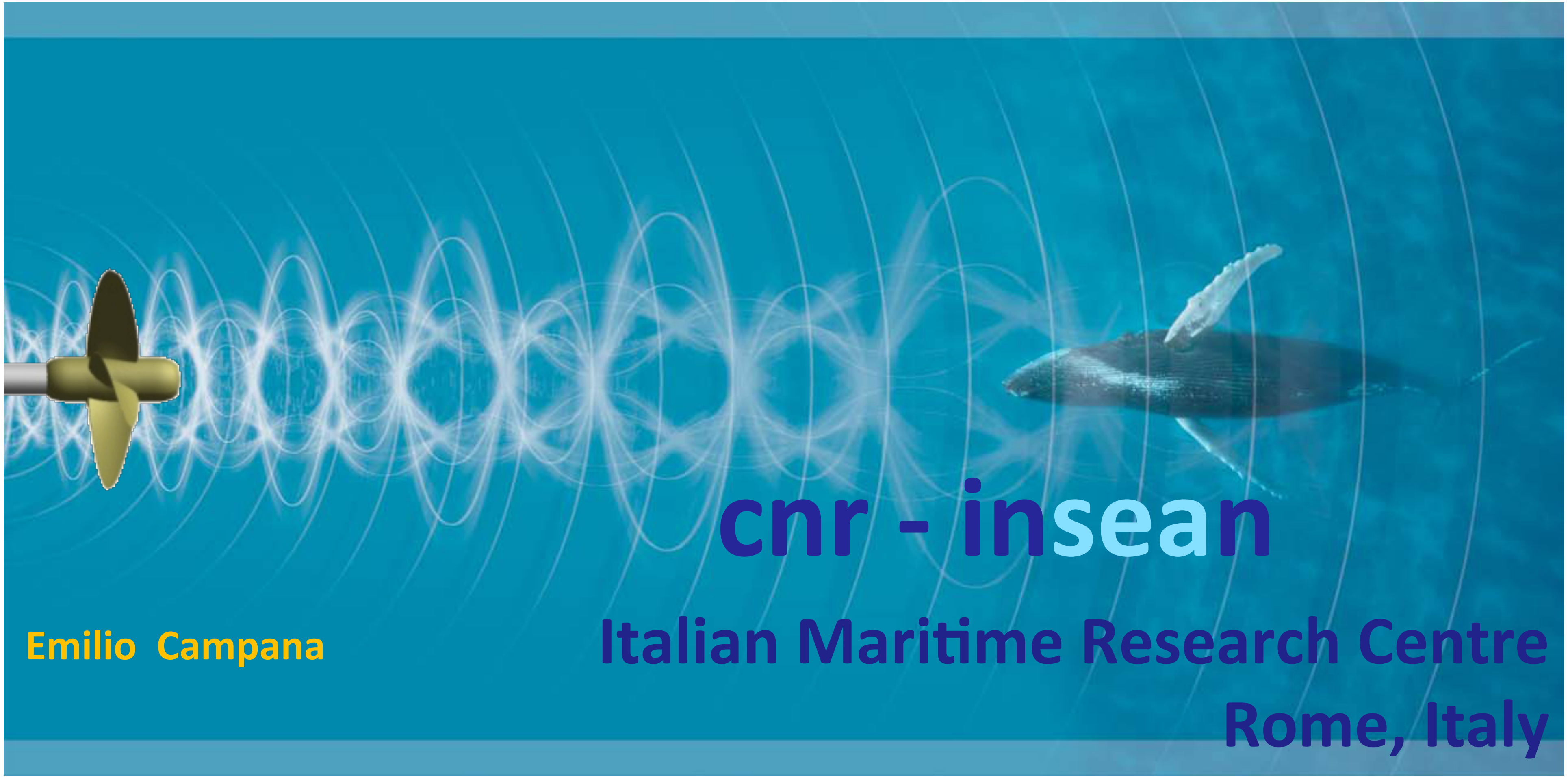
Designing green and silent RVs

What maritime research can do?



cnr - insean

Emilio Campana

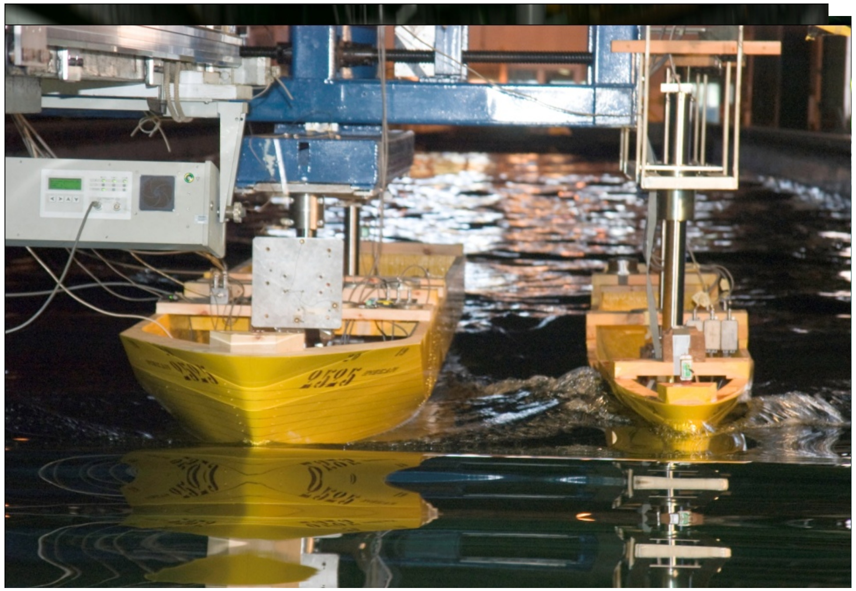
Italian Maritime Research Centre

Rome, Italy

INSEAN just joined CNR (March 21, 2011)

We perform:

- **Numerical / Experimental research** on naval hydrodynamic and marine engineering
- Tests of new **marine vessels**, **renewable energy devices**, **propellers**, etc.
- **130** people (**45** researchers & res. engineers + **15** temporary positions)

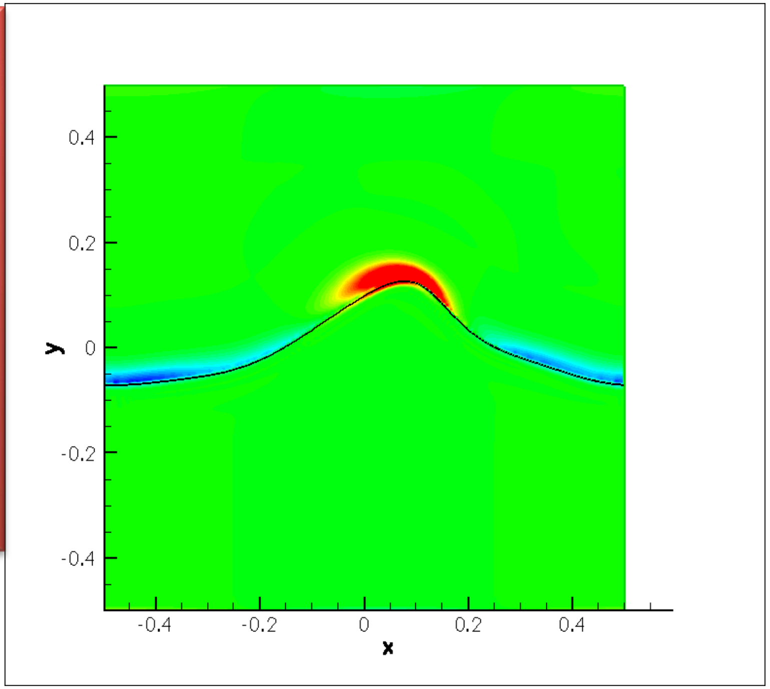


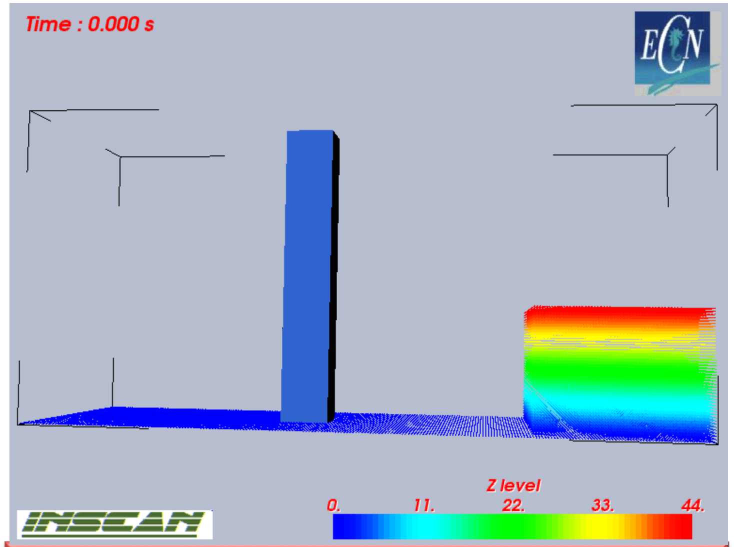
- Strong partnership with *universities, research labs*
- Industrial partnerships: *Airbus, Alenia, CONI, Piaggio, Ferrari, Fincantieri, Finmeccanica, Boeing, DSO National Laboratory, Thyssen-Krupp*
- ONR (USA DoD) funding since 1999
- Stage programs for graduate, PhD and post-docs from all-over the world
- Scientific support to the Italian and European Navies
- Large **experimental facilities**

INSEAN


Infrastructures
for maritime design and testing
Two towing tanks
#1) Among the largest worldwide (470 x 13.5 x 6.5 *m*, carriage max. speed 15 m/s);
#2) Half of #1, but equipped with a wavemaker for rough sea experiments
Two circulating water channels
Lases Doppler or Particle Image Velocimetry etc.
Water flume (with inclined floor)
Prototype/model factory
Sloshing lab

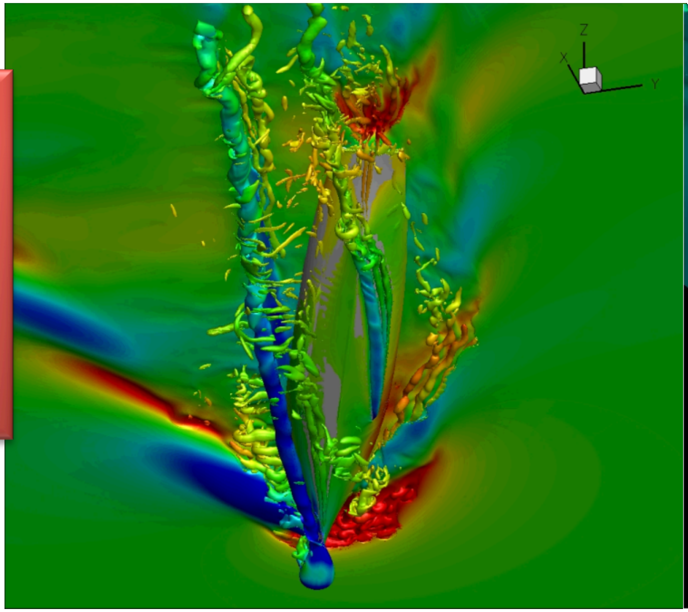
DNS – Finite difference Level-Set code for wave breaking phenomena and air-water interface simulations

