Introduction to Ship Radiated Noise

UNOLS Fleet Improvement Committee
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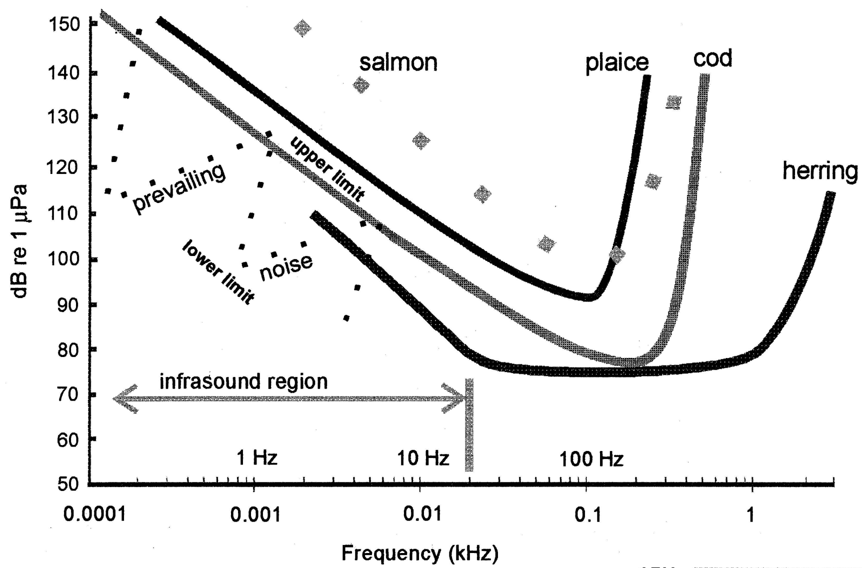
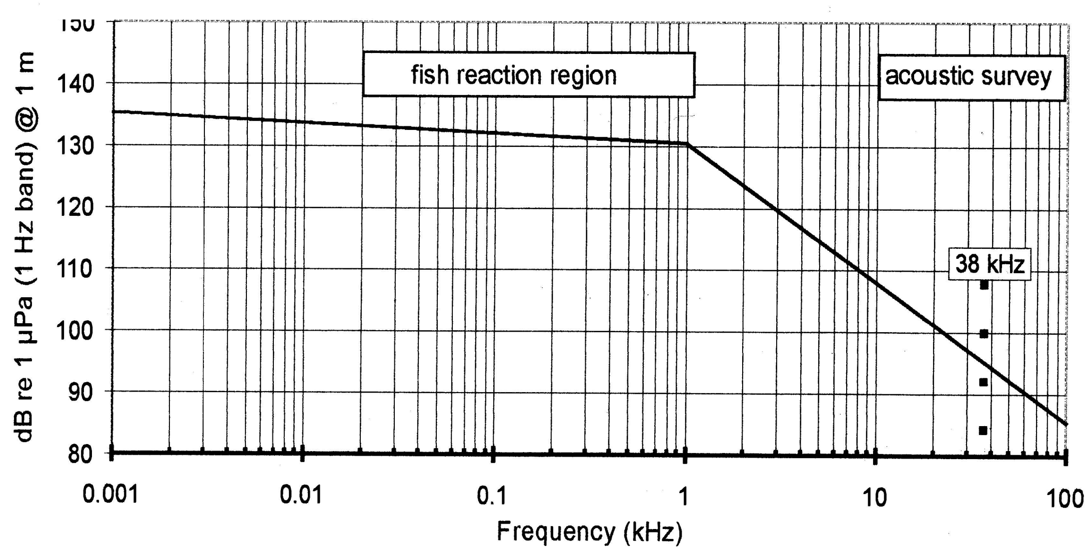
Ship Radiated Noise

- Why care?
  - ICES, marine mammals
  - Impact on Shipboard Mission Systems
  - Mutual Interference
  - Environmental Impact Assessment
- What makes noise?
  - Propellers
  - Machinery
  - Transient sources
- How do you measure it ?
  - Acoustic ranges
  - Shallow water / short range measurements
- How do you model or predict it?
  - Computational, empirical and hybrid methods
  - Machinery Noise Prediction Models

Radiated Noise Criteria





From Mitson, “UNDERWATER NOISE OF RESEARCH VESSELS, 1995

Definitions

- Radiated Noise
  - Ship noise that is transmitted into the water and can be detected by off-board receivers
    - Typically reported as One Third octave (OTO) Band
    - Narrowband (1 HZ) data used to characterize machinery tonals

- Radiated Noise Source Level
  - Equivalent simple source (omnidirectional monopole) level

    SL dB re 1 µPa @ 1m

    - Back-propagated to 1m assuming spherical spreading from a ***far field, free-field*** measurement

- Platform Noise
  - Ship noise that can be detected by acoustic or vibration sensors
    - Not necessarily detectable as radiated noise

