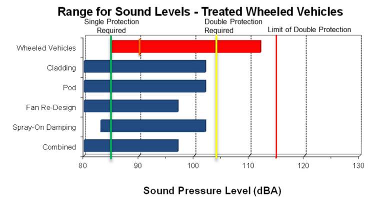
Estimated Number of DoD Acquisitions: 440,792

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



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

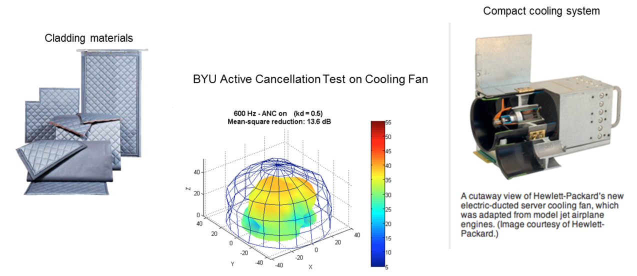
Worker Exposure Time Per Day Allowed Unprotected: 7.2 seconds @ 121 dBA and 8 hours @ 85 dBA

Noise Controls:

	Standard Commercial Off The Shelf (COTS) Treatment, Potential dB Reductions	Advanced Treatments, Potential dB Reductions
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

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

Noise Controls:



Feasibility: Yes, noise control is feasible.

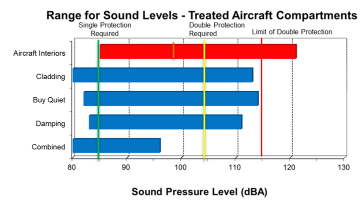
Estimated Number of DoD Acquisitions: 9,613

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

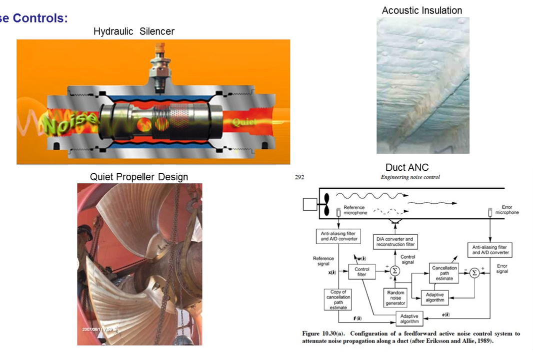
Worker Exposure Time Per Day Allowed Unprotected: 7 seconds @ 121 dBA and 8 hours @ 85 dBA

Noise Controls:

	Standard Commercial Off The Shelf (COTS) Treatment, Potential dB Reductions	Advanced Treatments, Potential dB Reductions
Airborne Noise Control	• 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)	• Improved light-weight high transmission loss materials (5-10 dB) • Active noise control (HVAC) (12 dB)
Structureborne Noise Control	• Vibration isolation (10-15 dB) • Hi-Impedance foundations (5-8 dB)	• Active Control – low frequency vibration (almost COTS) (15-25 dB)

Noise Sources: HVAC systems, propulsors, compressors and pumps

Noise Controls:



Feasibility: Yes, noise control is feasible.

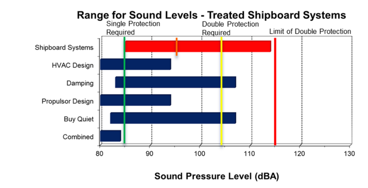
Estimated Number of DoD Acquisitions (Ships): 602

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

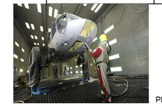
Noise Source: High level broadband noise defined by the nozzle and delivery system, size and composition of item being blasted, blasting area and work piece angle. Critical components are air blaster nozzle, air supply to hood, air compressors, exhaust ventilation and air releases during grit pot blow-down.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

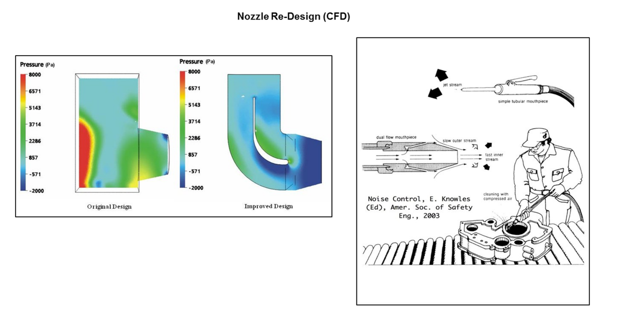
	Standard Commercial Off The Shelf (COTS) Treatment, Potential dB Reductions	Advanced Treatment, Potential dB Reductions
Airborne Noise Control	• Nozzle redesign-computational fluid dynamics (CFD) (2-4 dB)	• Partial nozzle barrier (2-4 dB)
Structureborne Noise Control	• None	• None



Plastic media blasting from www.army.mil

Noise Sources: Nozzle, air compressors and exhaust ventilation systems

Noise Controls:



Feasibility: Noise control will require research and development.