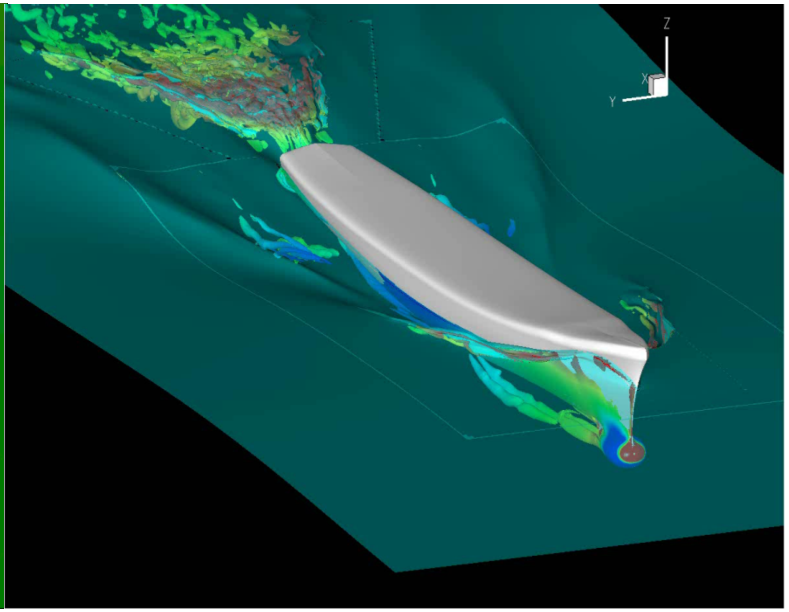




SPH – Lagrangian code for violent water phenomena

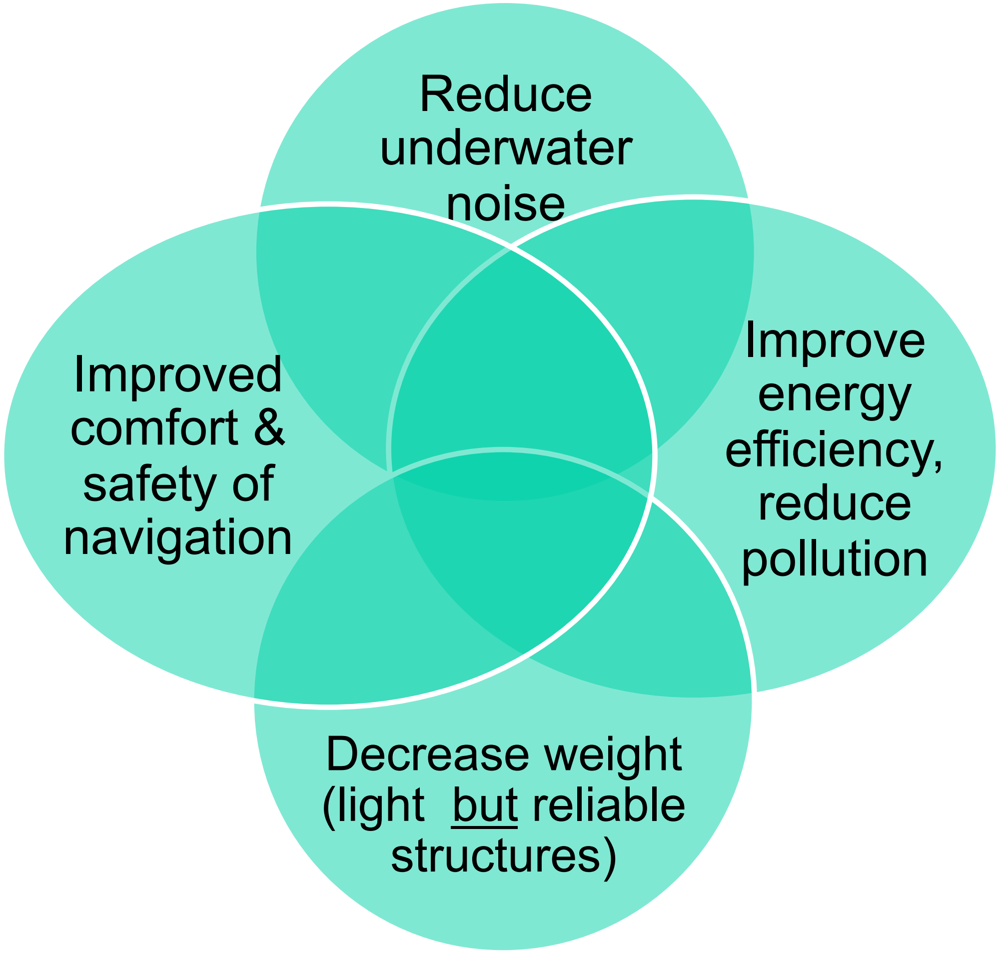
URANS – Finite volume code for unsteady turbulent Simulations with body dynamics



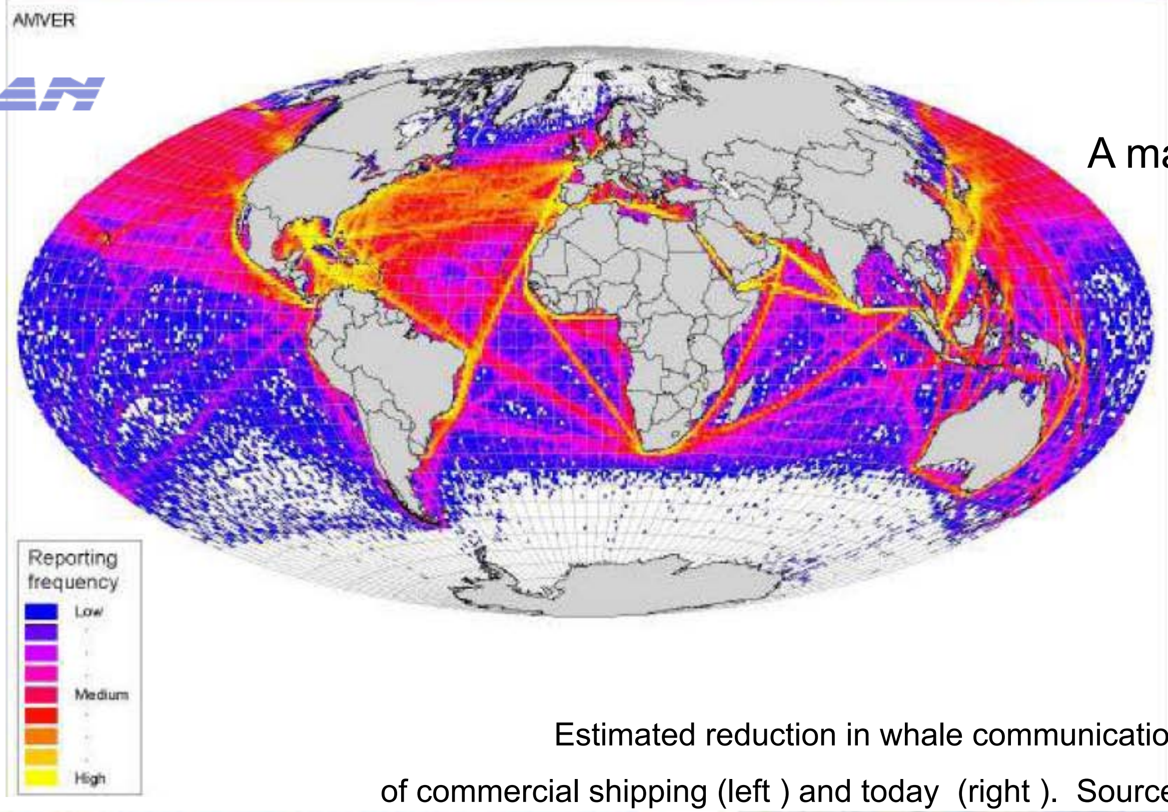


Maritime technologies for greener and more quite ships

Development of new **mathematical models** and **experimental methods** to establish new design tools and technologies for better ships



Reduce underwater noise



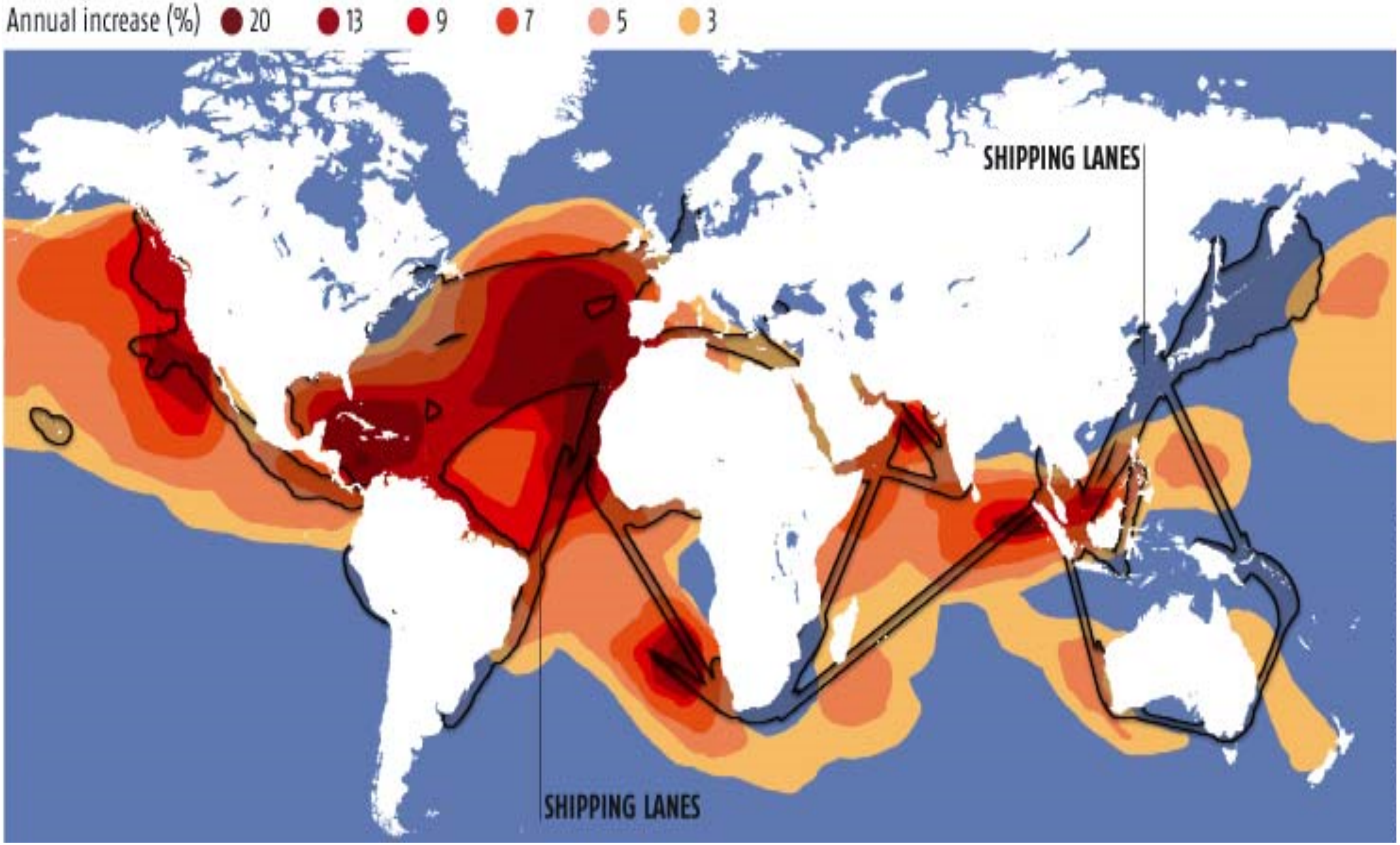
A map of the ship generated underwater noise

source: U.S. Coast Guard

Estimated reduction in whale communication range: prior to the advent of commercial shipping (left) and today (right). Source :C.W. Clarke, Cornell Univ.

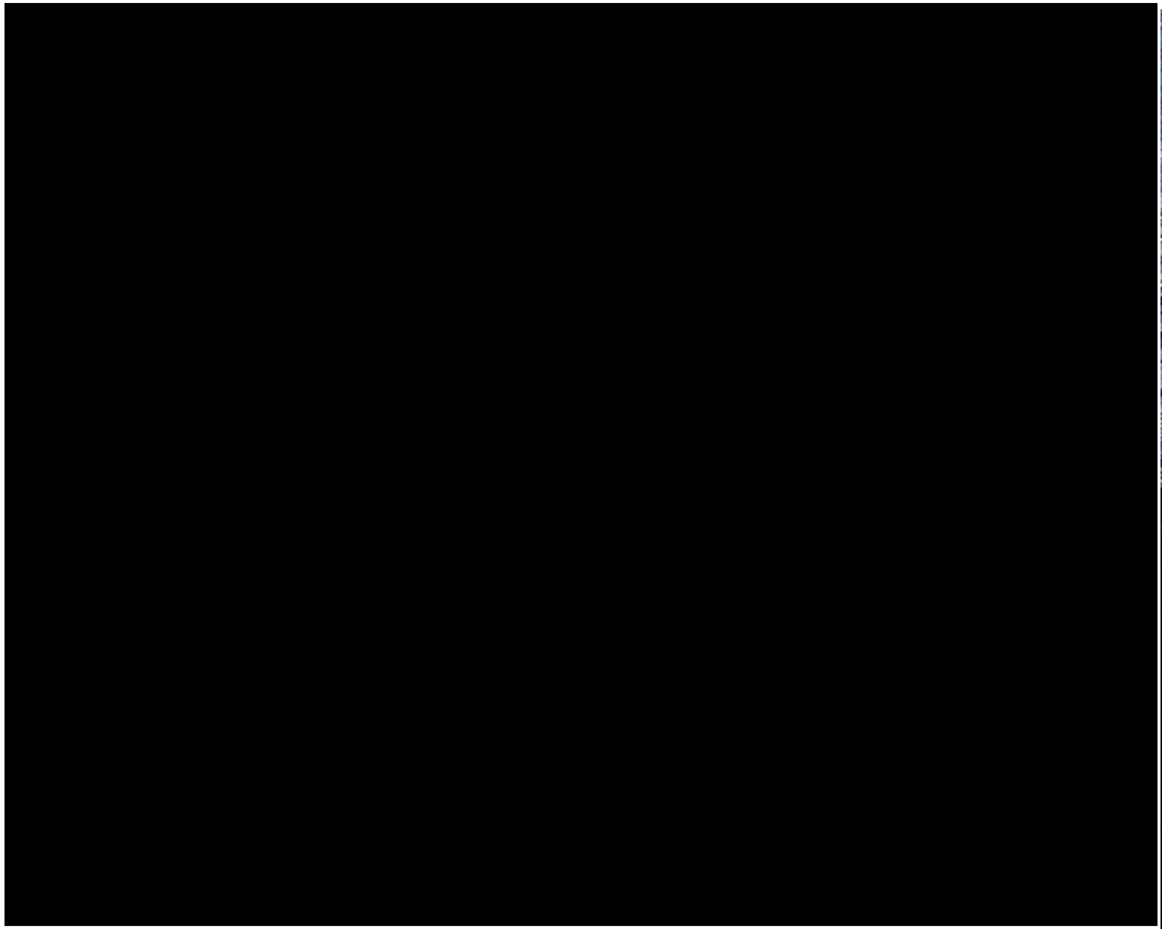
POLLUTION AT SEA

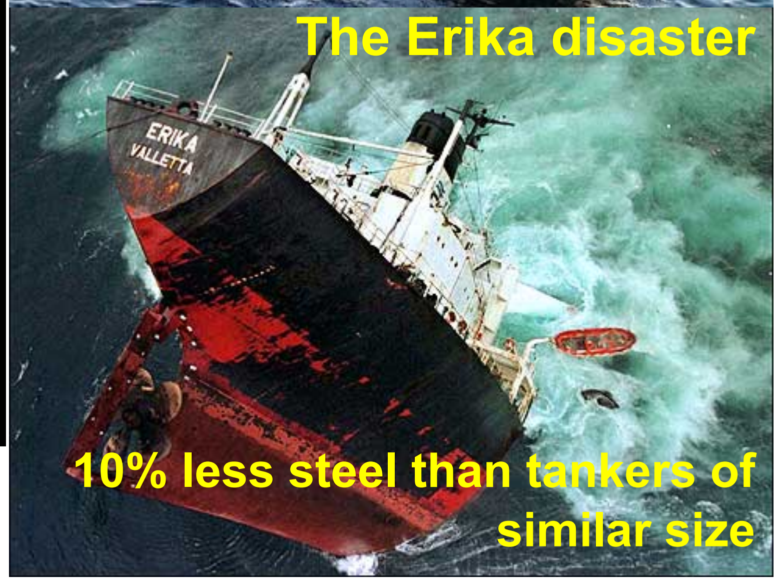
Sulphur emissions are increasing fastest close to the main shipping lanes