- Sonar Self-Noise
  - Received acoustic levels in the output of mission system receiving band(s) due to own-ship platform noise sources

Radiated Noise Characterization

- Propagation models treat a ship as a *spatially-compact simple harmonic source*

$\lambda >> a$ $\quad\quad$ $ka << 1$ $\quad\quad$ $k = \dfrac{\omega}{c}$

- Far field acoustic pressure assumed to have range varying component given by

$$p(r) = \frac{j\,k\rho_0\,cS_\omega}{r}e^{-jkr}$$

- Leads to familiar expression for spherically spreading sound pressure level (SPL)

$$SPL(r) = 10\log\left(\frac{p^2(r)}{p^2(r_{ref})}\right) = L_s - 20\log(r)$$

- For source with directivity

$$p(r,\theta,\phi)e^{j\omega t} = p(r)H(\theta,\phi)e^{j\omega t}$$

Example Radiated Noise Data

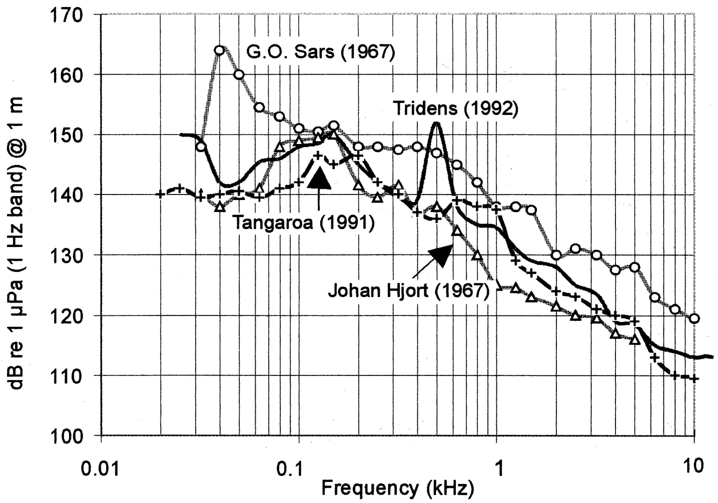


Figure 13. Comparison of noise levels between two vessels built in the 1960's and two built in the 1990's, all free-running at 11 knots.

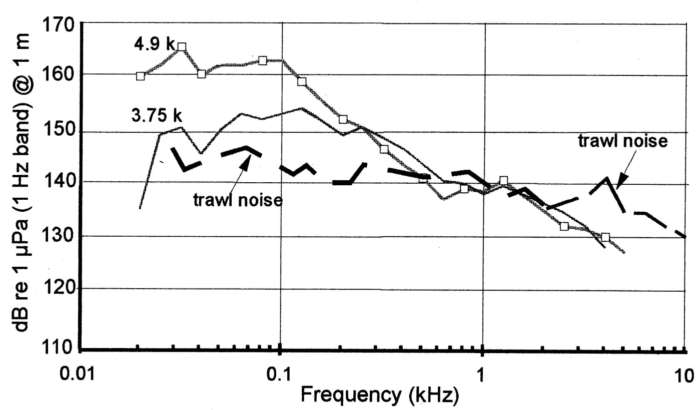
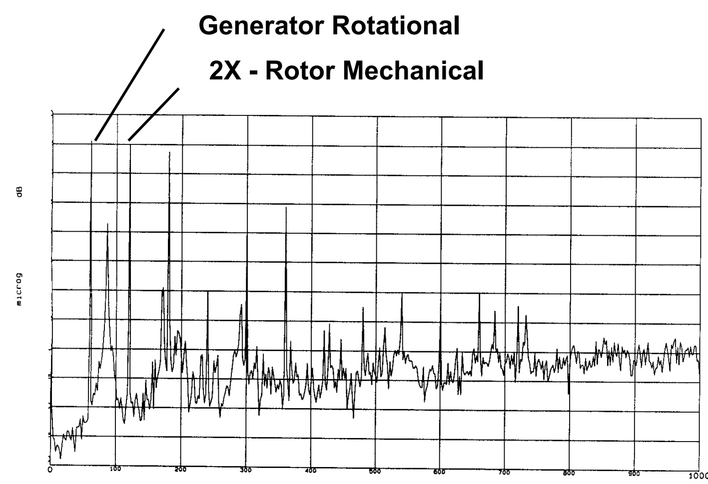
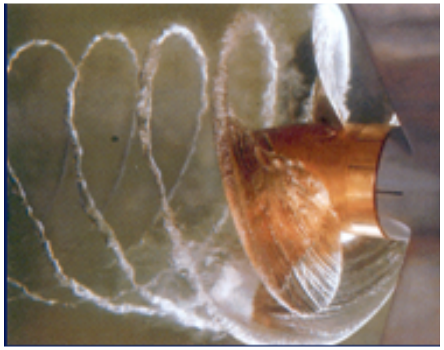


Figure 14. "Explorer" towing a bottom trawl at two speeds. Note that the trawl noise is less than the vessel noise below 500 Hz.

