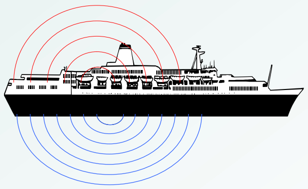
West Pomeranian University of Technology, Poland
FACULTY OF MARITIME TECHNOLOGY AND TRANSPORT
Applied Vibroacoustic Department

Stefan Weyna

SEEING NOISE

Noise reduction on ships and offshore platforms using sound imaging

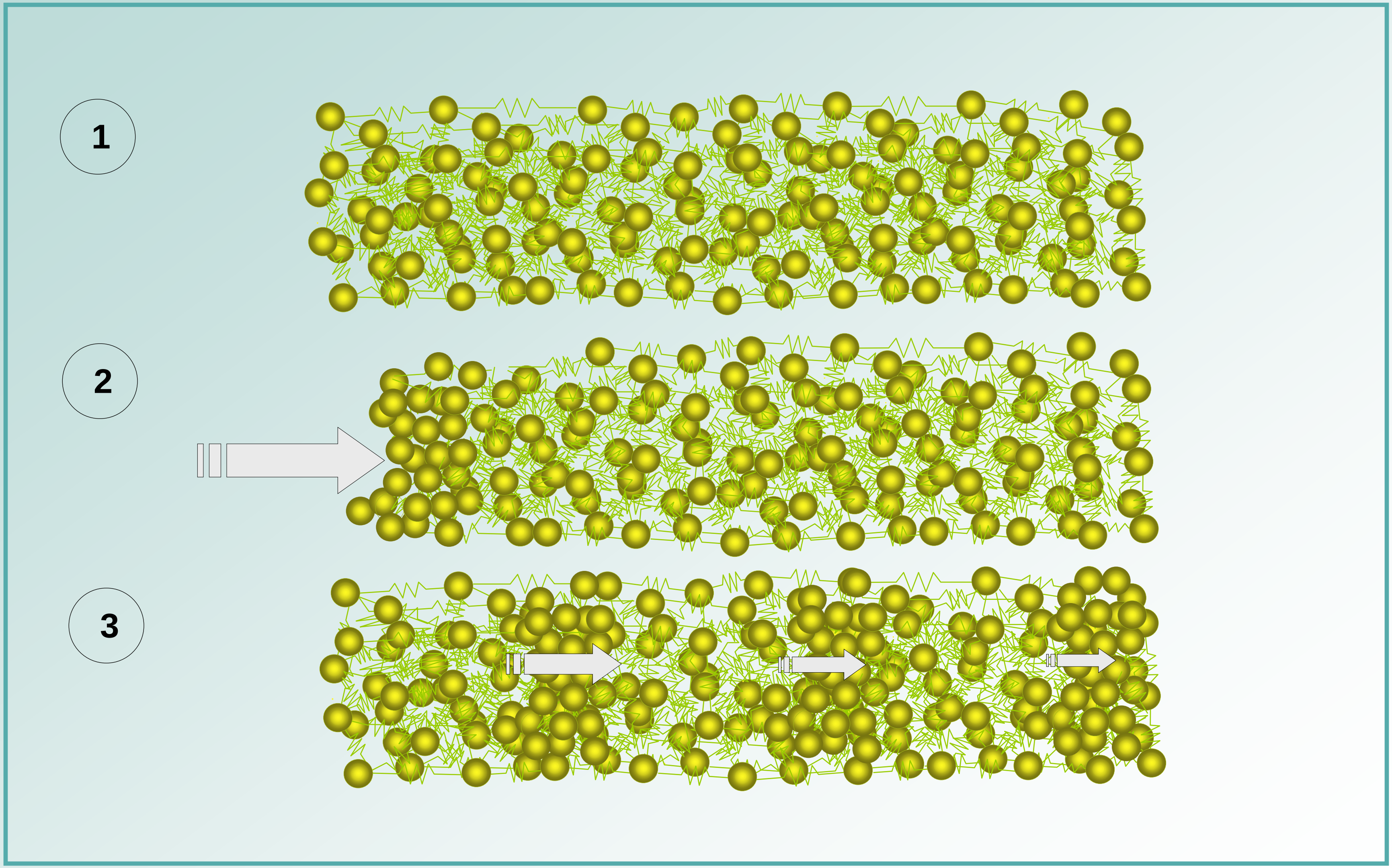


TU Delft *Seminar Maritime Technology of KIVI and SNAME*, **3 April 2014**

Contents of presentation

- Genesis of sound
- Sound intensity techniques
- Mapping of vector acoustic fields
- Ship noise vizualizations
- Laser anemometry in acoustics (A-PIV, A-LDA)
- Conclusions

The sound energy flow in the air



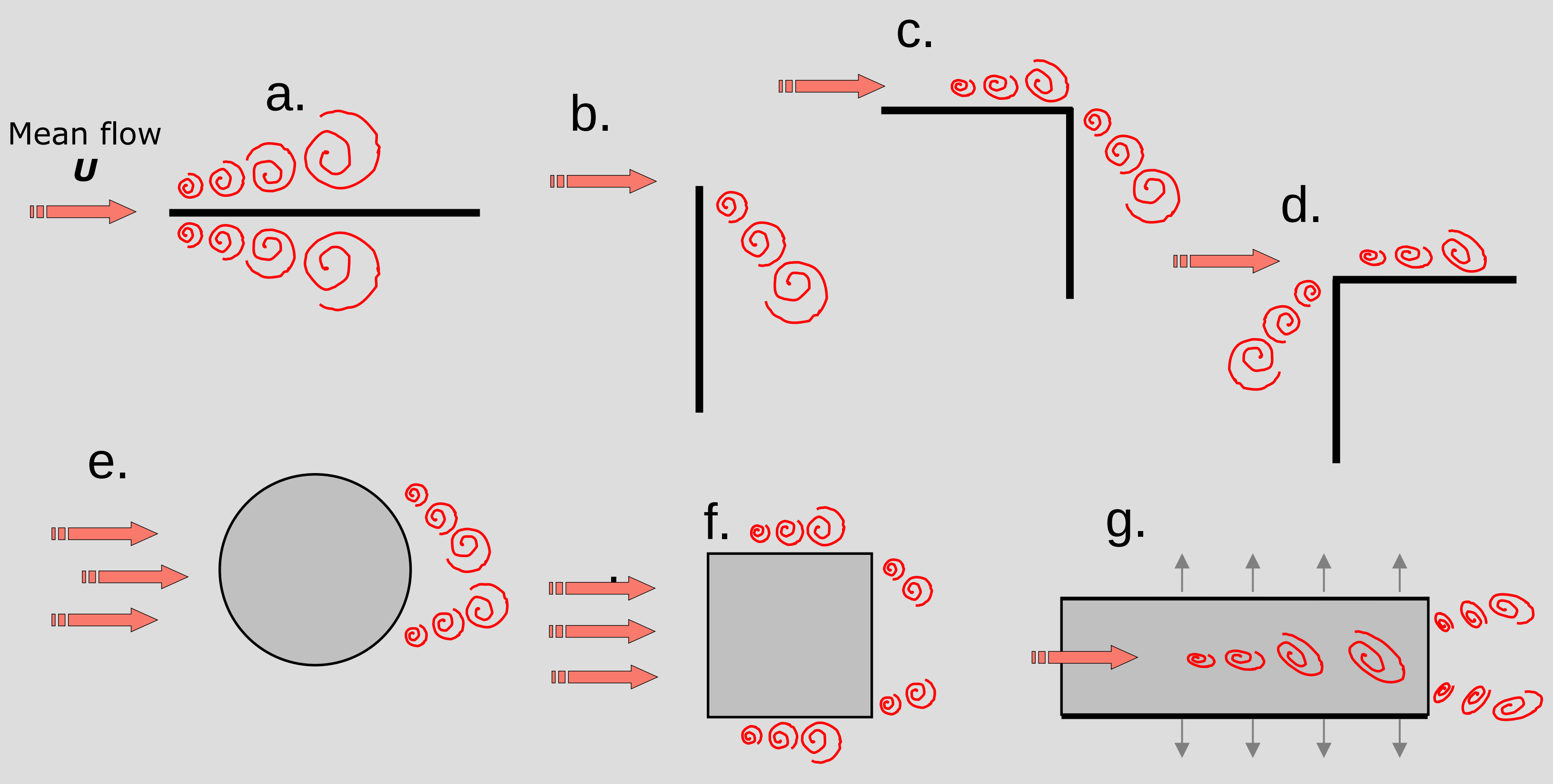
How the sound is born ?