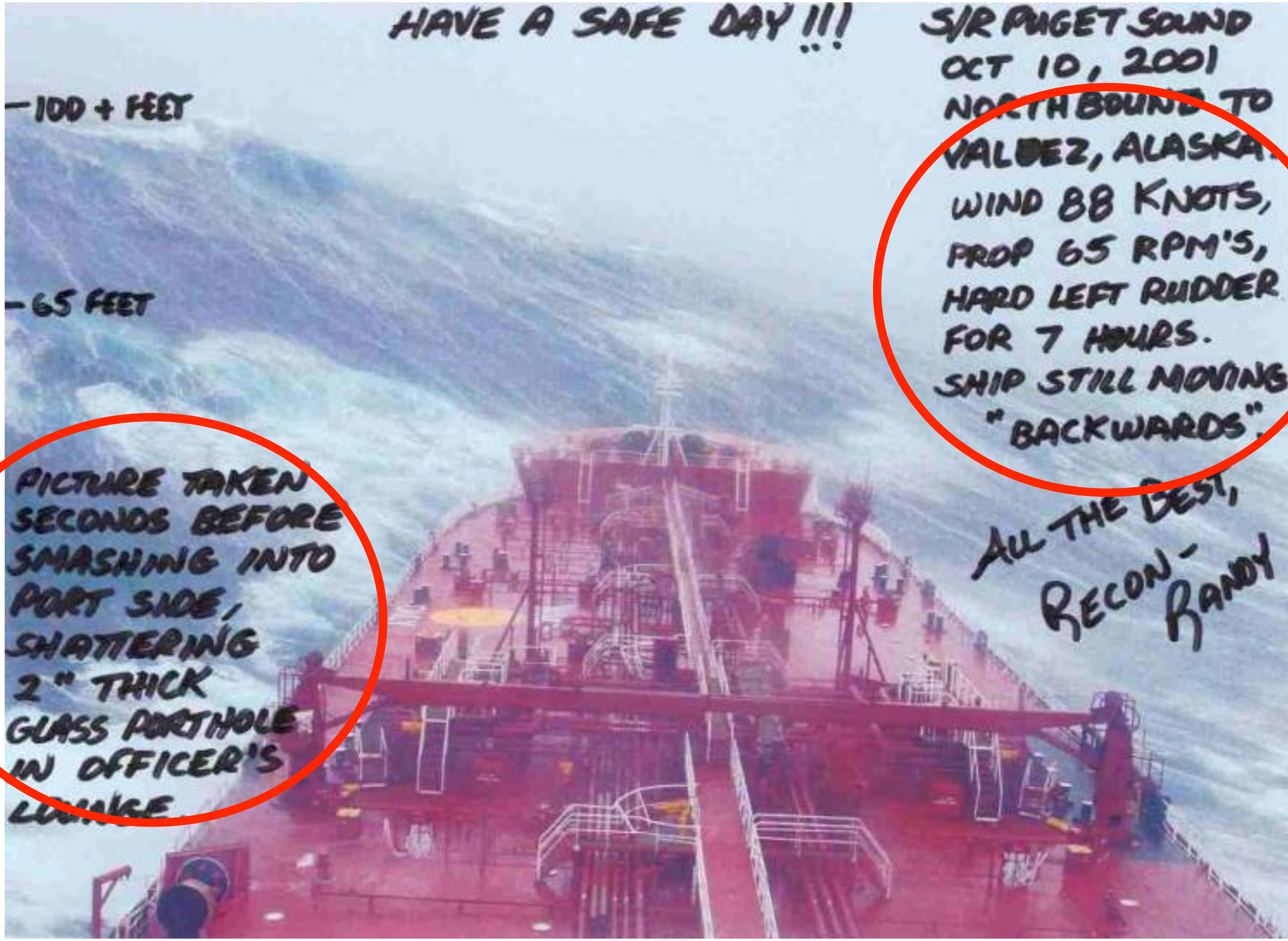


source: J. Geophysical Research

Decrease weight (light <u>but</u> reliable structures)






HAVE A SAFE DAY!!!
S/R PUGET SOUND
OCT 10, 2001
NORTHBOUND TO
VALDEZ, ALASKA.
WIND 88 KNOTS,
PROP 65 RPM'S,
HARD LEFT RUDDER
FOR 7 HOURS.
SHIP STILL MOVING
"BACKWARDS".
-100 + FEET
-65 FEET
PICTURE TAKEN
SECONDS BEFORE
SMASHING INTO
PORT SIDE,
SHATTERING
2" THICK
GLASS PORTHOLE
IN OFFICER'S
LOUNGE.
ALL THE BEST,
RECON-
RANDY

The low internal noise level in modern ships might give the impression that the vessel is quit in all respects. This is NOT the case

Steady upward trend since WW II mainly because the increase in propulsion power for all vessels

Quieting the new RVs: why?

1. Reinforce the **public commitment** to mitigate the threat to marine wildlife posed by maritime noise by avoiding that research activities may contribute to the increasing level of noise in the oceans (*especially while we all ask for a public environmental assessment in terms of noise pollution induced by major developments - industrial or military - in the marine environment)*

3. Reinforce the **public commitment,** employing this *design* chance to develop new technologies / use existing technologies in noise reduction

5. Reduce the chance that, while operating in marine protected areas and critical habitats, RV's might contribute to noise pollution themselves. *From the ERVO ToR: "Identify methods to minimize the impact of the operations of RVs ... On the environment".*

7. Ensure that marine wildlife natural behavior is not altered as the vessel approaches, and prevent the noise from being integrated a signal

Sources of marine noise

Natural noise

Vessel traffic

Oil and gas exploration

- Seismic surveys
- Marine seismic surveys
- The seismic source (airguns and airgun arrays)

Industrial noise associated with oil and gas exploration and production

- **Noise sources**
  - Machinery noise
  - Propeller noise
  - Hydrodynamic noise
  - Impulsive noise
- **Rig and platform noise**

Ocean experiments

- Acoustic thermography

Marine science research

Military

Purposeful scaring of marine mammals

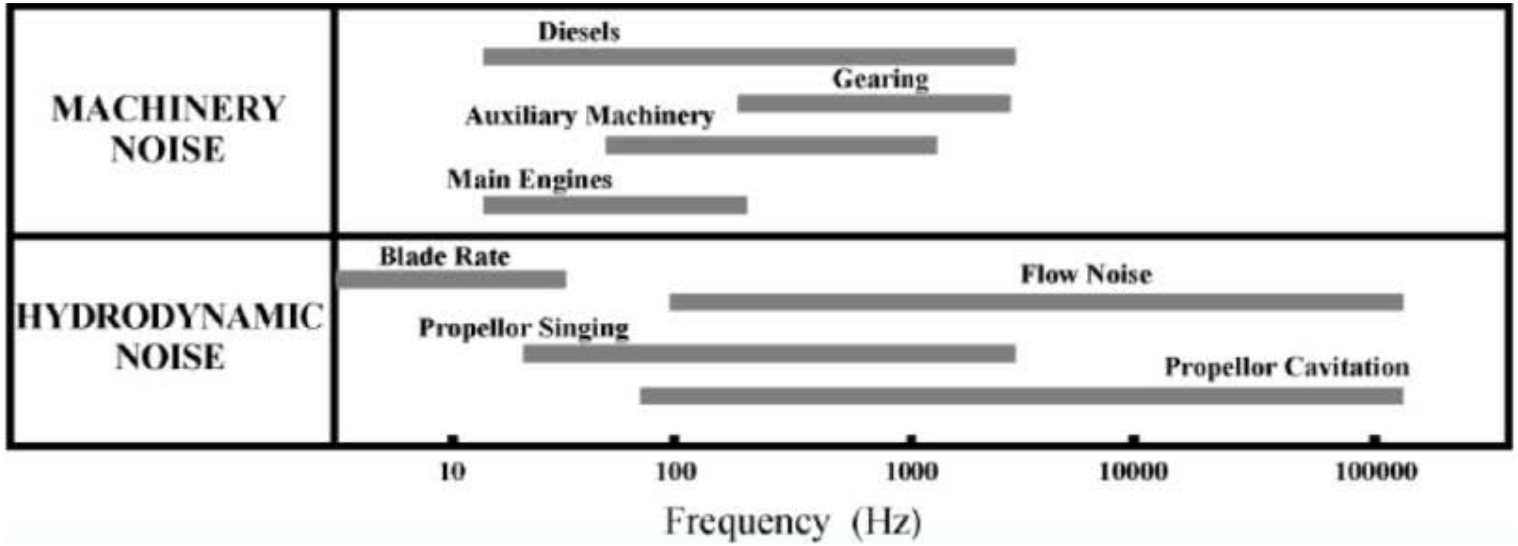
- AHDs
- ADDs

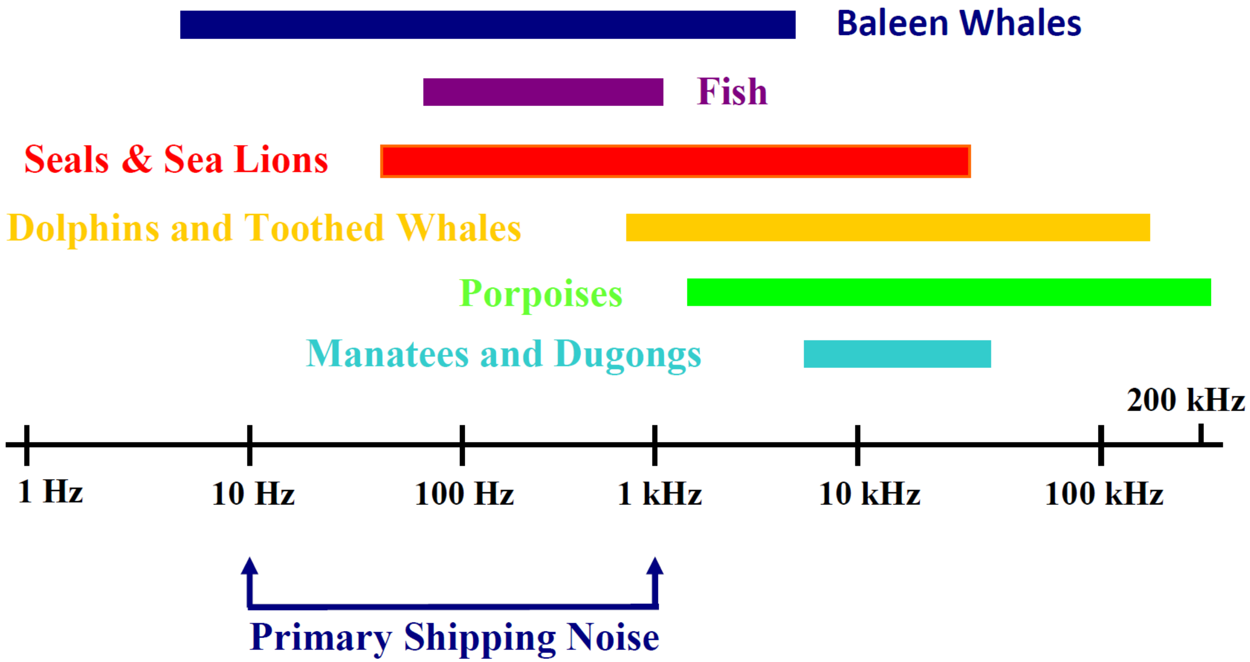
Dredging

Marine wind farms

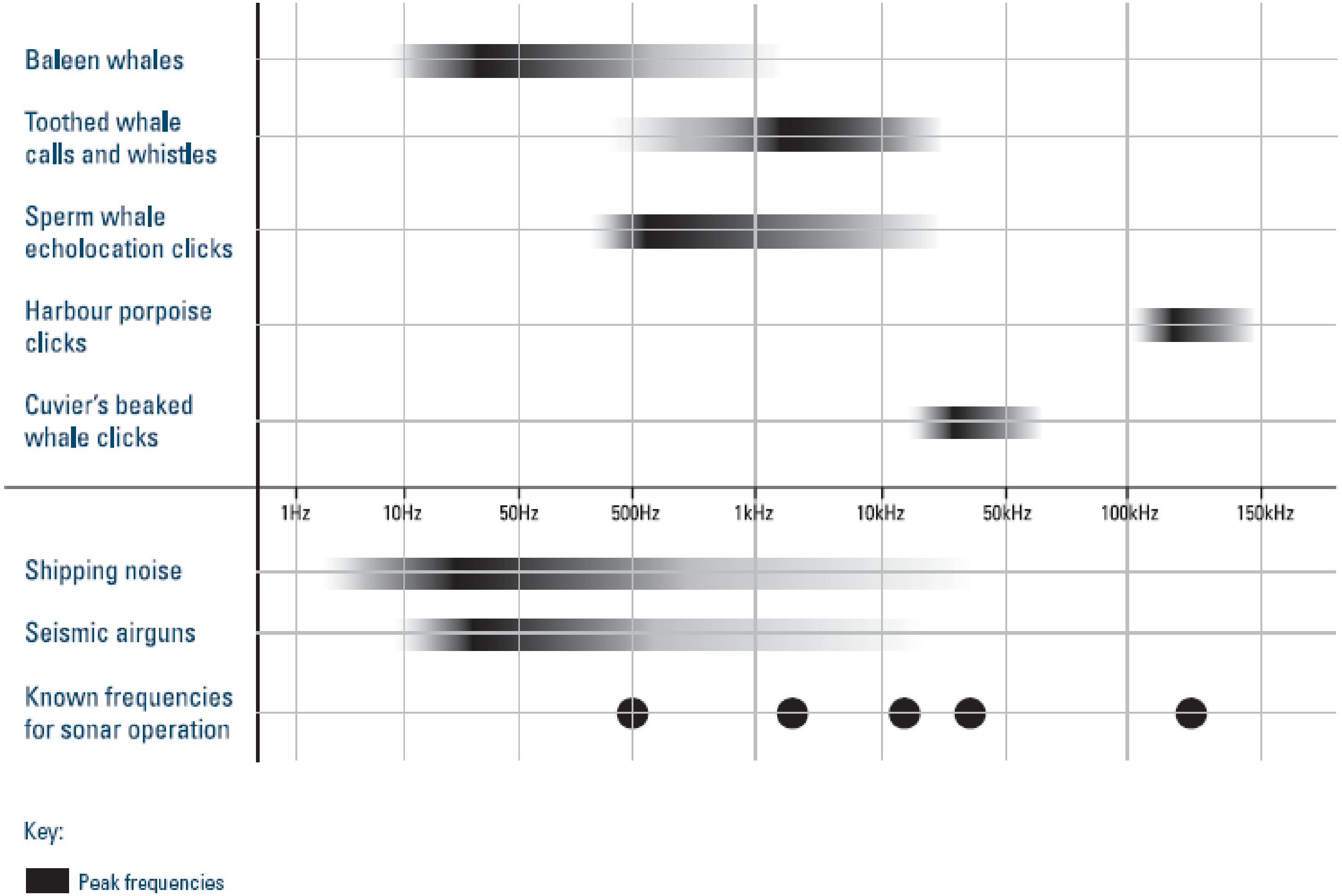
Ship noise - Sea life interactions

Source: IMO report, MPEC 58





Sound frequencies used by marine mammals and man-made sources of ocean noise pollution