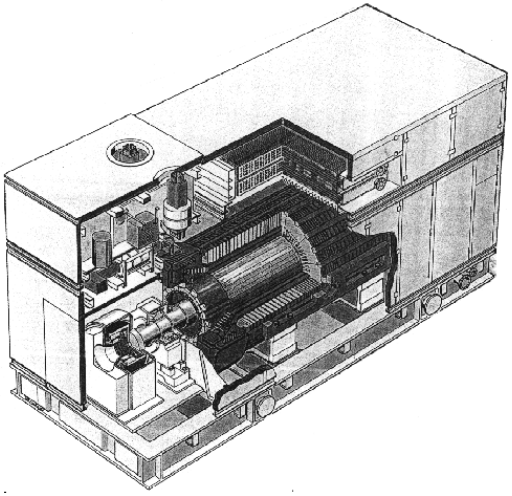


Radiated Noise Sources

- **Sources**
  - Propulsor Noise
  - Machinery Noise
  - Sea connected systems (pumps)
  - Transient sources

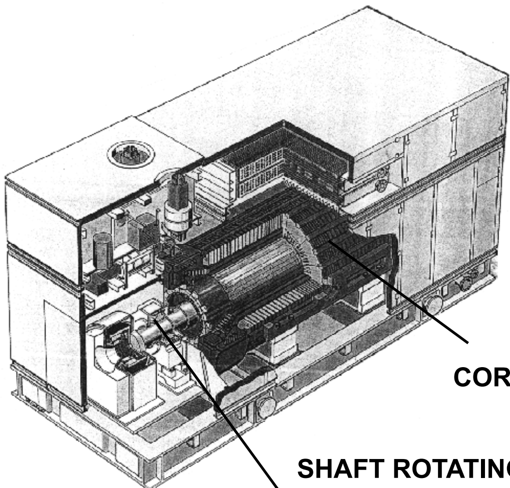


- **Paths**
  - Direct acoustic propagation
  - Shaft line propogation
  - Sound/structure interaction
  - Diffracted paths
  - Tankage