Sources of noise:

- Aerodynamic flow
- Aeroacoustics flow
- Fluid structure interactions
- Impact and explosions (*shock waves*)

Noise and Vortex Sound Theory

Vortex-dynamic description in accordance with **Vortex Sound Theory**



Energetic value of acoustic flow

- **Acoustic particle velocity** - ***v***
- **Sound intensity** - ***I*** $(I = p \cdot v)$
- **Acoustic impedance** - ***z*** $(z = p/v\ ,\ z_0 = \rho_0 c)$
- **Acoustic energy** - ***E*** $(E = \frac{1}{2} p^2/\rho_0 c^2 + \frac{1}{2} \rho_0 v^2)$

Energetic value of acoustic flow

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Five basic flow equations:

$$\boldsymbol{v_x}(r_x, t) = \boldsymbol{v_o} \pm \boldsymbol{v_a}(r_x, t) \qquad 1)$$

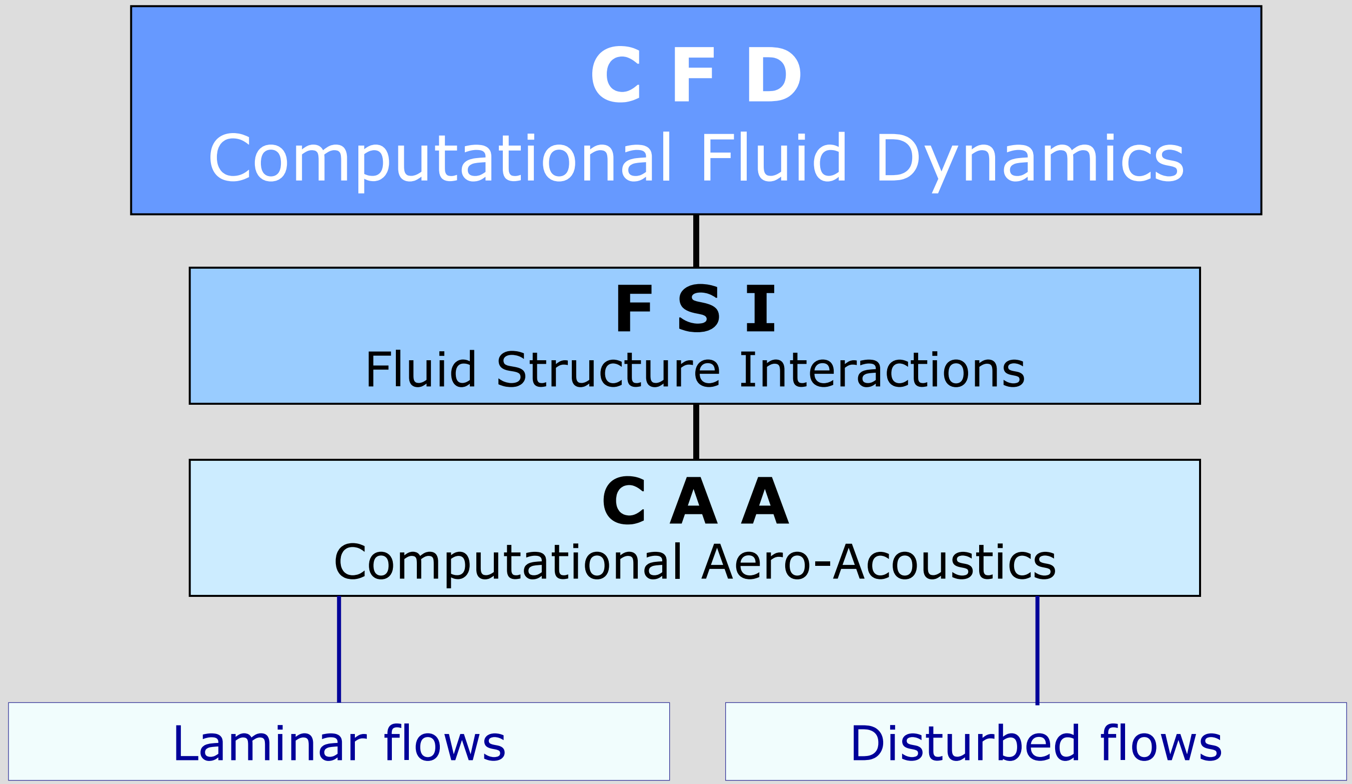
$$\boldsymbol{v_y}(r_y, t) = \boldsymbol{v_o} \pm \boldsymbol{v_a}(r_y, t) \qquad 2)$$

$$\boldsymbol{v_z}(r_z, t) = \boldsymbol{v_o} \pm \boldsymbol{v_a}(r_z, t) \qquad 3)$$

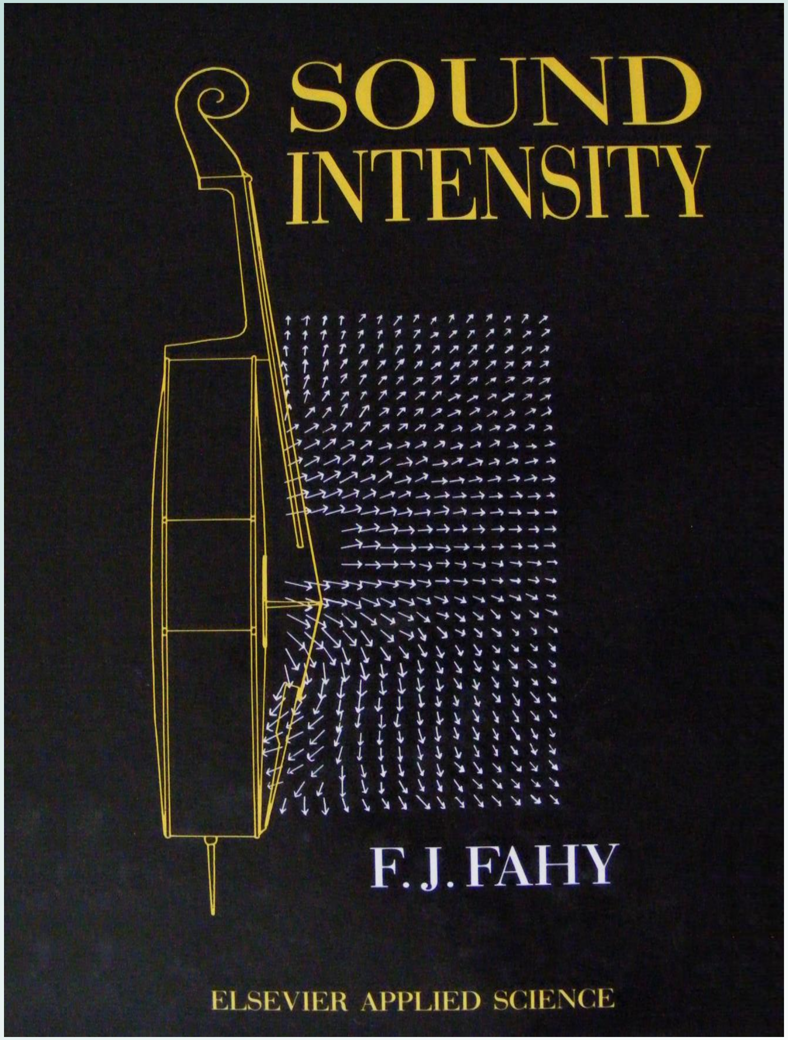
$$\boldsymbol{p}(r, t) = \boldsymbol{p_o} \pm \boldsymbol{p_a}(r, t) \qquad 4)$$

$$\boldsymbol{\rho}(r, t) = \boldsymbol{\rho_o} \pm \boldsymbol{\rho_a}(r, t) \qquad 5)$$

Numerical techniques for flow dynamics

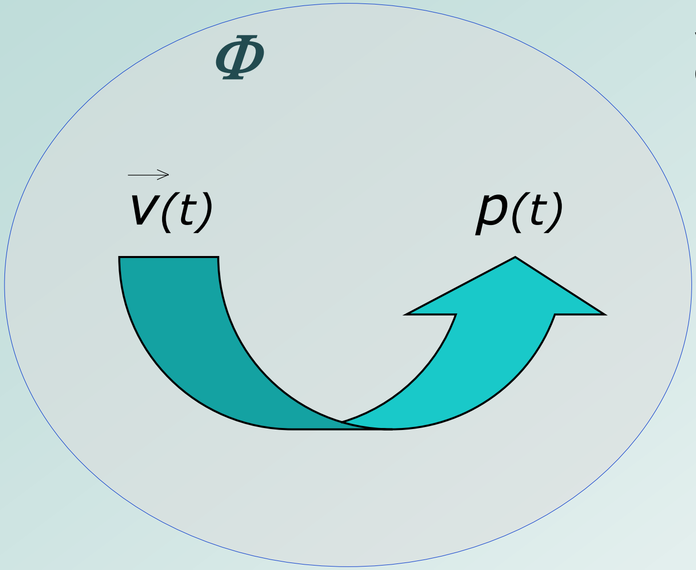


Sound Intensity measurement techniques (1989)



Physics of musical instruments → sound genesis

The sound energy flow in the air



Sound intensity "I", as a stream of acoustic energy expressed in terms of :

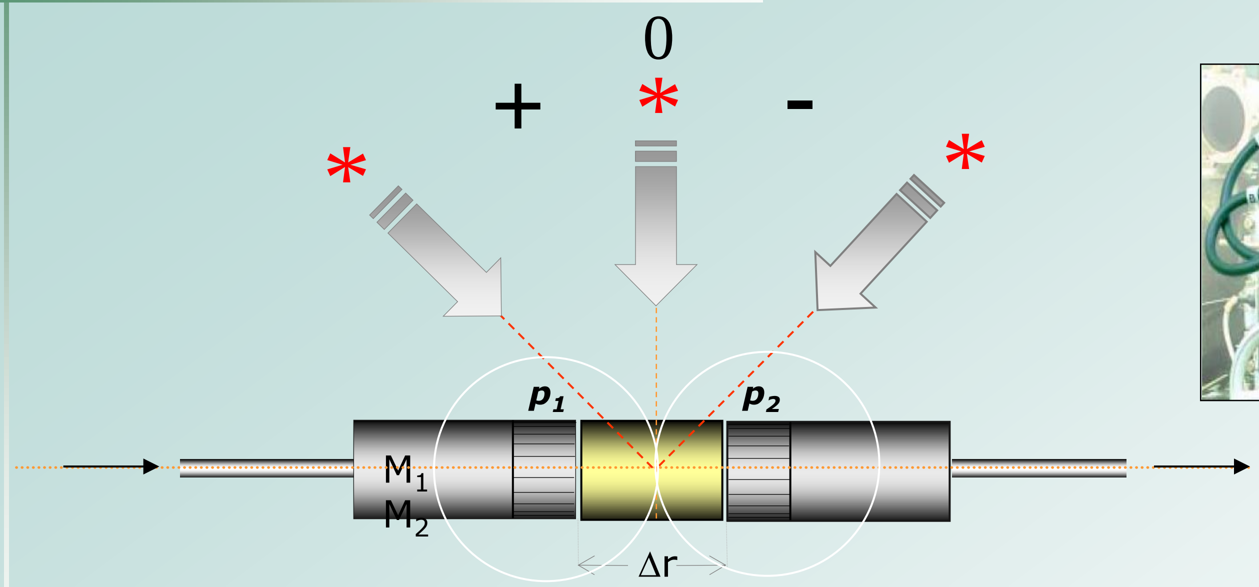
$$\vec{i}(t) = p(t)\vec{v}(t)$$

The value of the instantaneous sound intensity *(W/m²)*

v<<c !