Source: Ocean Noise: Turn it down, 2008, IFAW report

The origin of underwater noise

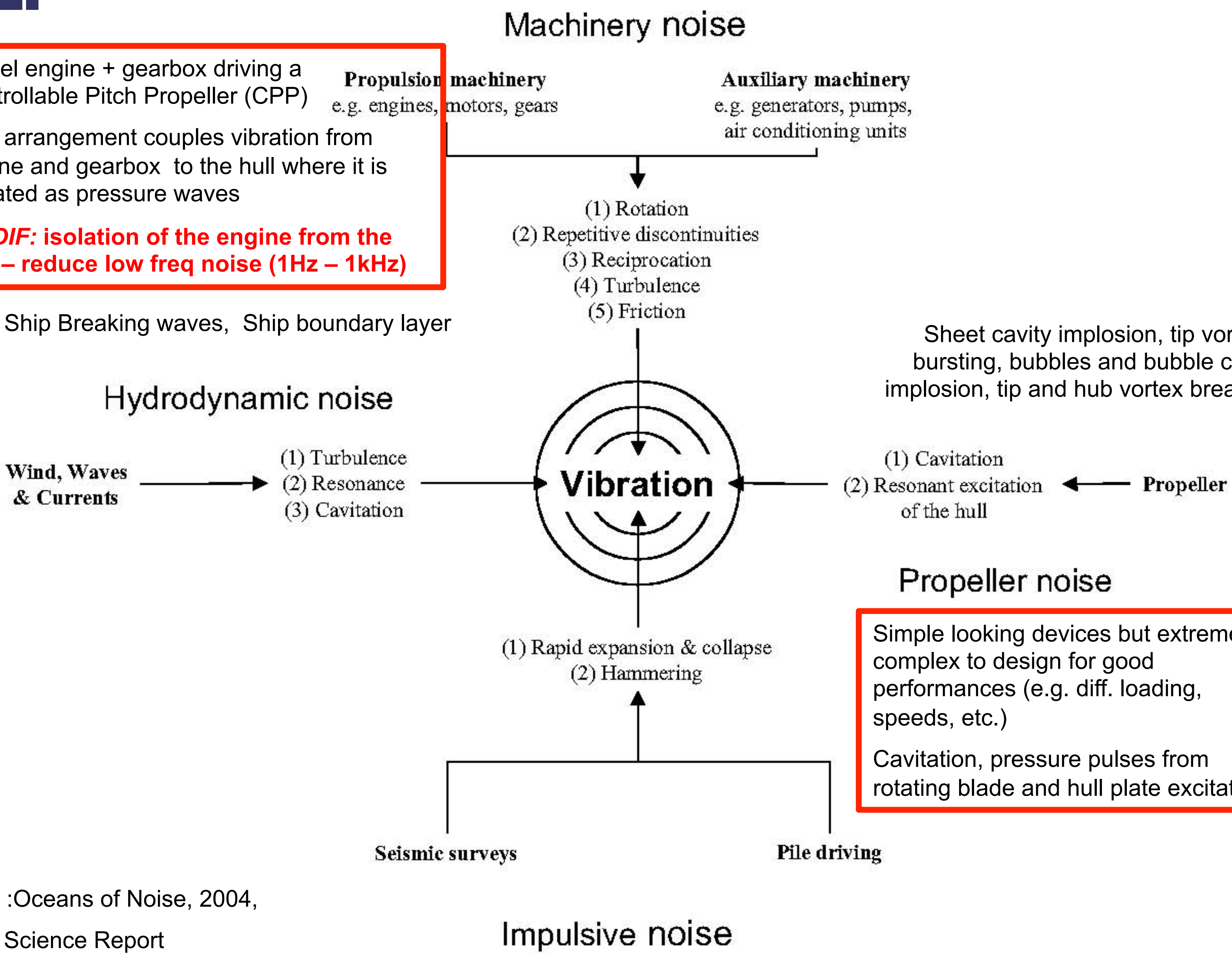
Diesel engine + gearbox driving a Controllable Pitch Propeller (CPP)

This arrangement couples vibration from engine and gearbox to the hull where it is radiated as pressure waves

MODIF: **isolation of the engine from the hull – reduce low freq noise (1Hz – 1kHz)**

Ship Breaking waves, Ship boundary layer

Sheet cavity implosion, tip vortex bursting, bubbles and bubble cloud implosion, tip and hub vortex breakdown



Simple looking devices but extremely complex to design for good performances (e.g. diff. loading, speeds, etc.)

Cavitation, pressure pulses from rotating blade and hull plate excitation

Source :Oceans of Noise, 2004,

WDCS Science Report

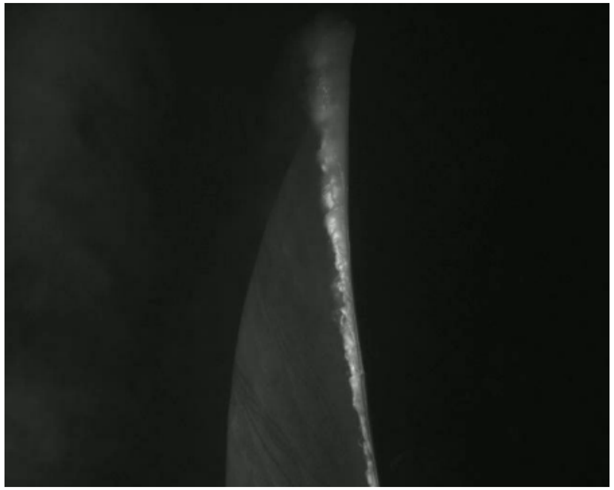
Propeller noise

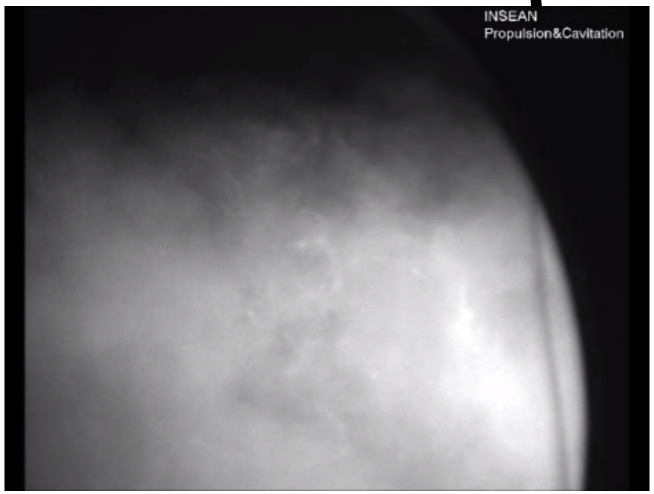
Ship propeller noise is affected by operations:

Wide range of operational conditions require a deep analysis of the design points

Propellers are designed for predicted operating conditions, which rarely occur in practice

Full scale propeller





Design condition **Off Design Condition**

Lower acoustics emission → **Very large acoustics emission**

Propeller behavior at different operational condition can be investigated at model scale

NEW DESIGNs / RETROFITTING options for vessel-quieting

IMO - MARINE ENVIRONMENT PROTECTION COMMITTEE , MEPC 60/18, 2009, Noise from commercial shipping and its adverse impacts on marine life

NEW DESIGN

Type	Pros	Cons	Cost	Effect
Minimize Propeller Cavitation (propeller shape, configuration, size, etc.)	Reduction of tip vortex; reduction of pressure pulses; forward-skewed ducted props expected to increase cavitation inception speeds, hence lower cavitation noise levels (duct can serve for site of injecting air and also a *de facto* prop guard); "ring" propeller can eliminate tip vortex	Variable results in terms of quieting, operational efficiency	**Variable (potentially low)**	**High**
Minimize Propeller Cavitation (variable pitch propellers)	Good in terms of radiated noise at nominal pitch; can identify minimum noise output	Poor in terms of operational efficiency; Potentially misused for speed control	**High**	**Variable (potentially high)**
Twin vs. Single Screw Propulsion Systems	Enables the use of large diameter propellers that turn more slowly; System redundancy is safety benefit	Only have half the thrust per system; major difference in design of entire ship	**High**	**Variable (potentially high)**
Podded Propulsion (Azipods)	Potentially great improvement of wake field; reduced cavitation; reduced vibration	Not sufficiently powerful yet; high electrical noise; efficiency can be poor	**High**	**Moderate (especially for low-frequencies, but some high frequency tonal spikes)**

• • •

Other:

PROPELLER/HULL FORM OPTIMIZATION (requires model basin testing)

• Determining optimal hull design for propulsion system and propeller type, in order to reduce hull resistance and minimize turbulence in the wake field

• Propagation and radiation of pressure fluctuations induced structure-born noise

HULL DESIGN

• Flow noise associated with various hull forms

• Flow noise as function of vessel speed

• Flow around underwater appendages, e.g., skeg shape, trailing edge, bow thruster, rudder, other hull openings

• Bow shape and form

• Use of dampening coatings and variability among coating types

Technologies for Reducing Propeller Noise

New propeller design: *better efficiency, and improved cavitation characteristics*

High skew propellers

Contracted and loaded tip pr

Kappel propellers

New blade section propellers

Propeller hub caps

Propeller boss cap fins

Propeller cap turbine

Wake inflow devices

Schneekluth duct

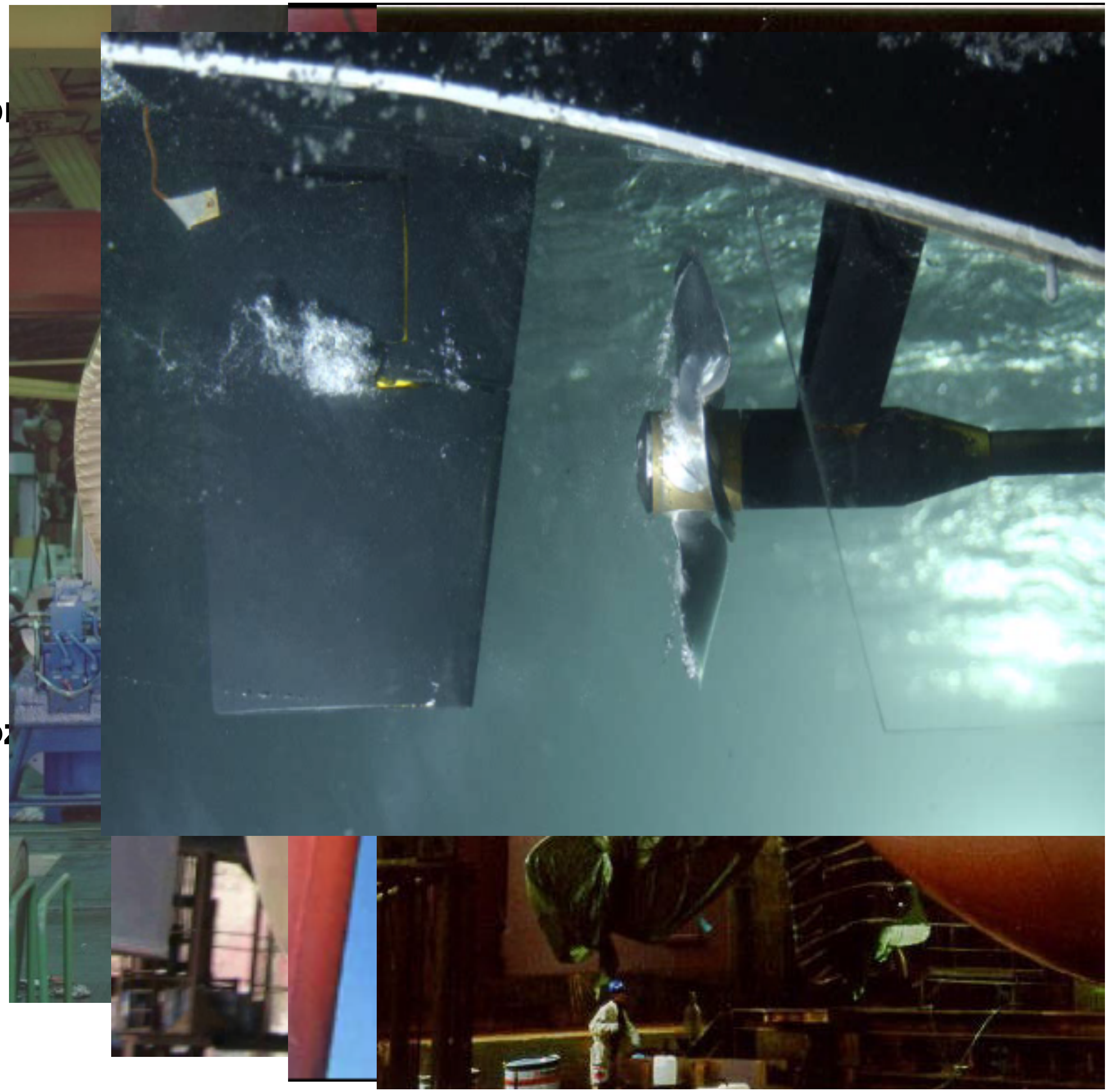
Mewis duct

Simplified compensative no

Grothues spoilers

Propeller/rudder interaction

Changes to the hull form



Mathematical modeling of ship underwater noise

At present, the underwater noise is considered (more or less) as a sort of *ungovernable* and *unverifiable* consequence of the ship motion and **no prediction tool is used to estimate the hydroacoustic behaviour of a ship** (or some of its sub-components) **at the *design stage***.