Machinery Sources

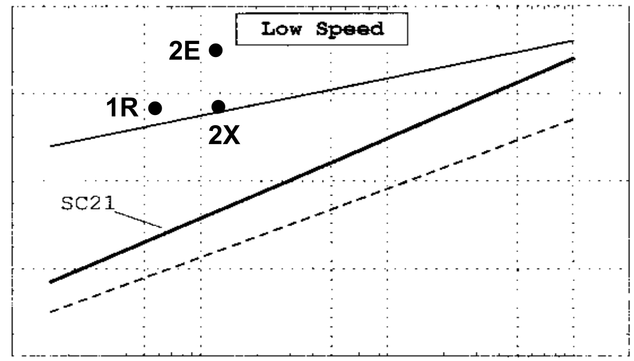
25 MW Alstom Generator



Measurements taken 30 Sept 1998

CORE MAGNETOSTRICTION 2E

SHAFT ROTATING 1R AND 2R

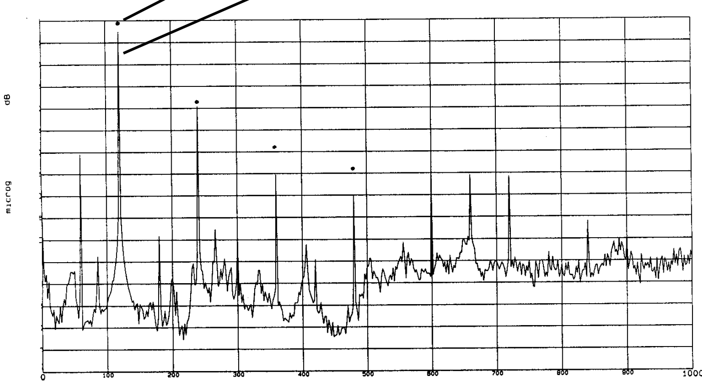


Frequency, Hz

5 to 15 Knots
Low Speed Limits

2E - Full load

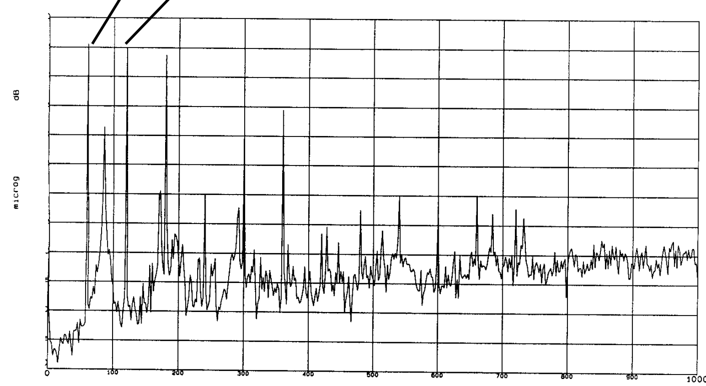
2E - No load with excitation



Stator Core Radial

Generator Rotational

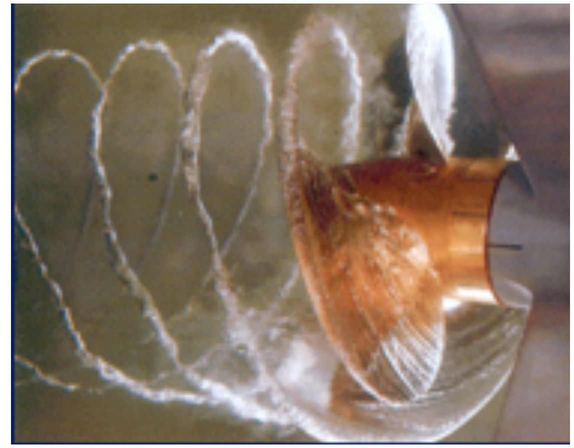
2X - Rotor Mechanical

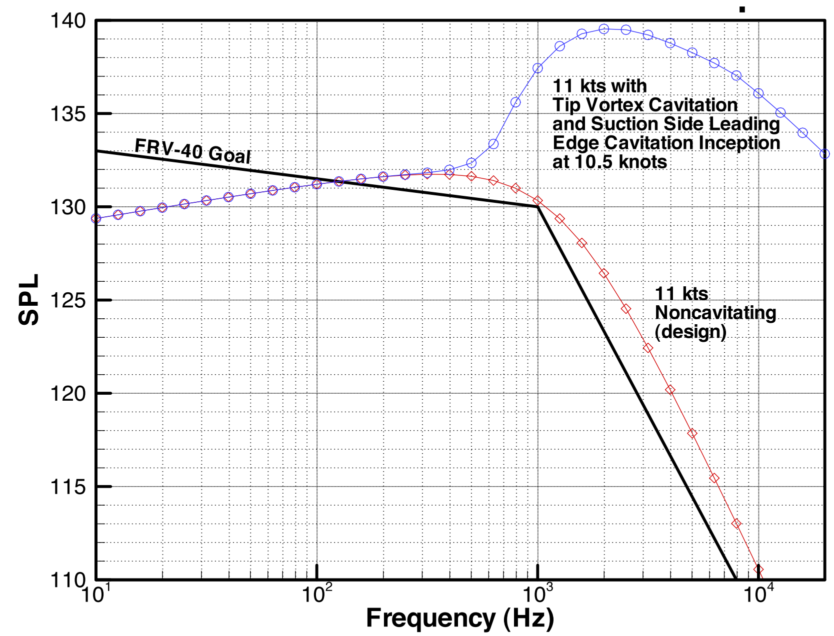


Bearing Cap Vertical - 3600 RPM

Propeller Noise

- Cavitation typical dominates broadband ship signature
  - Mitigation:
    - Design prop for maximum cavitation inception speed
    - Restrict noise-sensitive operations to speeds less than cavitation inception
- Propeller Broadband Noise