*Sound intensity is an **<u>inseparable combination</u>** of the two parameters of acoustic waves: **acoustic particle velocity v** and **acoustic pressure p***

Sound intensity *p-p* transducer



Euler's equation

$$\frac{\partial \boldsymbol{u}}{\partial t} = -\frac{1}{\rho} grad(p)$$

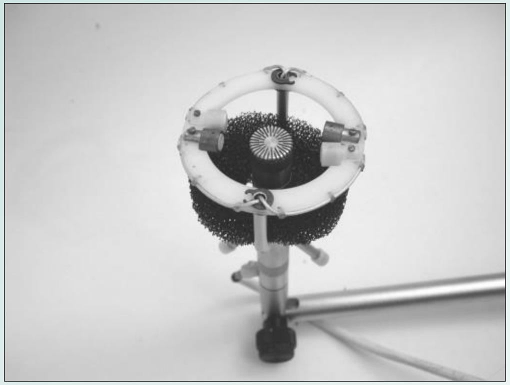
$$u_x(t) = -\frac{1}{\rho \Delta r}\int \left(p_2(t) - p_1(t)\right)dt$$

$$p_x(t) = \left(p_1(t) + p_2(t)\right)/2$$

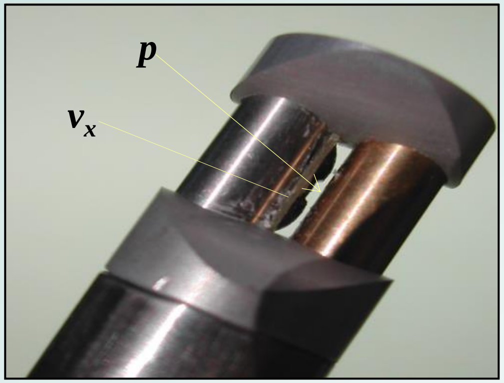
$$I_i(t) = u_x(t) \cdot p_x(t)$$

Different type of Sound Intensity transducers

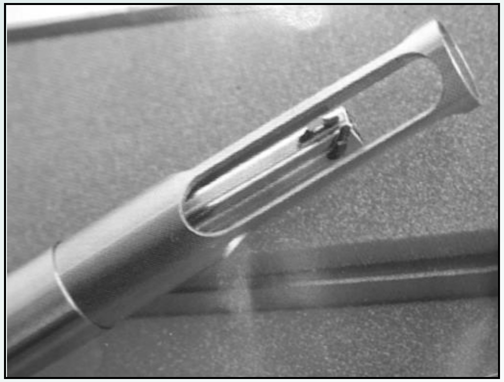
Two microphones probe „p-p” t. 50AI-A



Probe „p-v” type NE-216



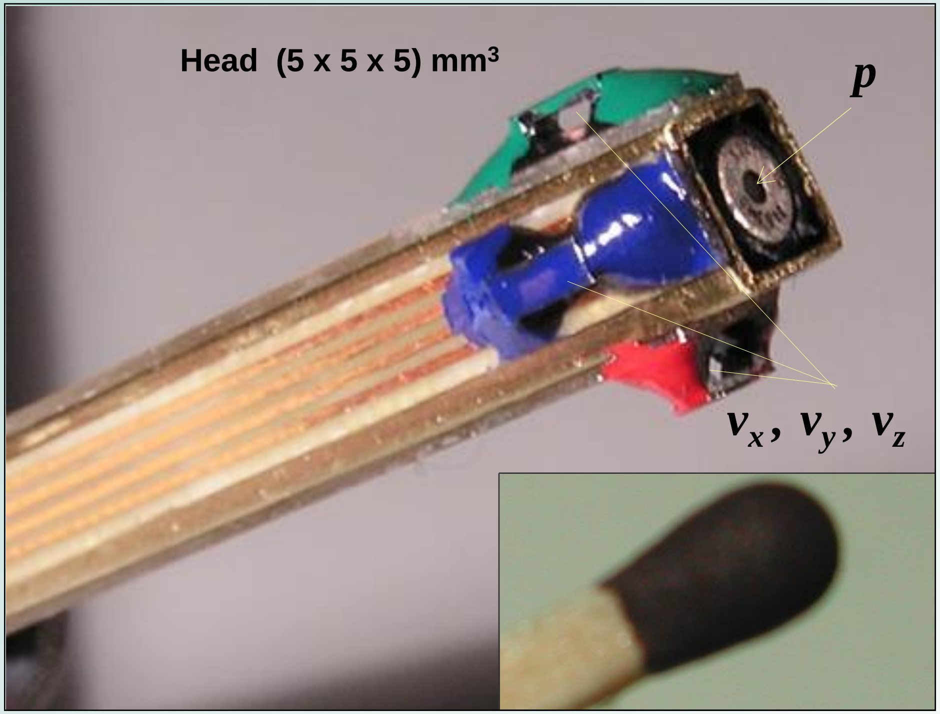
Probe *Microflown* type PU



Probe *Microflown* 3D type USP

Subminiature 3D sound intensity probe

3D SI probe
'Microflown" t. USP



Intensity components:

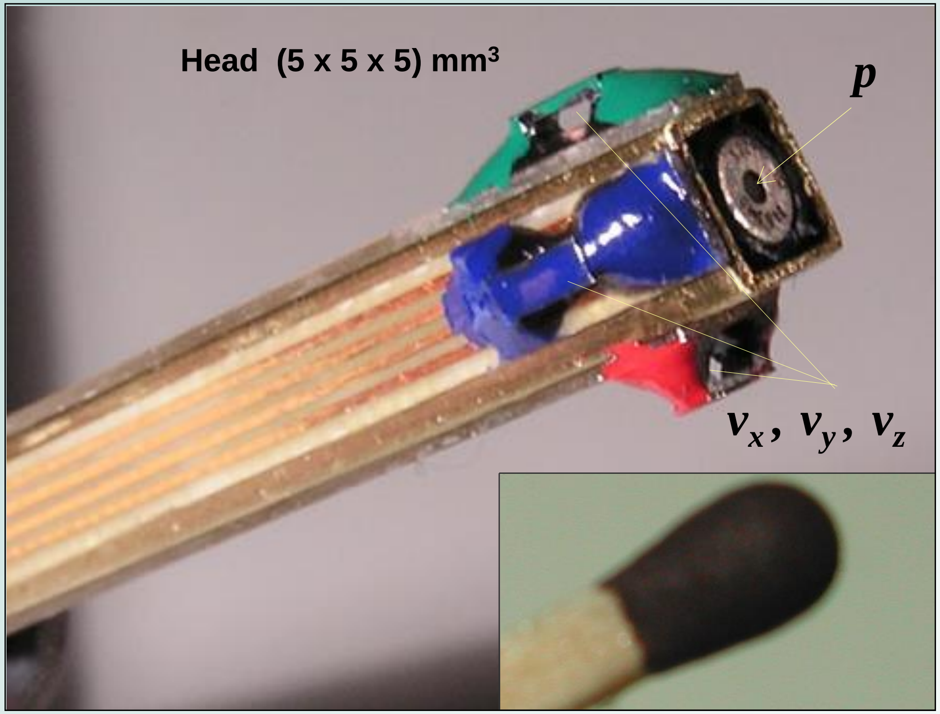
$I_x = v_x \; p$

$I_y = v_y \; p$

$I_z = v_z \; p$

Disadvantages of sound intensity probe

3D SI probe
‘Microflown” t. USP



Intensity components:

$I_x = v_x \ p$

$I_y = v_y \ p$

$I_z = v_z \ p$

<u>DISADVANTAGES:</u>

- **probe placed in the flow sound field interferes with the source field** („probe contamination effect”, especially at high frequencies),
- **minimum distance of the probe geometric center from the obstacle area is limited to about 3.5 mm** (head r = 2.5 mm + 1 mm).