The ***Ffowcs Williams - Hawkings equation*** (1969) is an extension of the Lighthill equation (1952). It directly arises from the fundamental conservation laws of mass and momentum and *governs the sound generated by a body moving in a fluid flow*.

$$\Box^2 p' = \frac{\bar{\partial}}{\partial t}\left[\rho_0 v_n \delta(f)\right] - \frac{\bar{\partial}}{\partial x_i}\left[p \hat{n}_i \delta(f)\right] + \frac{\bar{\partial}^2}{\partial x_i \partial x_j}\left[T_{ij} H(f)\right]$$

Noise = *body shape* + *aero/hydrodynamic loads* + *nonlinear effects*

Thickness | *Loading* | *Quadrupole*

- *Well-defined generating noise mechanisms.*
- *"Hybrid" approach advantages: generation and propagation phenomena* can be treated in a separate way.

1) Characterize the sources through the knowledge of the **body shape**, of the **pressure distributions on the hull** and, of the **pressure and velocity** fields in the bulk of the fluid around of the ship
2) Then use the **FWH** equation to propagate the noise in the far field.

New Perspectives in the Use of Ffowcs Williams-Hawkings Equation for Aeroacoustic Analysis of Rotating Blades, Ianniello S.,Journal of Fluid Mechanics**,** Vol.570, **2007**

The FWK equation in hydroacoustics

In air the most important terms are the linear terms (on the hull).

In the few papers focused on the use of the FWH equation for marine propellers (always limited to *open water* conditions), such an assumption is assumed to be *valid*, but *has never been investigated…*

$$\square^2 p' = \frac{\bar{\partial}}{\partial t}\left[\rho_0 v_n \delta(f)\right] - \frac{\bar{\partial}}{\partial x_i}\left[p \hat{n}_i \delta(f)\right] + \frac{\bar{\partial}^2}{\partial x_i \partial x_j}\left[T_{ij} H(f)\right]$$

The main aim of our research is to provide an answer to the following questions:

What are the main noise generating mechanisms underwater ?

Is it possible to achieve a reliable prediction of the ship underwater noise ?

1. *Hydroacoustic pure linear analysis and hull scattering effects*
2. *The role played by the nonlinear sources*
3. *The prediction of the ship underwater noise field (through the FWH "porous formulation")*

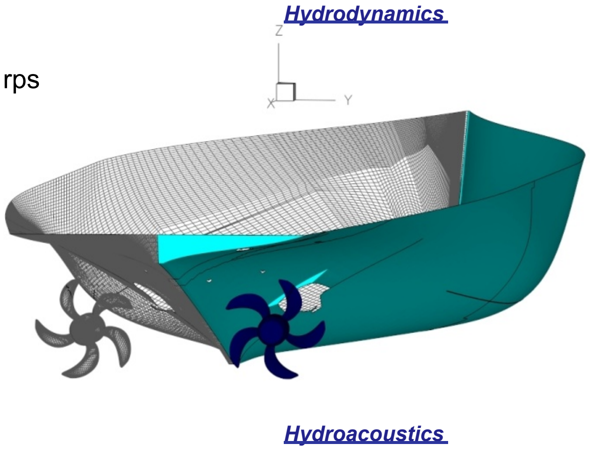
Hydroacoustics linear analysis

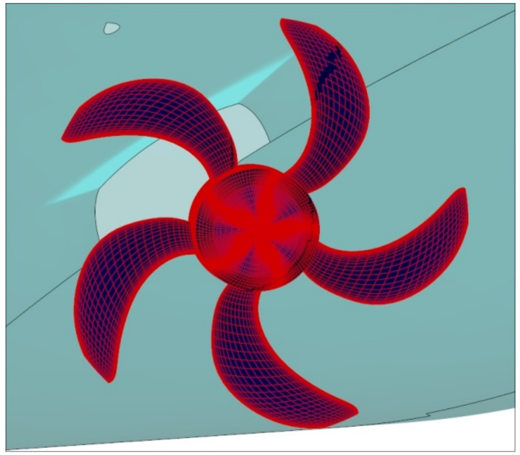
Test-case: ***numerical investigation on hull scattering effects***

Hydroacoustic *pure linear* analysis by using a **steady RANSE simulation of a *propeller + hull* configuration**. *Only* the unsteady pressure distributions on propeller blades and hull are available. *Noise maps* at ship stern region and different depths.

Speed: 16 knots
Propeller: normal pitch, D=3.35m, rps=2.21rps
Azimuthal step: 4°

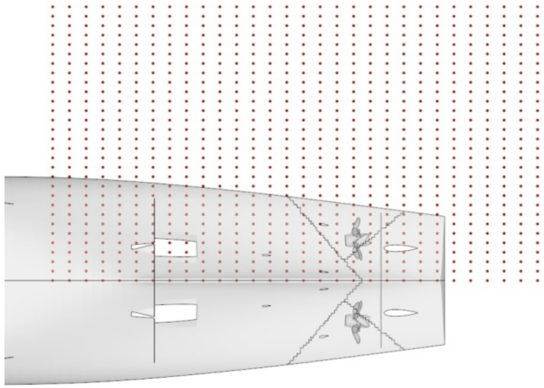
Symmetrical problem
No appendages
Unstructured mesh

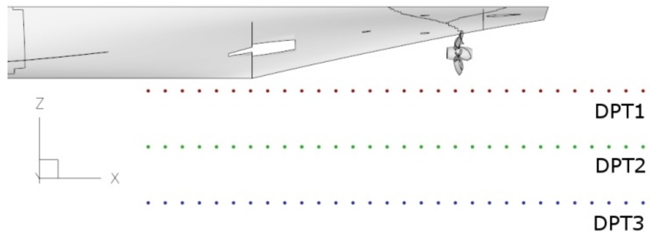




Noise maps: 900 hydrophones on each plane

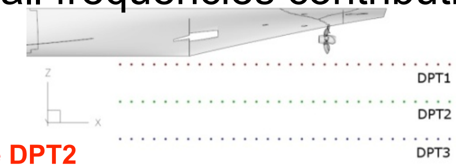
Footprints from:
1. Propellers
2. Hull
3. Complete configuration





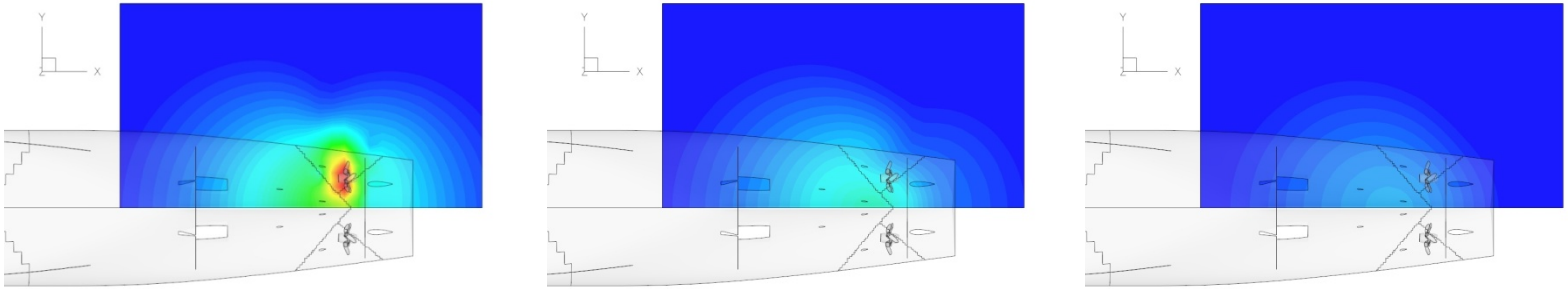
Local noise index (in dB) : time integral of all frequencies contribution for a complete period

Hydroacoustics linear analysis



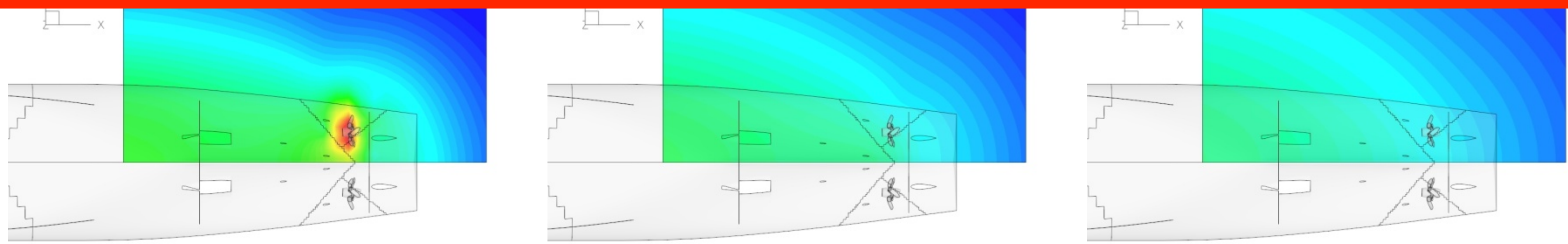
Plane **DPT1** Plane **DPT2** Plane **DPT3**

Propellers



The propeller noise dominate the acoustic field in a *limited space region* surrounding the body-source. Moving far from the rotating blades, their effects rapidly *decrease*. The hull scattered pressure becomes the *dominant* *linear* *noise source*.

Unlike the analogous aeronautical case, *the acoustic far field is not characterized by the linear sources due to the rotating blades*.



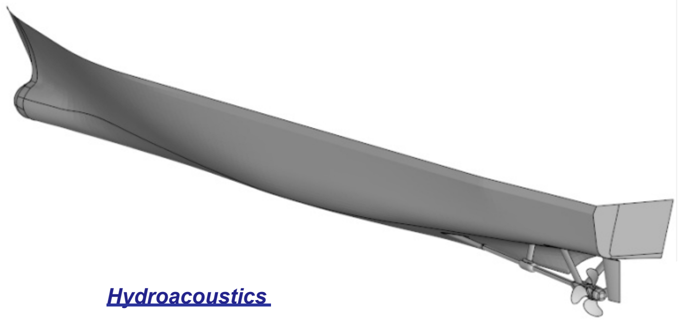
The role of non-linear sources

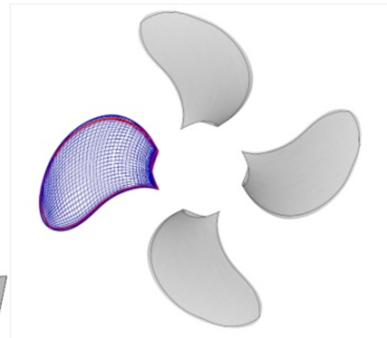
Test-case: *numerical investigation on hull scattering effects*

Full hydroacoustic analysis by using an **unsteady RANSE "*Chimera*" code** to simulate a complete ship (scaled model of a patrol boat) in steady course, equipped with a four-bladed propeller.