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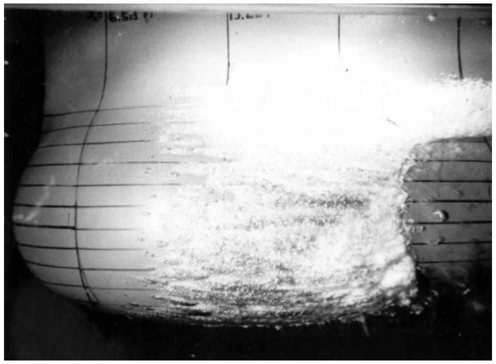
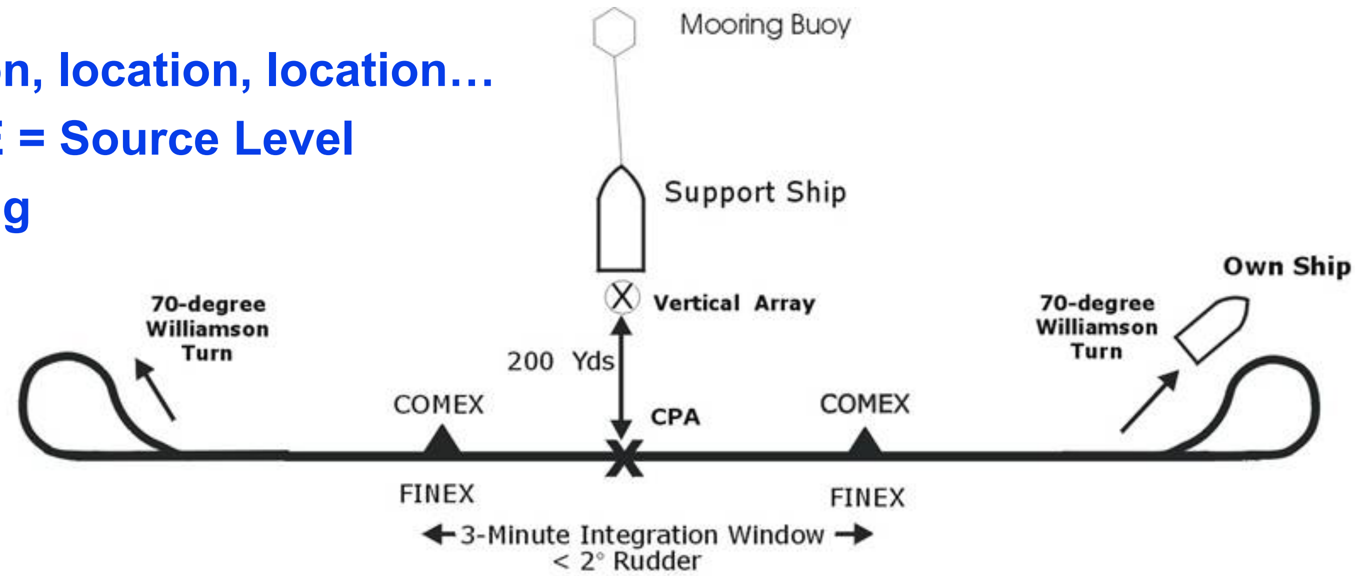
Non-propulsion Flow-related Noise

- Hull and appendage cavitation
- Bow wave transients
- Rudders + Struts



Radiated Measurements

- Measurements *AT SEA* using *UNDERWATER* instrumentation
  - Logistics
  - Instrumentation
  - Personnel
  - Assets
- Moving Source + Moving Receiver
  - Location, location, location…
  - RANGE = Source Level
  - Tracking