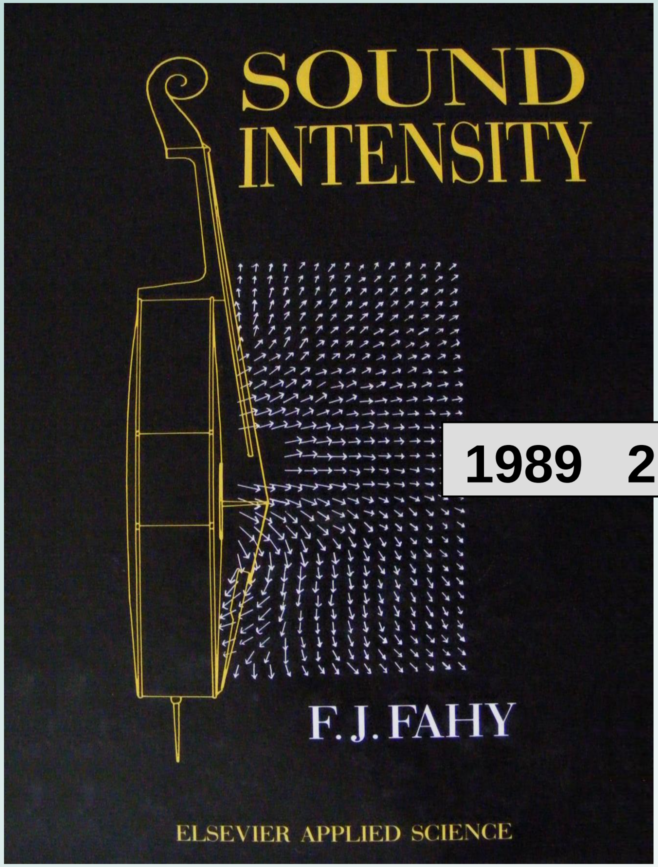
Mapping of acoustic vector fields with:

Sound Intensity Method

(Experimental examples)

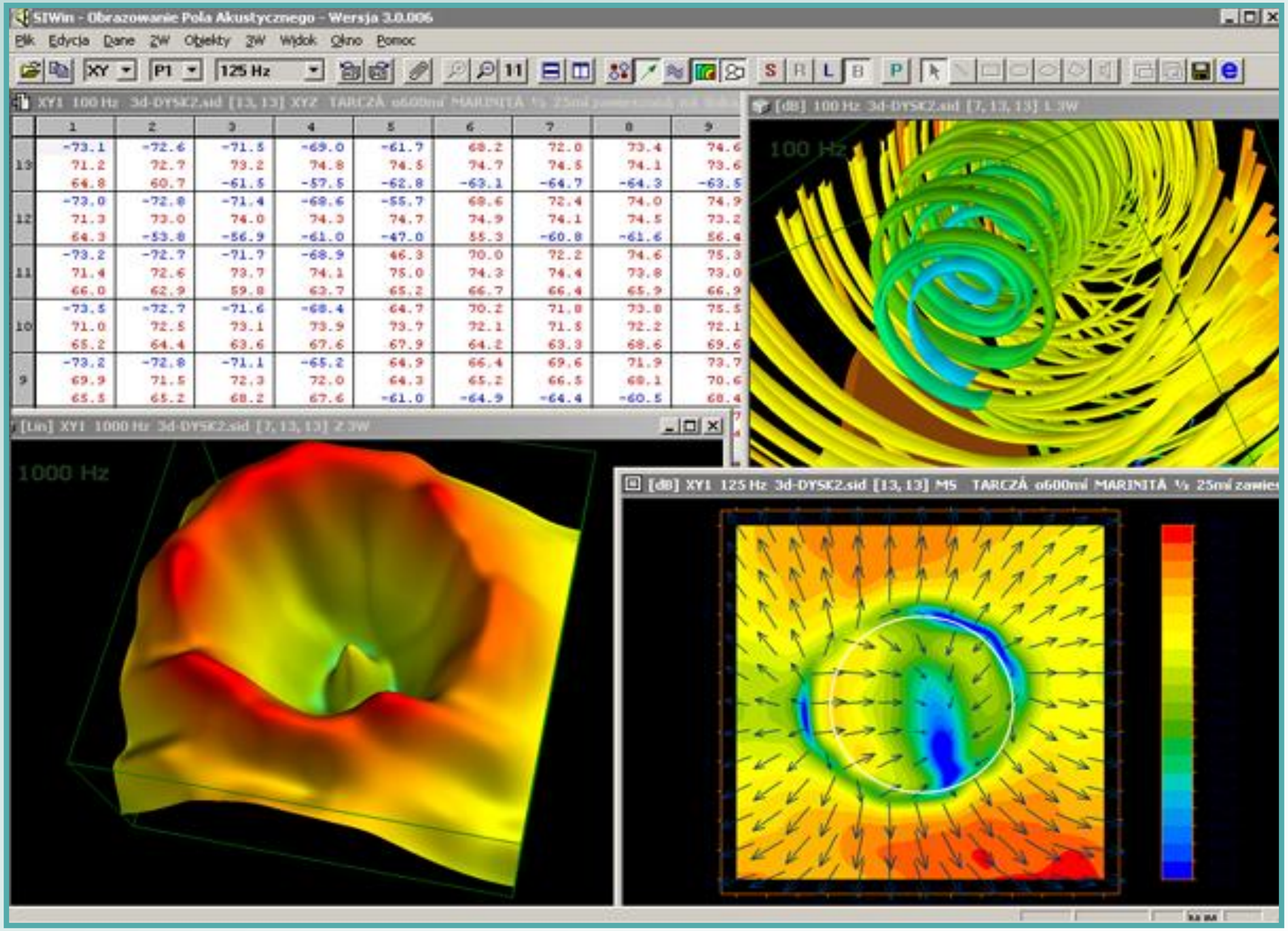
Development of SI research and flow image

Progress in the study and acoustical imaging



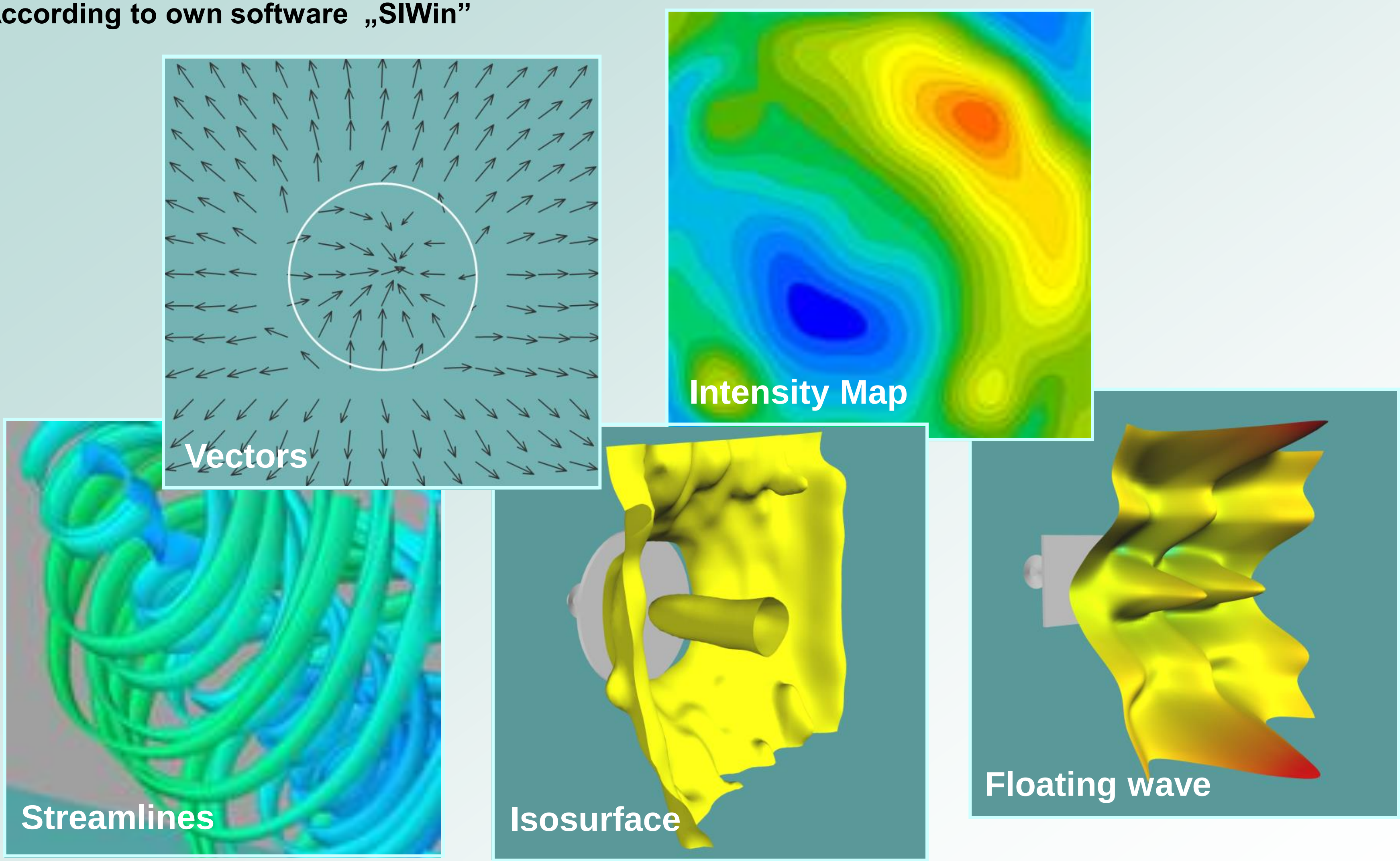
1989 2005

Sound intensity postprocessing – „**SIWin**”