Hydrodynamics

Speed: 2.52 m/s
Propeller: INSEAN E1630, D=0.21m, rpm=820
Reynolds: 1.18e+07
Froude: 0.348
Azimuthal step: 1°
Symmetrical problem
All appendages
Structured mesh

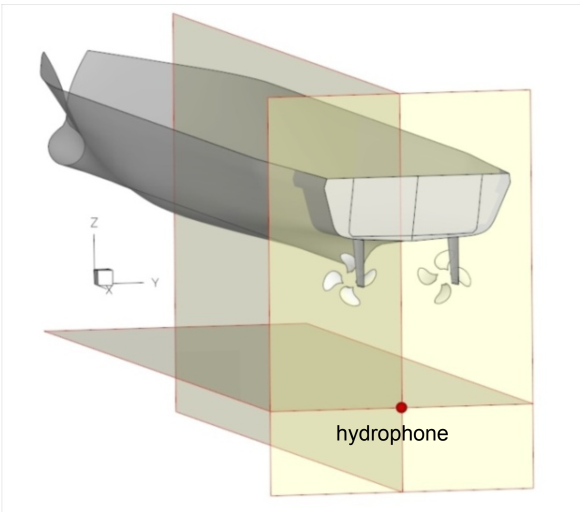


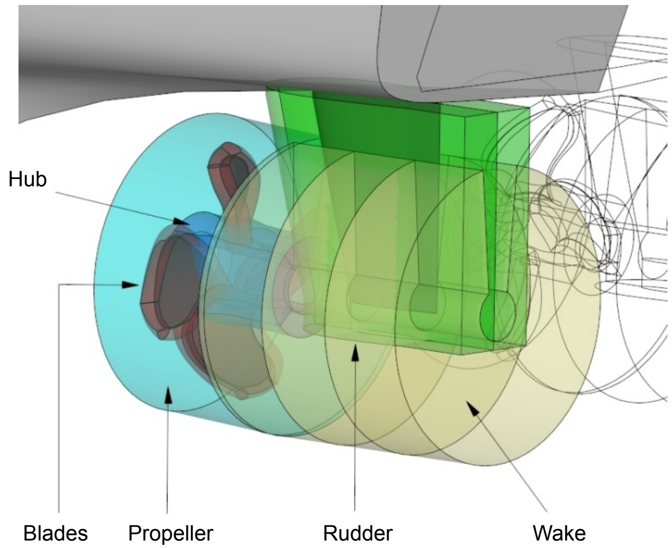


Hydroacoustics

Evaluation of the acoustic pressure time history:

- ✓ Linear (surface) terms from propellers, hull and rudders
- ✓ Nonlinear (volume) terms: 3D region surrounding the propeller/rudder





The role of non-linear sources: 3D integration of the Lighthill tensor is required. In general the effect of viscosity on sound generation is neglected and compressive tensor reduces to a scalar and non-linear terms are neglected

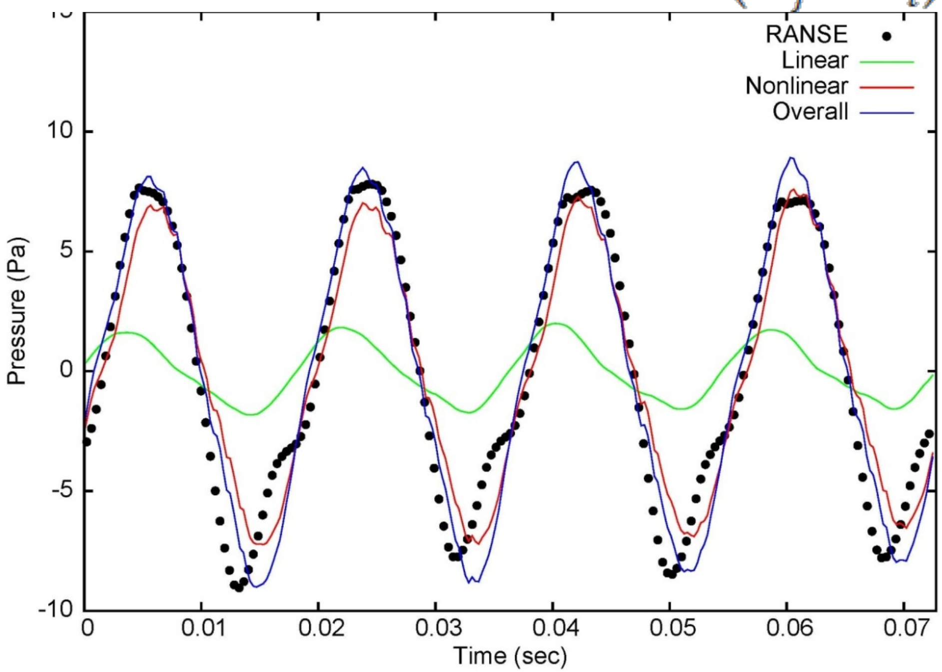
Lighthill stress tensor

Viscous effects neglected

$$T_{ij} = \rho u_i u_j + P_{ij} - c_0^2 \tilde{\rho} \delta_{ij} \Rightarrow T_{ij} = \rho u_i u_j + (\tilde{p} - c_0^2 \tilde{\rho}) \delta_{ij} \Rightarrow T_{ij} \approx \rho u_i u_j$$

Instead, by including the nonlinear source and considering the turbulent components

RANSE: $u = \bar{u} + u' \Rightarrow \rho u_i u_j = \rho \overline{u_i u_j} - \mu_T \left(\frac{\partial \bar{u}_i}{\partial x_j} + \frac{\partial \bar{u}_j}{\partial x_i} \right)$



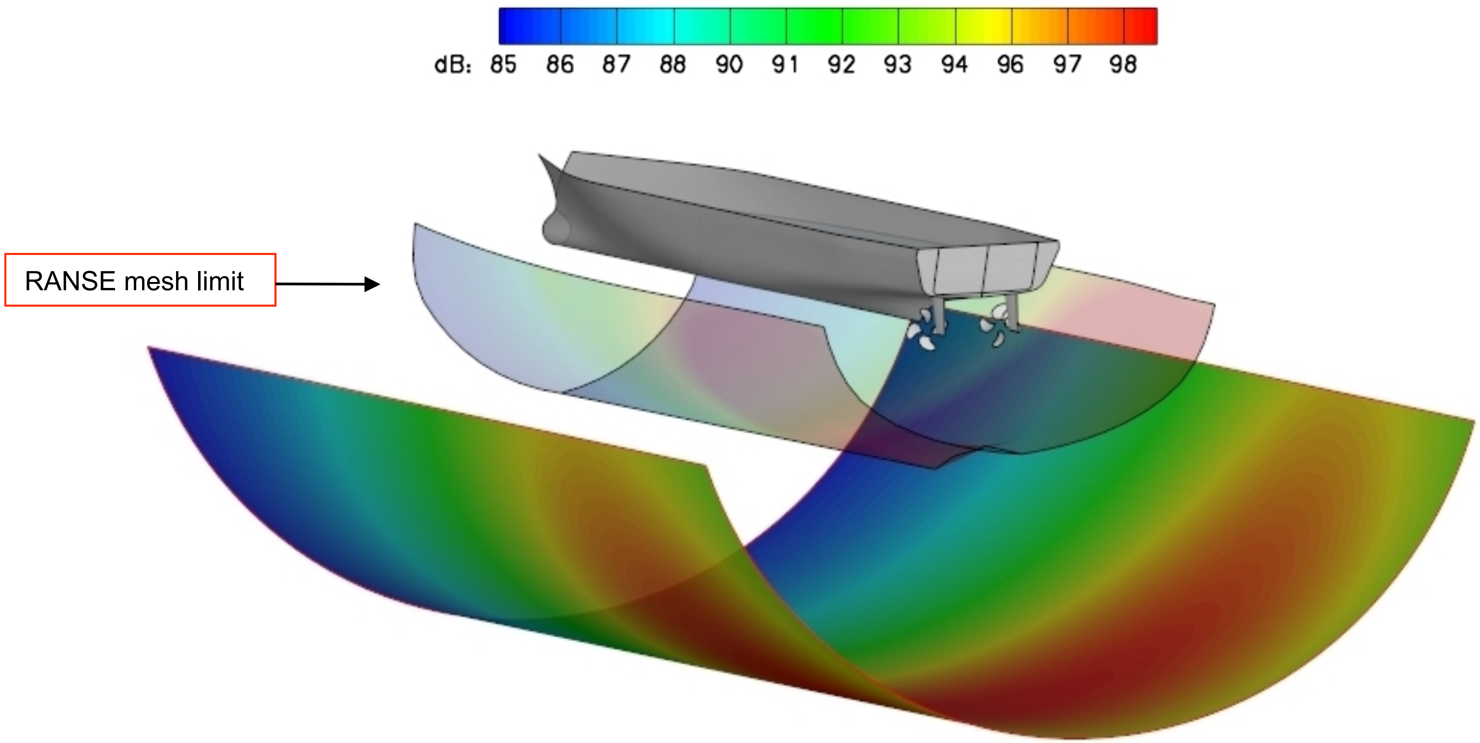
New results:

FWK nonlinear term is fundamental in achieving a reliable estimation of the underwater pressure field, i.e. the **pressure is mainly determined by the velocity gradients** occurring in the region **downstream the propeller**

Numerical prediction of underwater noise

Current research activity – EU project SILENV (7FP)

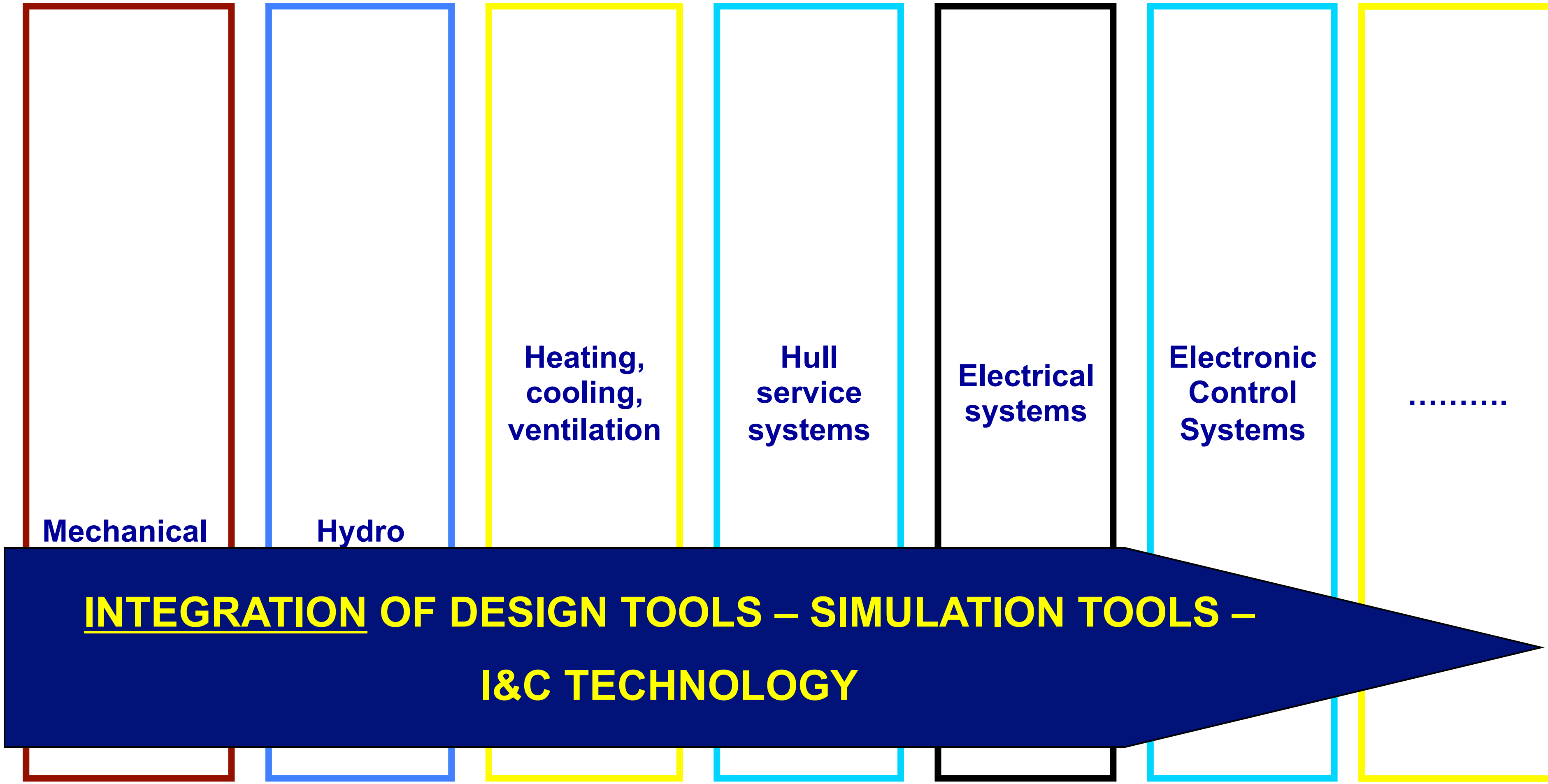
Noise map (traced by 2500 hydrophones) of the *actual acoustic pressure far field* and the analogous footprint determined on the most external layer of the RANSE mesh. This result represents a reasonable *hydroacoustic characterization* of the ship.