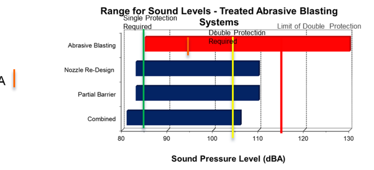
Estimated Number of DoD Acquisitions: 500

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



PROMISING TECHNOLOGY

Modular Cabin/Capsule/Pod-Promising Technology
Noise Control – Shipboard Noise

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.

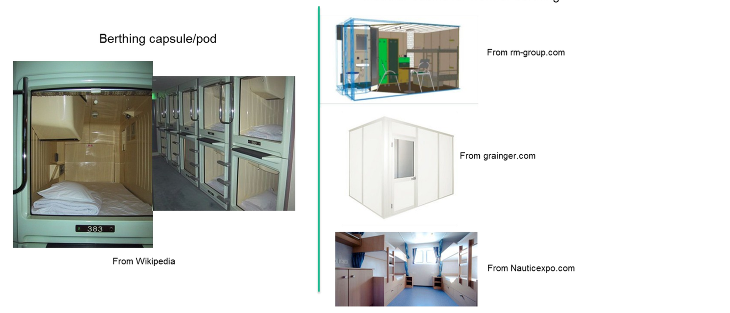
Current Shipboard Noise Range Lower Estimate – Upper Estimate at ear level: 85-121 dBA

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.

	Benefit of Standard Commercial Off The Shelf (COTS) Modular Cabins and Berthing Capsules/Pods
Navy	• 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.
Cruise Industry	• Standard on many cruise ships to provide guests cabins with quiet spaces [Noise standard for cruise industry 49 – 55 dB(A)]

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

Noise Controls: Modular Cabin or 'Capsule'/'Pod'



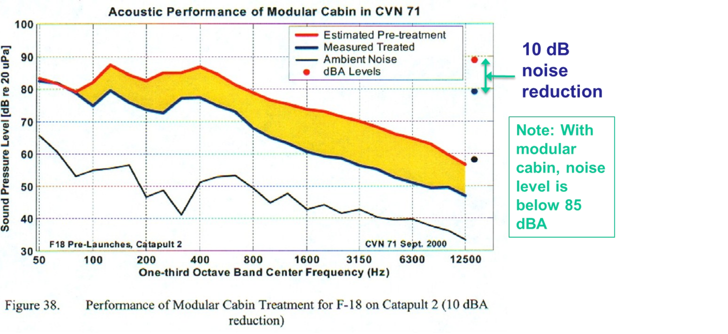


Figure 38. Performance of Modular Cabin Treatment for F-18 on Catapult 2 (10 dBA reduction)

Ref.: Kurt Yankaskas & Mike Shaw, "Landing on the Roof: CVN Noise," Naval Engineers Journal, Vol. 111, Issue 4, July 1999.

WAY AHEAD

CONCLUSIONS

- For each of the nine high noise sources, controls were found to be technically and economically feasible, with positive estimated returns on investments
- Modular cabin/capsule/pod technology can be used to (1) make ship berthing quieter and increase "noise recovery" and (2) be used as isolation booths in high noise work areas.

This poster and report will be available at: http://www.public.navy.mil/navsafecen/Pages/acquisition/noise_control.aspx

RECOMMENDATIONS

- Use the results of this investigation to more effectively target opportunities for future noise control.
- Consider a Buy Quiet approach for noise control that are available as commercial off the shelf (COTS)
- Conduct area surveys (not only personal dosimetry) for high noise operations, in order to assist acoustical engineers in designing noise control.
- Recommend ACGIH develop an additional Noise TLV for the limit of double hearing protection. Such a TLV would provide impetus for greater emphasis on engineering controls.

ACKNOWLEDGEMENTS

This initiative was inspired by Technology for a Quieter America, Dr. George Maling, et.al, National Academy of Engineering, available at: http://www.nap.edu/catalog.php?record_id=12928

Dr. Howard, Director of NIOSH, for advising us to review the excellent noise control work that the NIOSH Pittsburgh Office (David Yantek, et.al) is doing for the mining community. They showed us what is possible.