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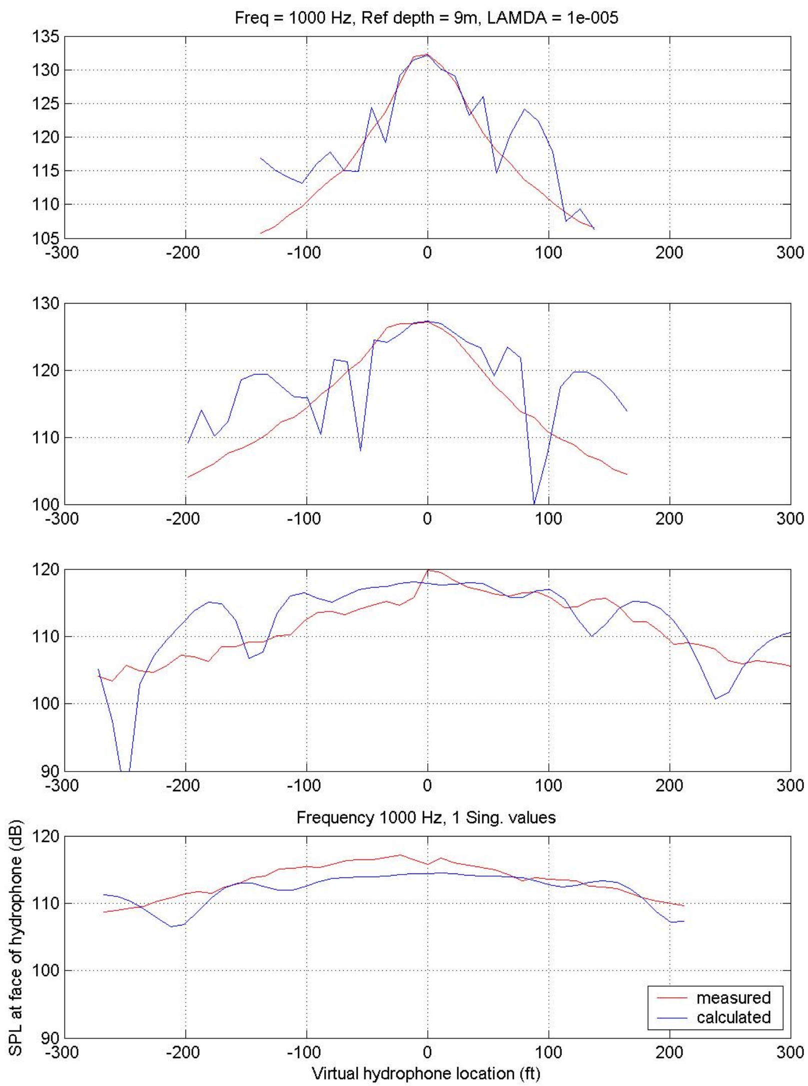
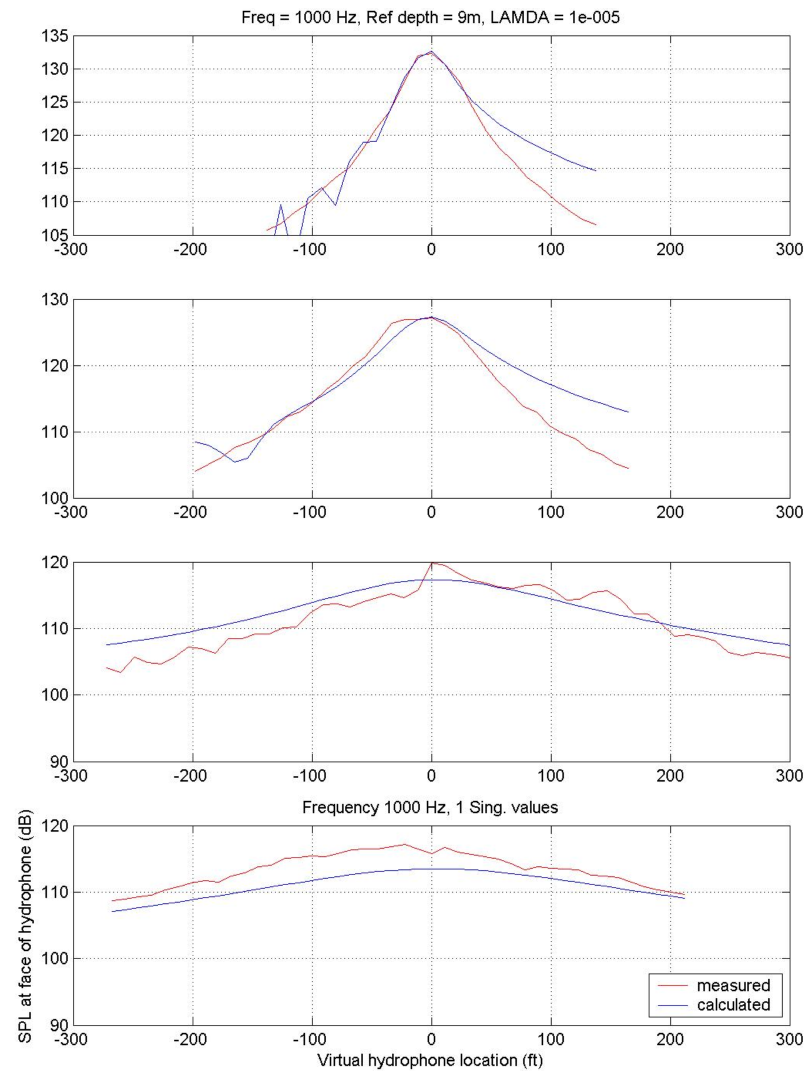
Deep Water Measurements

With Surface Reflected Path (Lloyd Mirror)