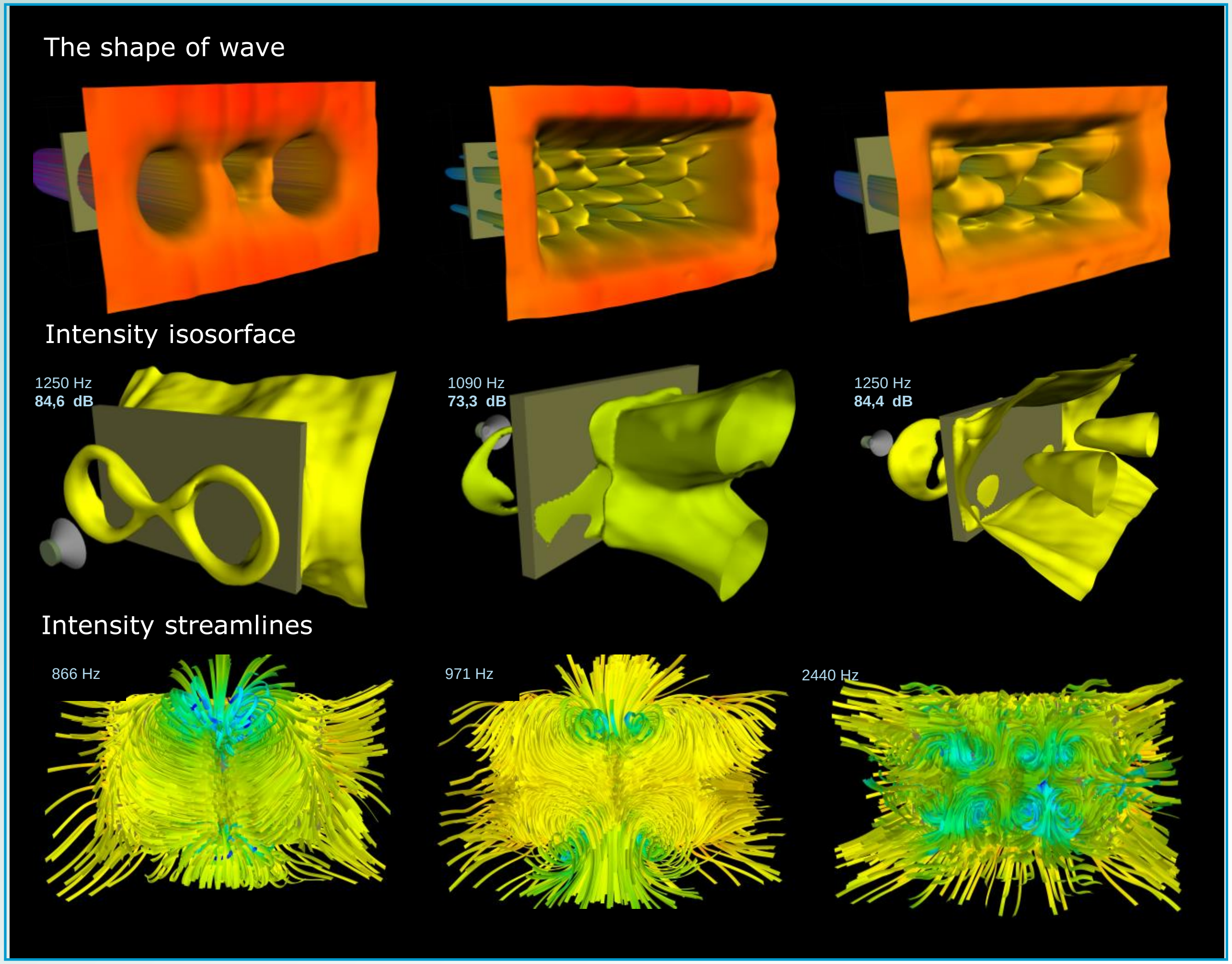


Mapping of vector acoustic fields with sound intensity

According to own software „SIWin”

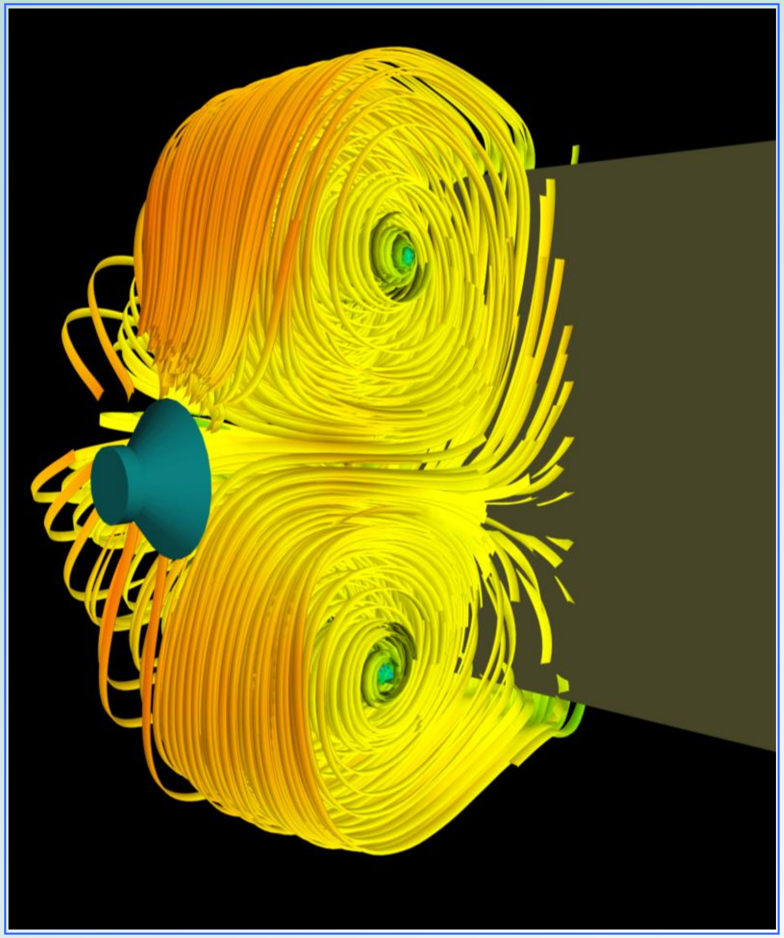


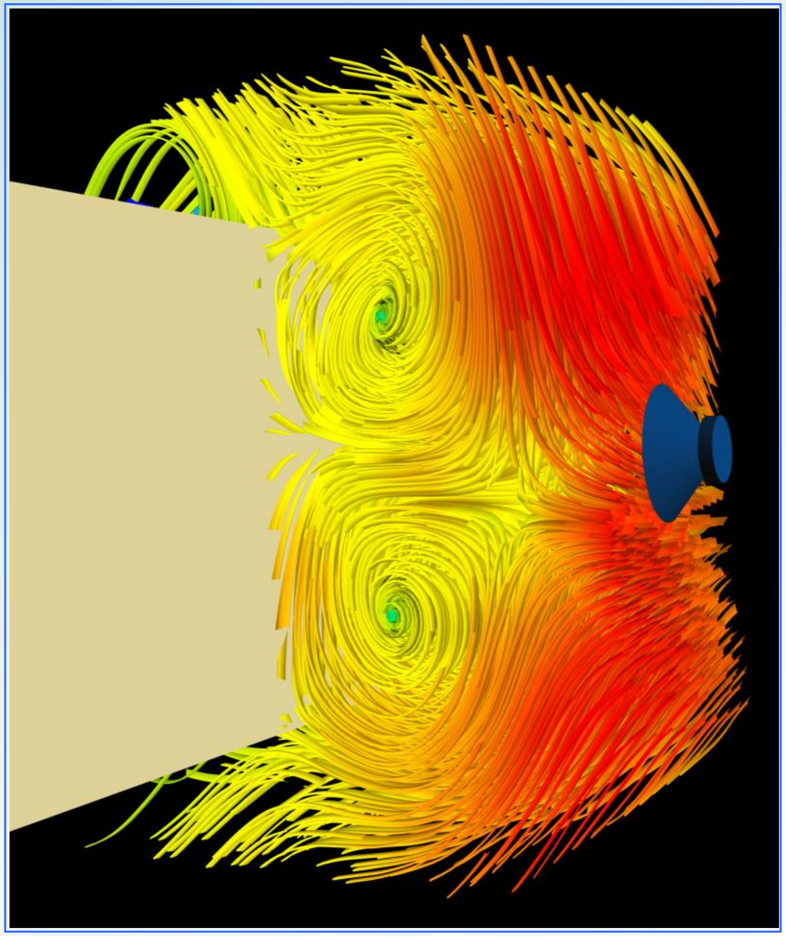
Vector field distribution (3D) around the plate