FWH – Noise map

The FWH equation represents a very effective approach to investigate on the ship generating noise mechanisms taking place underwater. We believe it could be adopted as a *standard technique* to characterize the hydroacoustic behavior of a ship and/or its sub-components, even at a *design stage.*

Improve energy efficiency, reduce pollution. The role of design tools



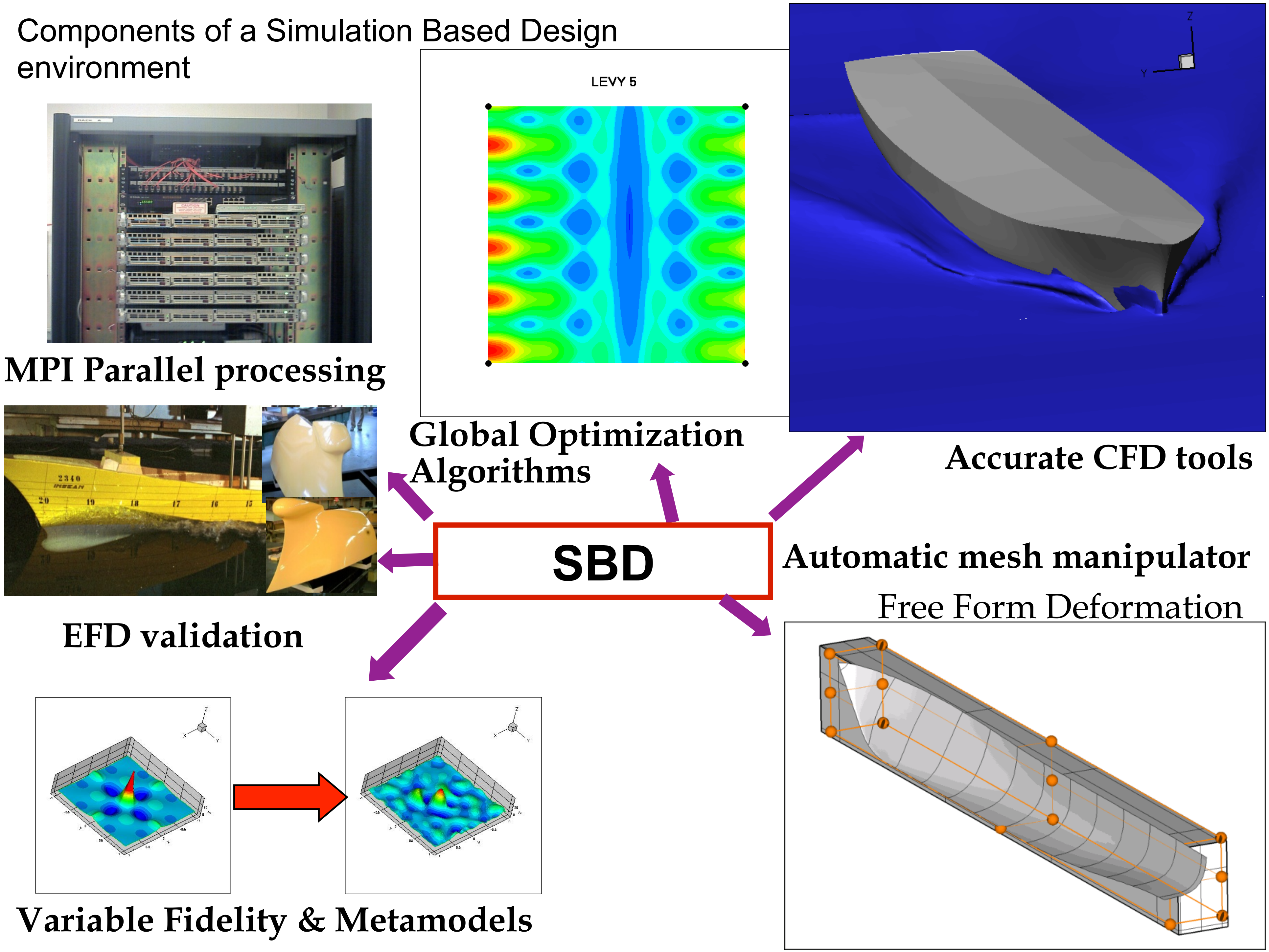
GREEN APPROACH

New Global Optimization Methods for Ship Design Problems, Campana EF et al., Optimization and Engineering (OPTE), Vol. 10 (4), 533, 2009.

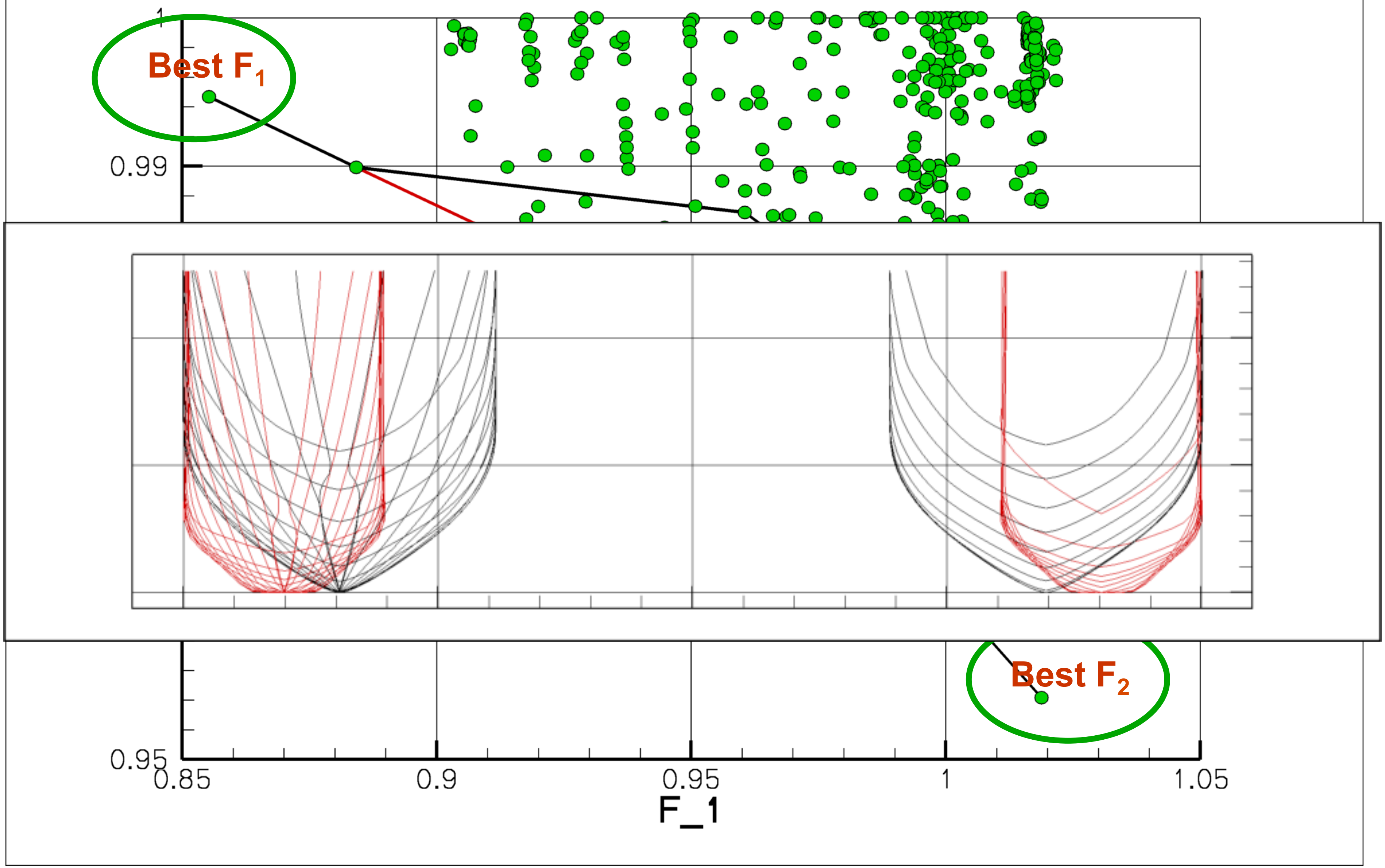
Algorithms and Methods for Numerical Optimal Ship Design

- **Optimization** is an important branch of contemporary mathematics, with great implications on design engineering (e.g. aerospace, aeronautical, automotive, …)
- **Simulation Based Design (SBD) optimization** adopt algorithms and methods of ***Optimization in combination with simulations of the unknown objective functions***
- Despite great potentialities, SBD optimization in the naval context often clashes against
  - *Tradition and background of ship design engineers*
  - *Lack of confidence on simulations*
  - *It is sometimes considered too ambitious or unrealistic*
- Our opinion: the growing complexity and size of modern engineering systems makes ***the use of traditional design methods alone increasingly challenging***
  - *New designs presents difficult problems (no historical databases)*
  - *Some areas of design experience a loss of design knowledge with the retirement of designers*
  - *Current simulation tools are increasingly fast, accurate and robust. Offer great possibilities*

Components of a Simulation Based Design environment



Solution of a multiobjective design problem (Resistance & Seakeeping)



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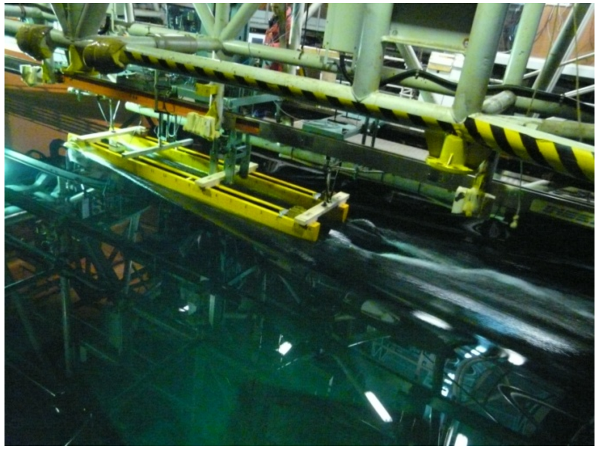
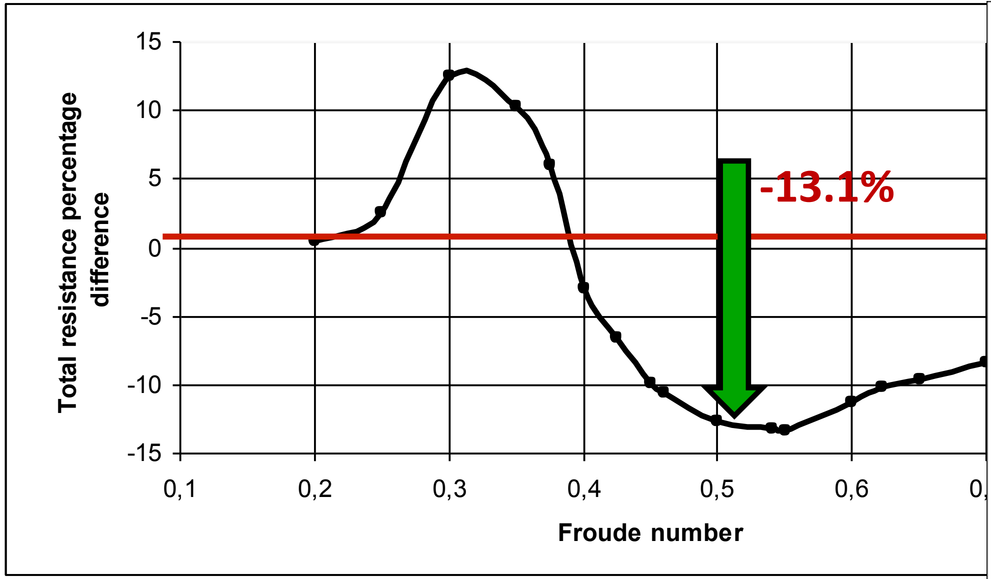
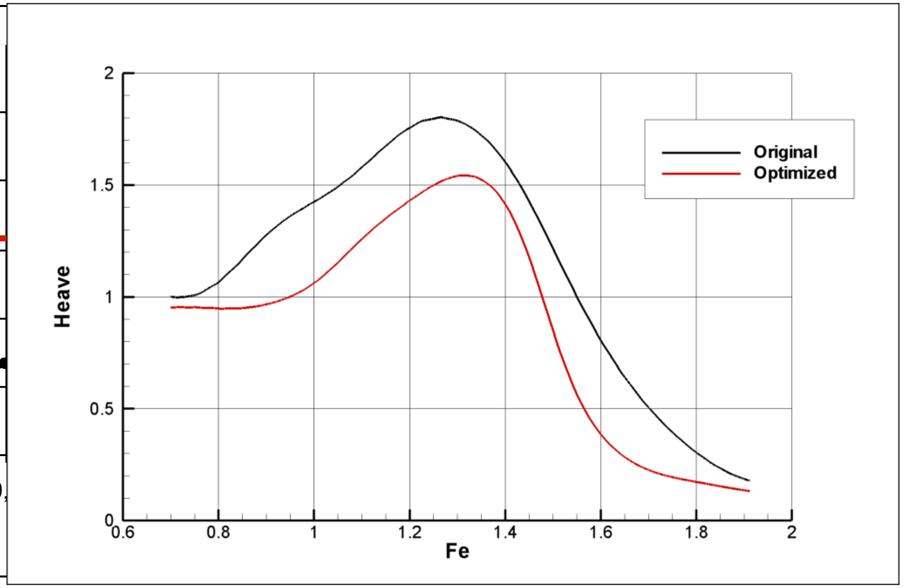


Experimental assessment

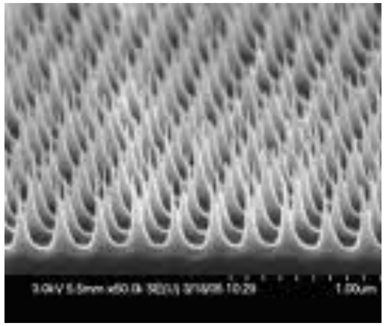
f_1 (Resistance) reduction = -13.1 %

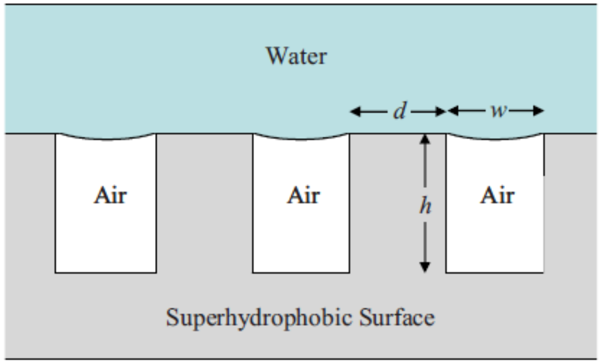


f_2 (Seakeeping) reduction = -11.2 %

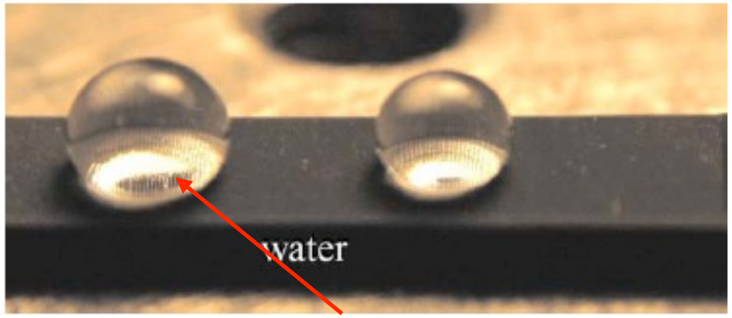


Super-Hydrophobic Materials – Drag reduction and vibration reduction



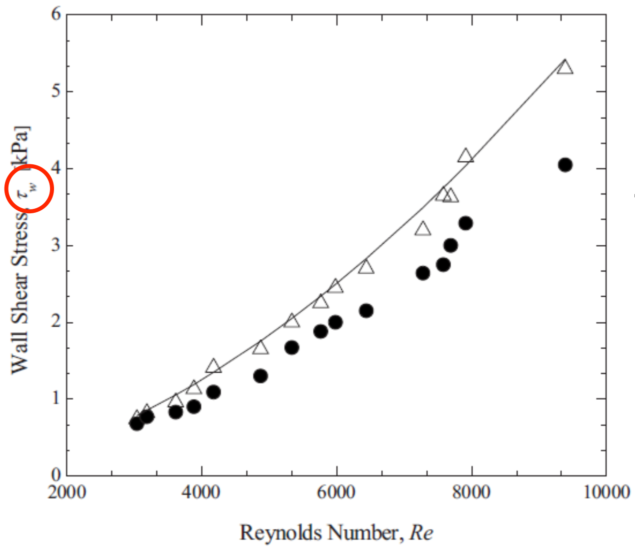


w, d, h ~ 10^{-6}- 10^{-9} m



Air-water interface

On super-hydrophobic surfaces, water drops take an almost spheric shape: with a high contact angle (>160°) and an almost-zero hysteresis angle, the water drops tend to faster on the surfaces