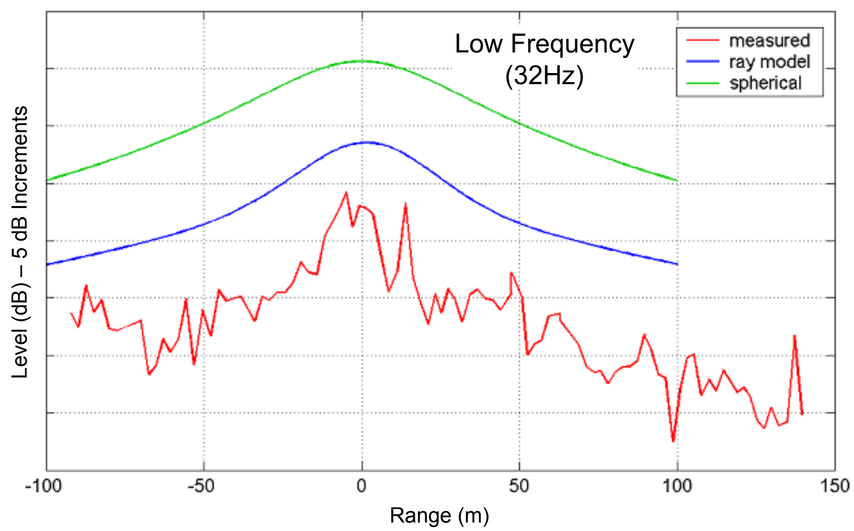


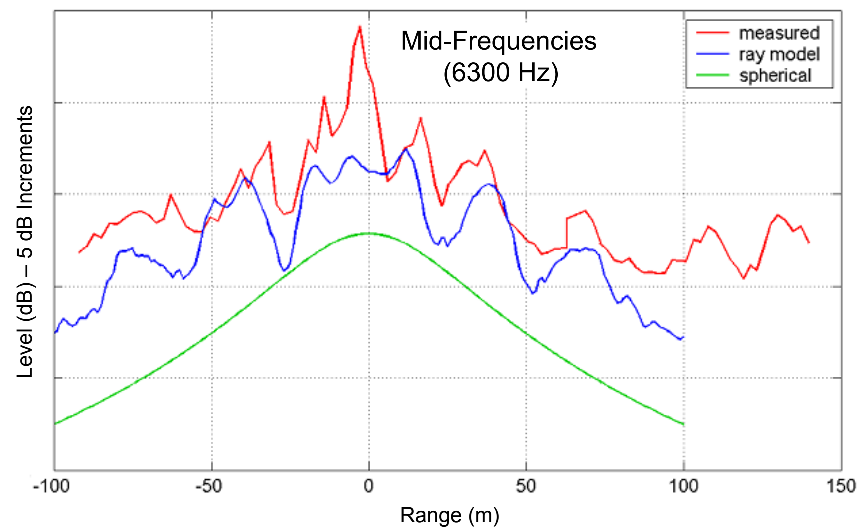
Without Surface Reflected Path



Shallow Water Data

- **Simple source models coupled with simplified propagation assumptions *inadequate* to capture sound field variability for real sources in shallow water**





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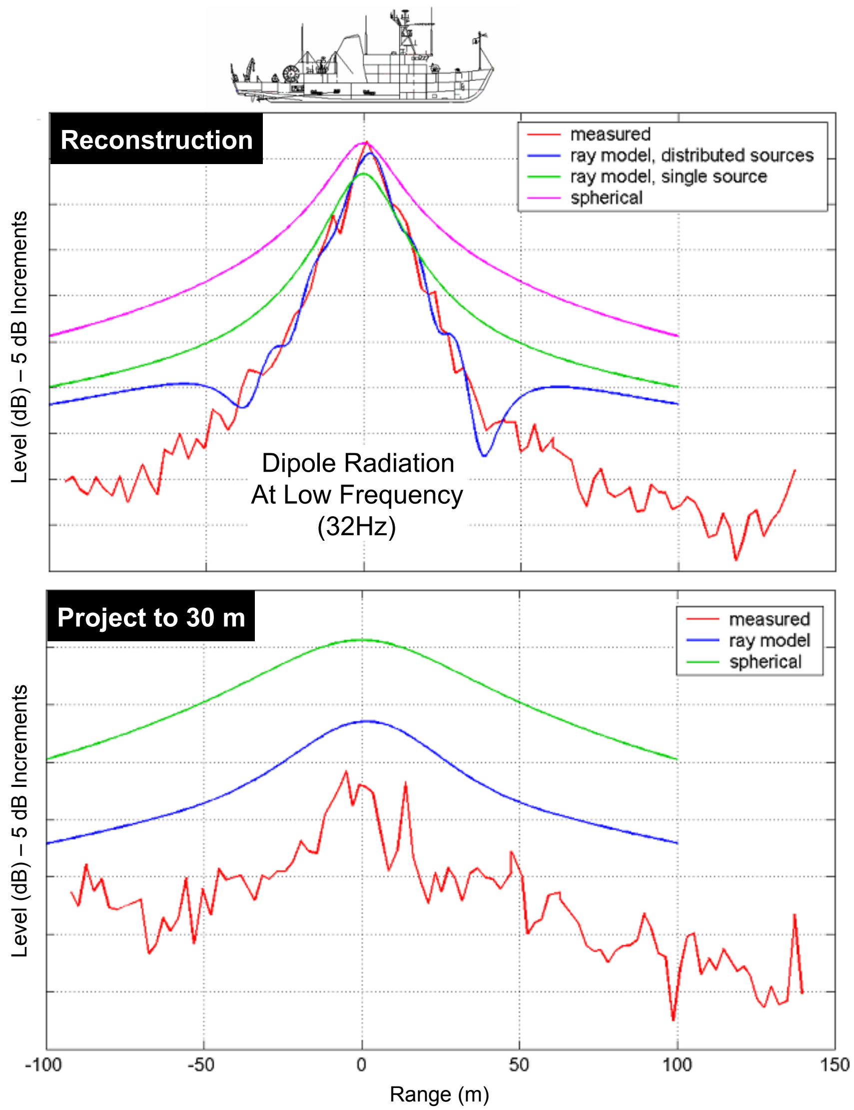
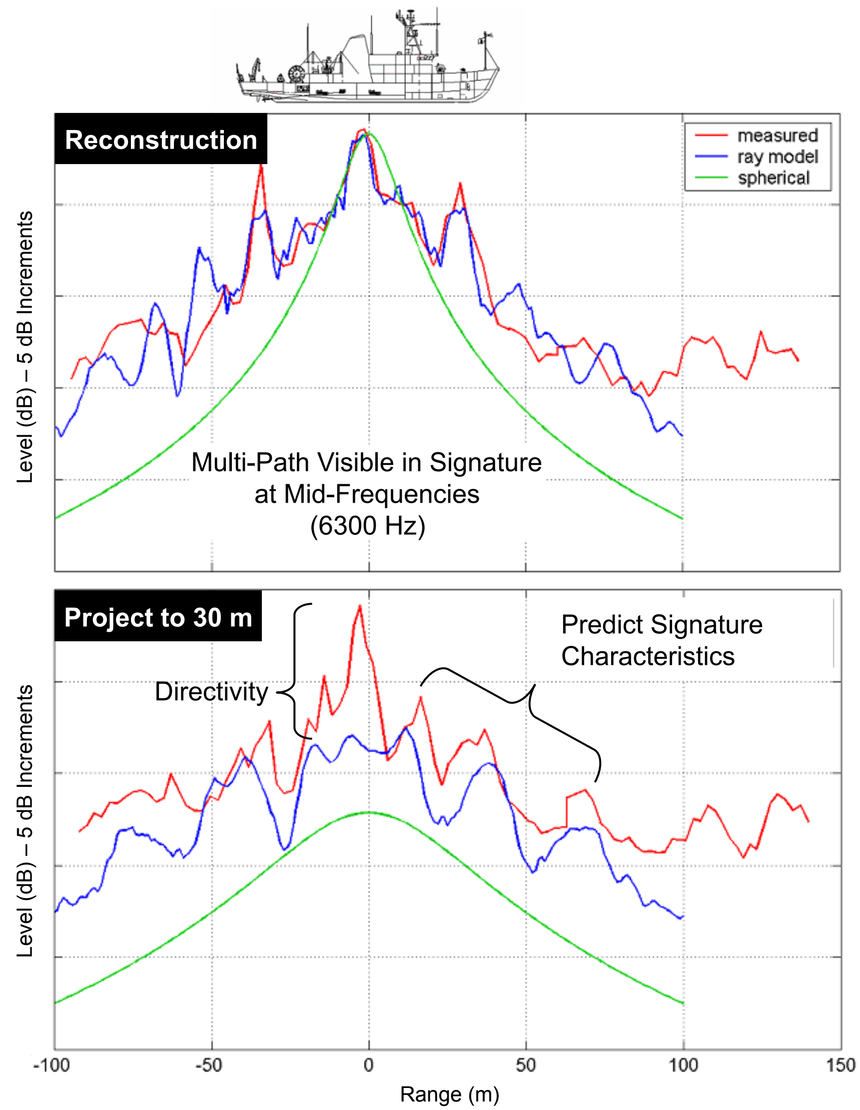