Intensity streamlines before rectangular plate

1/12 octave **686 Hz** **869 Hz**

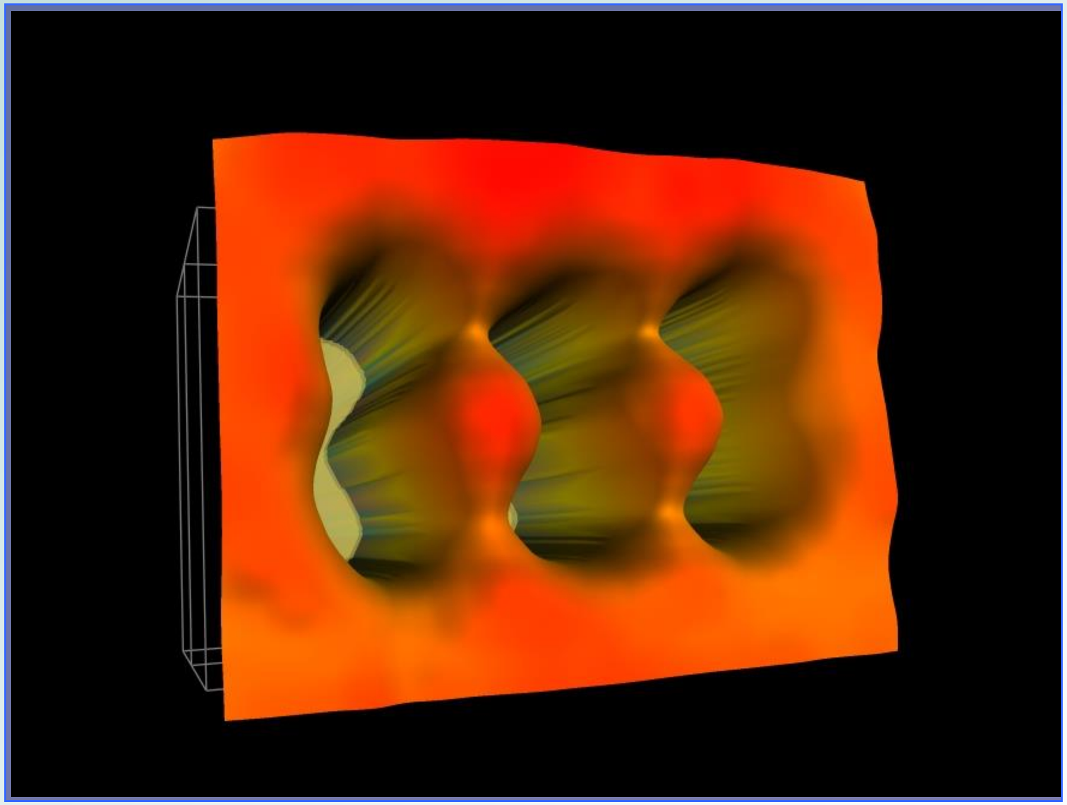




Only the half of the measure space is shown

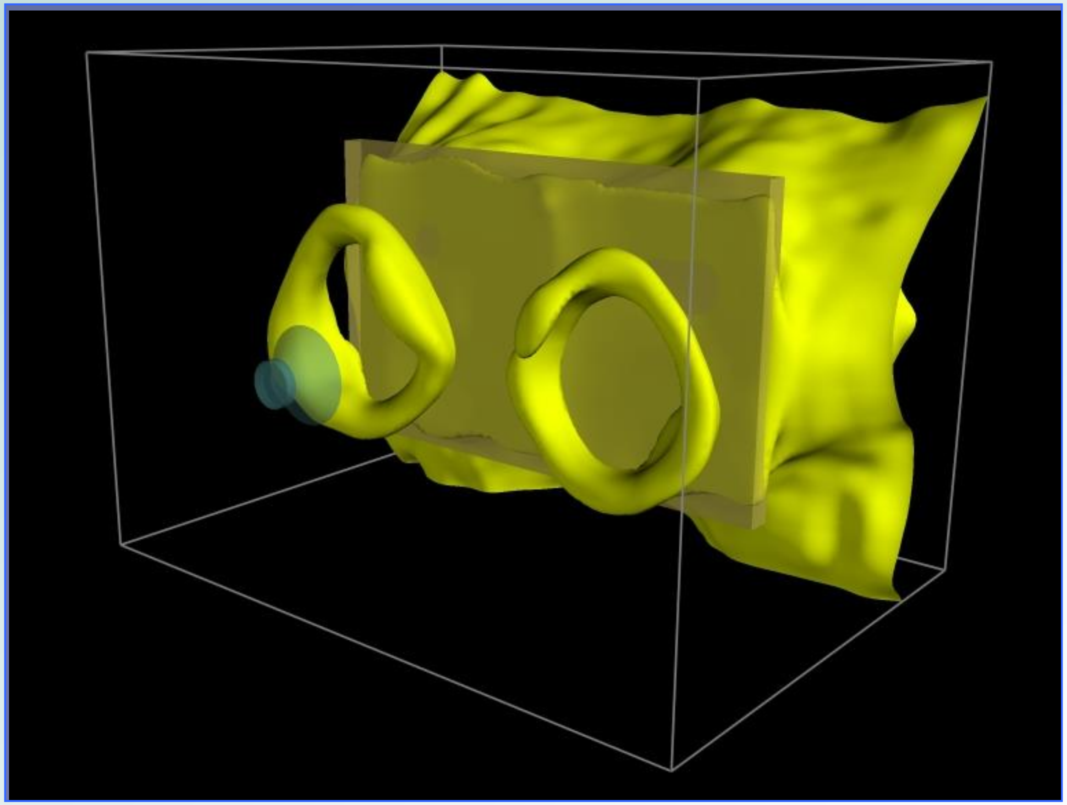
The shape of wave - animation

Acoustic wave in shadow area beyond the plate



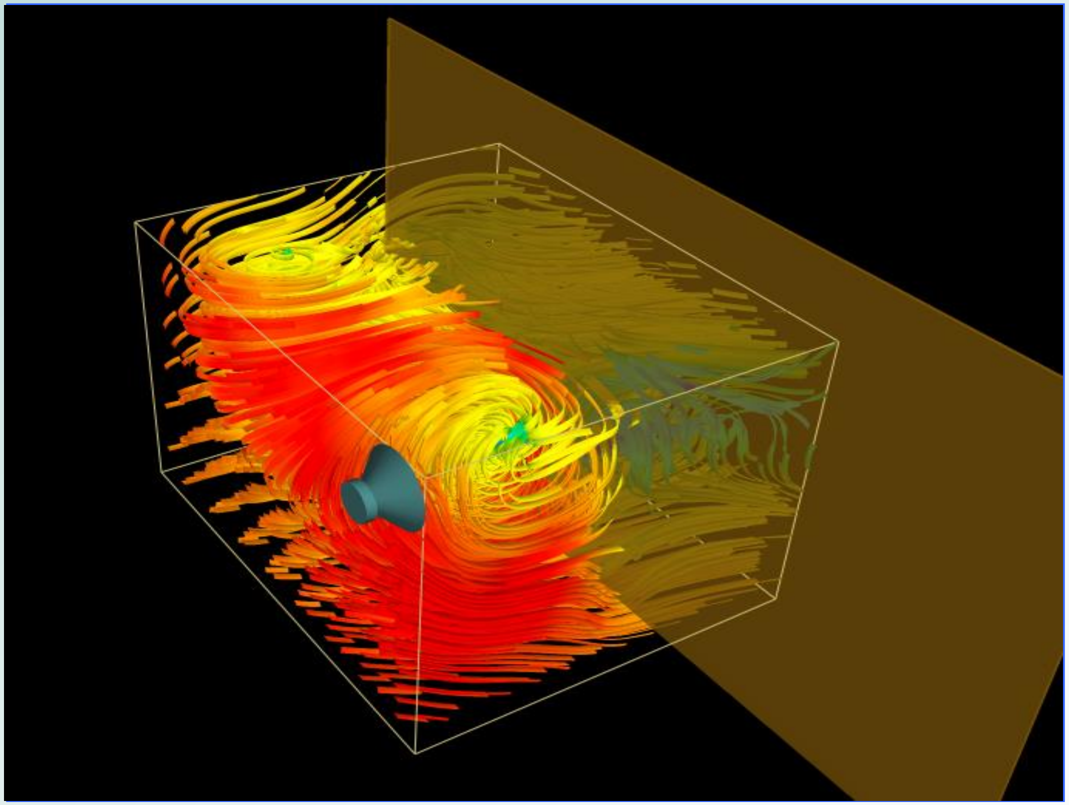
Sound intensity isosurface - animation

Sound intensity isosufrace around the plate - 1250 Hz, 84,6 dB



Sound intensity streamlines - animation

Sound intensity streamlines around left/down corrner of plate