The shear strees at the wall decreases τ_w

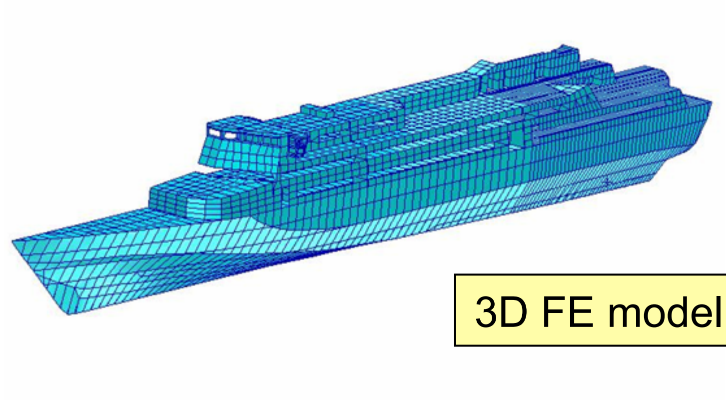
Lower drag

Spectrum of the fluctuation pressure component changes

$$\Phi_{pp}(\omega) = \frac{\tau_w^2 \delta}{U} \frac{3\left(\frac{\omega\delta}{U}\right)^2}{\left[\left(\frac{\omega\delta}{U}\right)^{0.8} + 0.5\right]^{3.7} + \left[\left(1.1\left(\frac{u_\tau^2\delta}{U\nu}\right)^{-0.6}\right)\left(\frac{\omega\delta}{U}\right)\right]^7}$$

Elastically scaled ship model

Real Ship

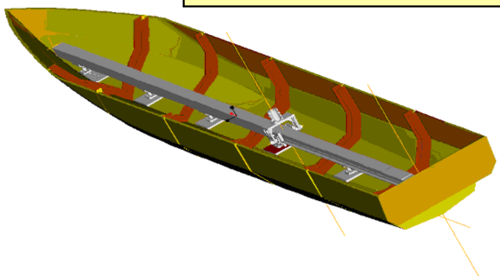


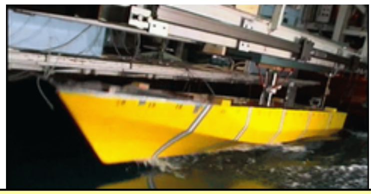
3D FE model

Reference
Ship Data

- ✓ mass distribution
- ✓ bending stiffness distribution
- ✓ shear area distribution

Equivalent scaled structure





Test in irregular waves

Check

Ship Data
for validation

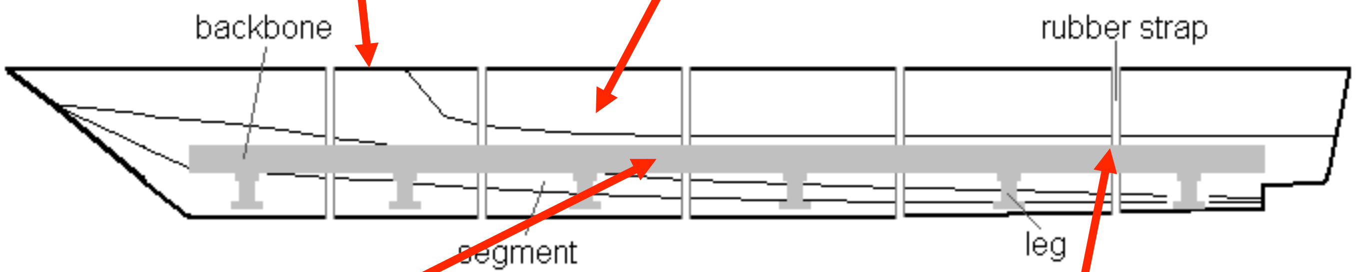
- ✓ natural frequencies, mode shapes

Segmented-hull concept

Each elastic segmented model is built using the backbone technique

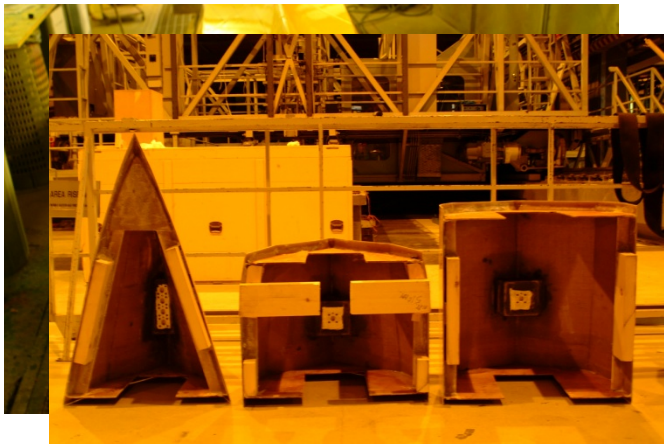
The hull is built in fiber glass.
It is supposed to be rigid.

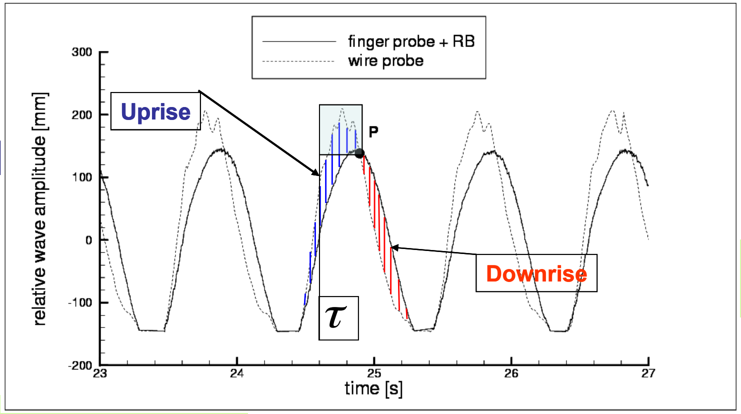
The hull is divided into segments.



The beam is the elastic backbone of the model.

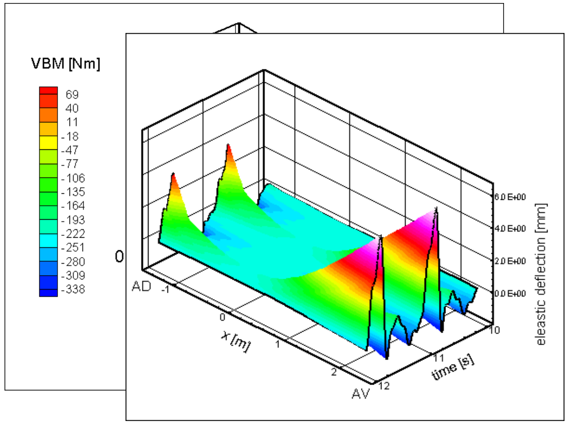
Rubber straps provide water tight feature.





on - board

ve and pitch motion



Draft and slamming detection

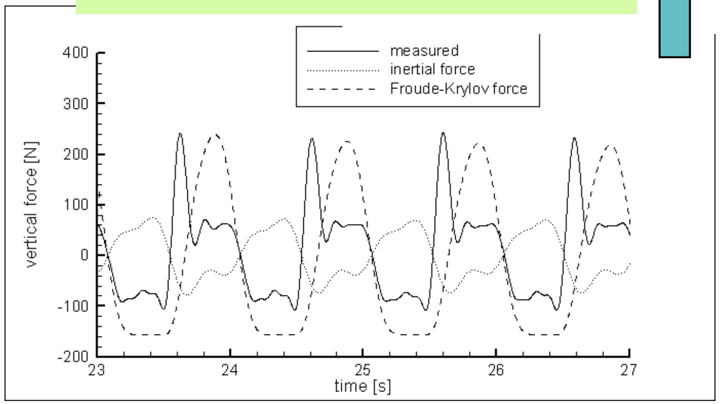
On-board wave probes

Beam deformation

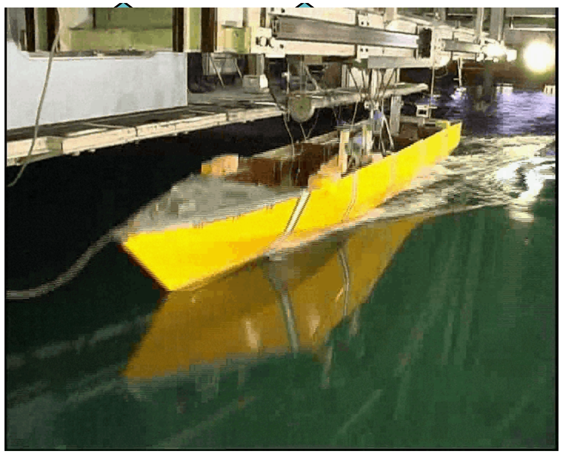
Strain gauges

Head waves

Fluid Load identification

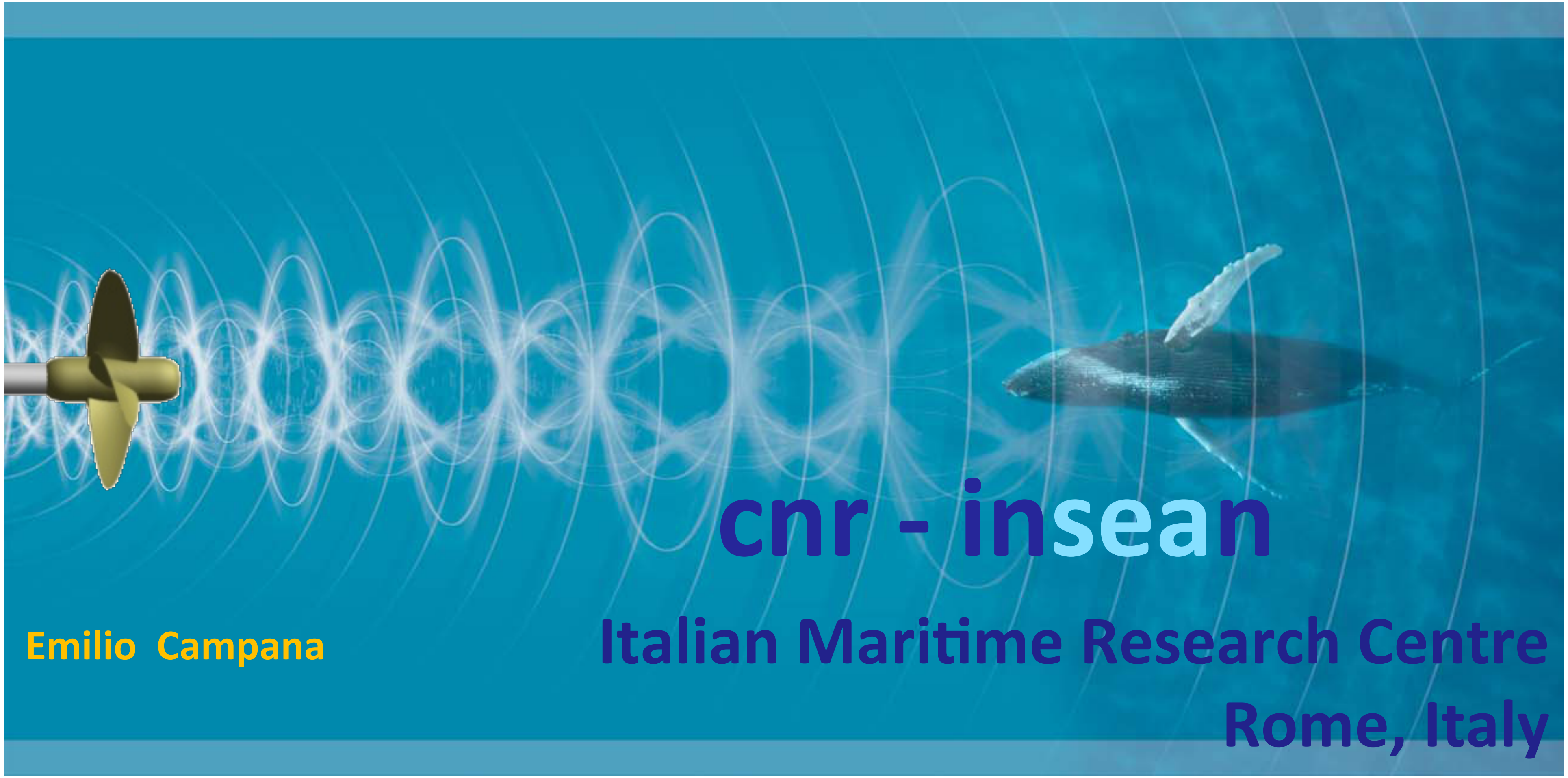


Wave loads exerted through the legs



Designing green and silent RVs

What maritime research can do?



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