Reconstruction
measured
ray model, distributed sources
ray model, single source
spherical
Dipole Radiation
At Low Frequency
(32Hz)
Level (dB) – 5 dB Increments
Project to 30 m
measured
ray model
spherical
Level (dB) – 5 dB Increments
-100
-50
0
50
100
150
Range (m)


Reconstruction
measured
ray model
spherical
Multi-Path Visible in Signature
at Mid-Frequencies
(6300 Hz)
Level (dB) – 5 dB Increments
Project to 30 m
Directivity
Predict Signature
Characteristics
Level (dB) – 5 dB Increments
-100
-50
0
50
100
150
Range (m)

Sonar Self-Noise Sources

- **Flow –related (non-propulsion)**
  - Bow-area flow noise
  - Bow wave transient
  - Flow-induced structural excitation
- **sonar windows**
  - window material
  - window attachment mechanism
- **Propagation of AFT sources into sonar**
  - machinery / prop noise via hull grazing path
  - Bottom reflected path

SONAR Self-Noise

Active Sonar Equation

$$SNR = [SL-2TL + 20\log H_T H_R + TS]-\{NR+(NL_0-DI_R)\}$$

- Source Level → SL
- Transmit/Receive Directivity → $H_T H_R$
- Receive Reverb → NR
- Ambient + Self-Noise → NL_0
- Transmission (Propagation) Loss → TL
- Target Strength → TS
- Directivity Index → DI_R

Passive Sonar Equation

$$SNR = [SL-PL + 20\log H_R(\theta,\phi)]-\{NL_0-DI_R\}$$

- Source Level → SL
- Receive Directivity → $H_R(\theta,\phi)$
- Ambient + Self-Noise → NL_0
- Prop Loss → PL
- Directivity Index → DI_R

Sonar

Target

Environment

Sonar/Platform/Environment

Sonar Self-Noise Model