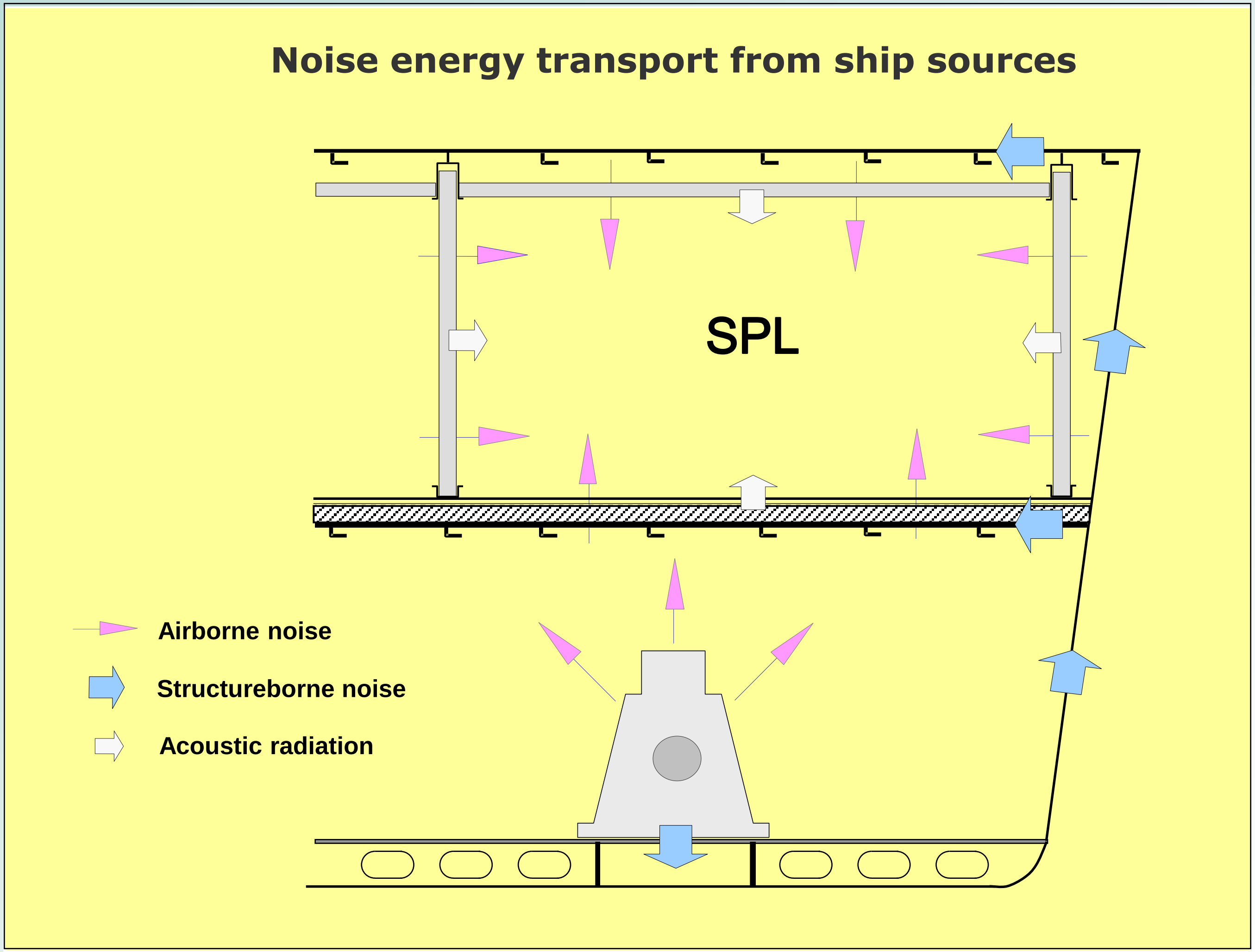


Mapping of noise on shipboard

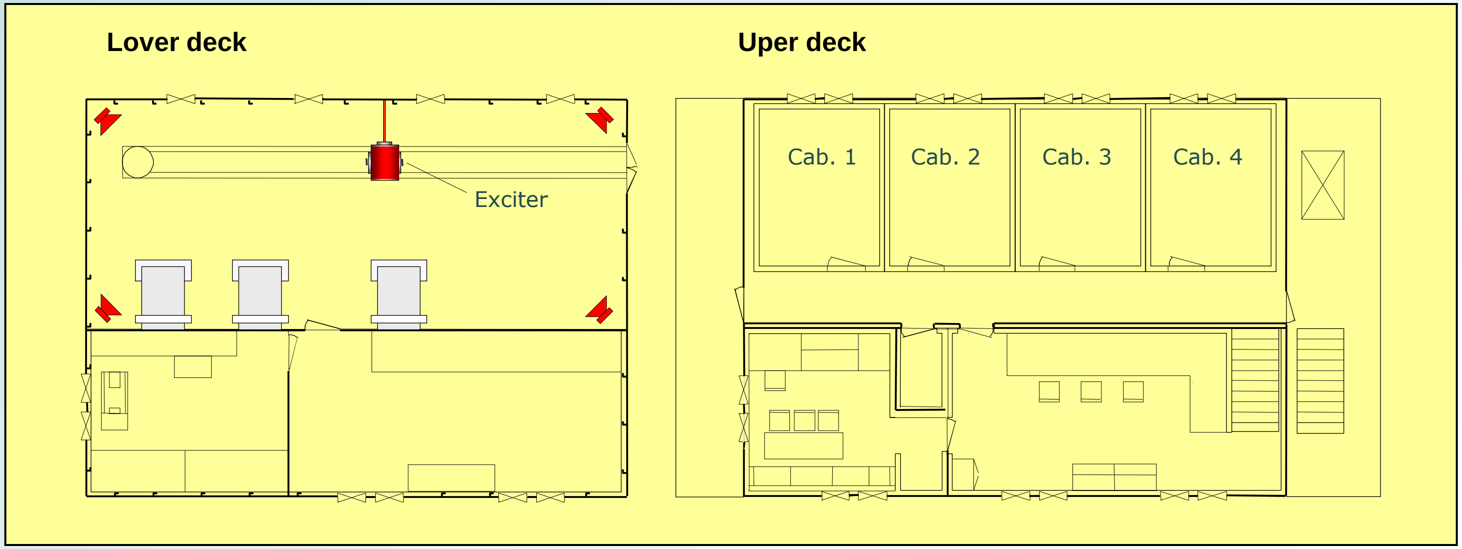
with

Sound Intensity Method

Noise transport to the interior of ship accommodations



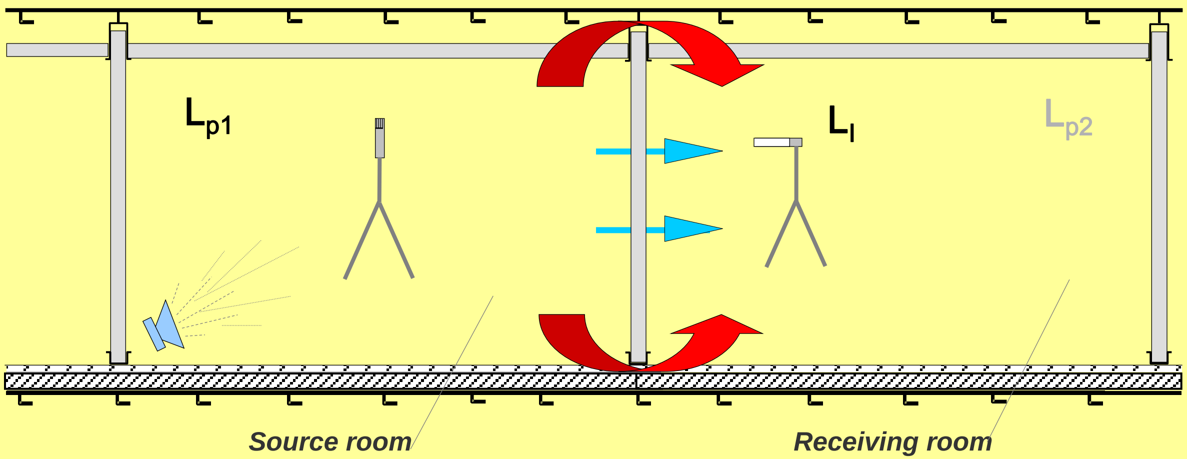
Muck-up ships superstructure



Structureborne noise excitation „on board”

Transmission loss measurement method

Measurement of TL with flanking effects of cabin bulkhead



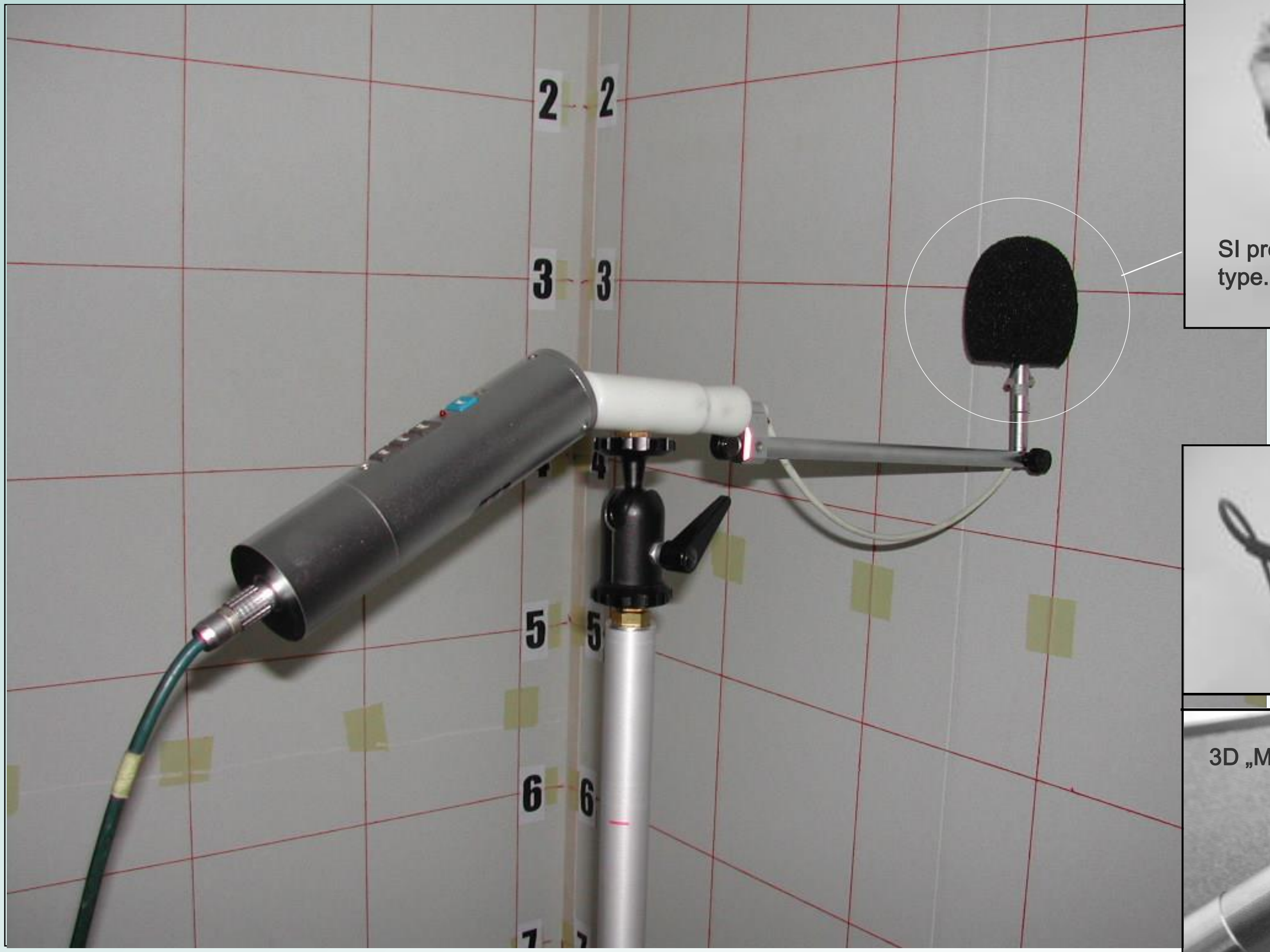
$$R' = L_{p1} - L_{p2} + 10\log S/A \qquad [dB]$$

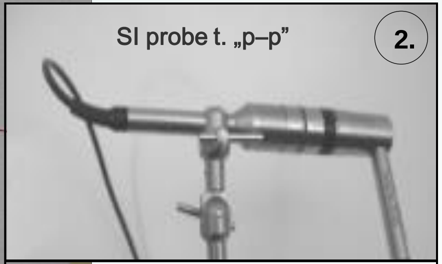
S – bulkhed surface, [m^2]
A – total room absorption, [m^2] **, A = 0,161 V/T**

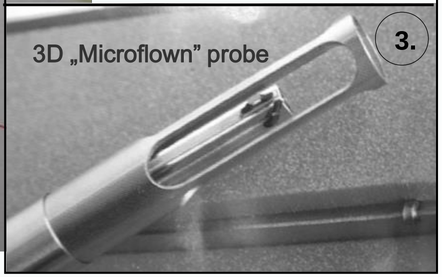
$$R' = L_{p1} - L_I + 6 \qquad [dB]$$

L_I – sound intensity level, [W/m^2]

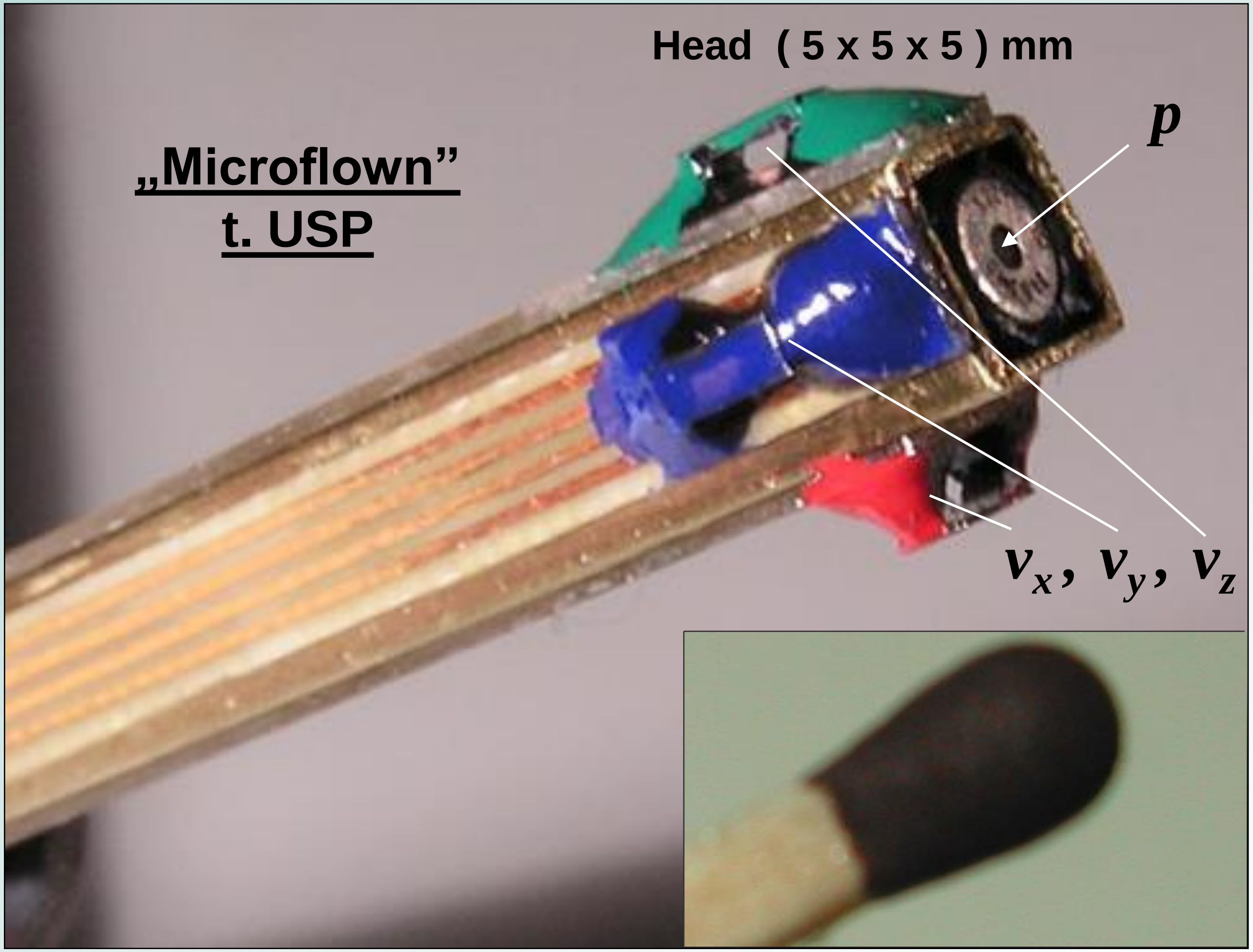
Noise radiation by the cabin partitions







Subminiature 3D sound intensity probe



Intensity Components:

$$I_x = v_x \; p$$
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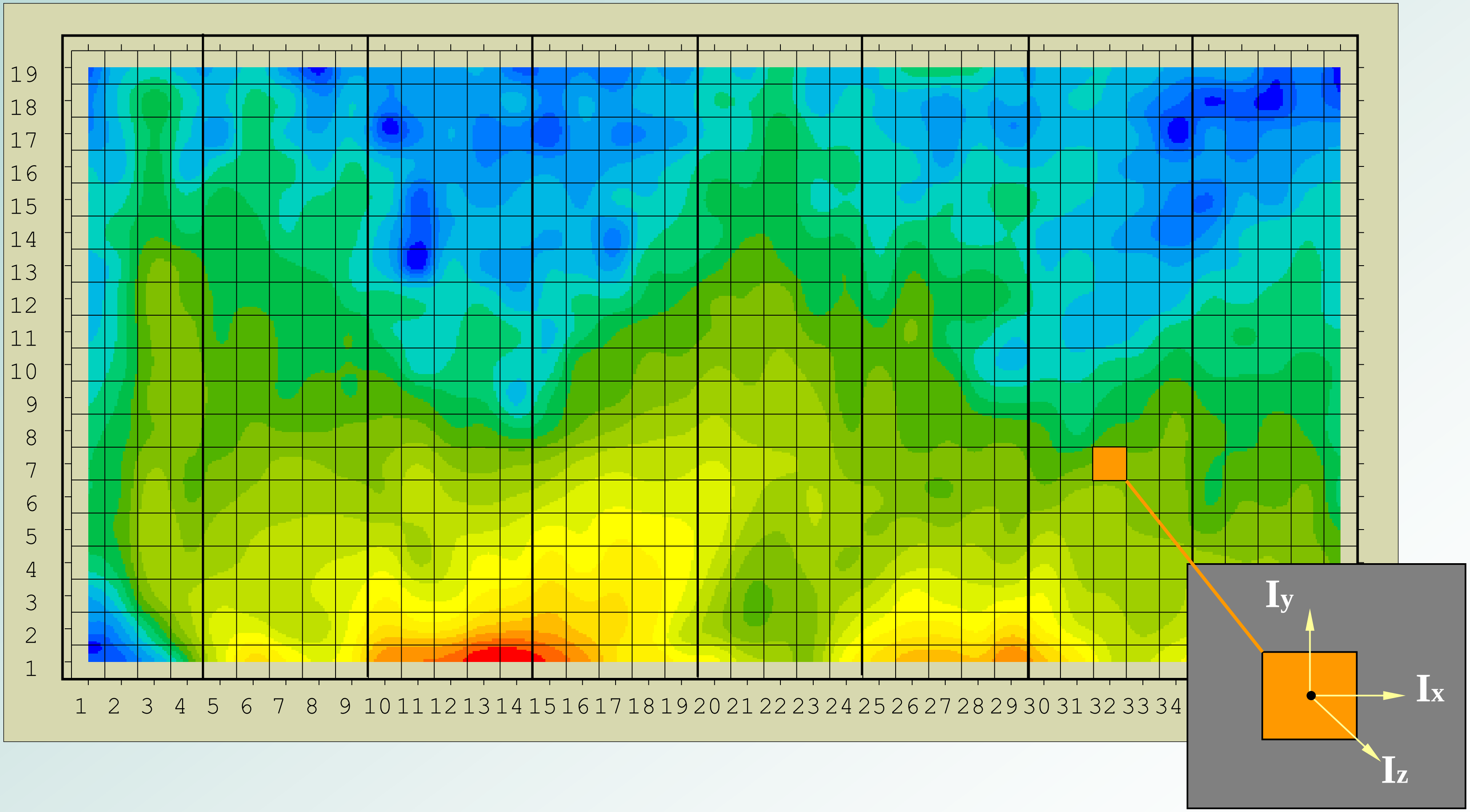
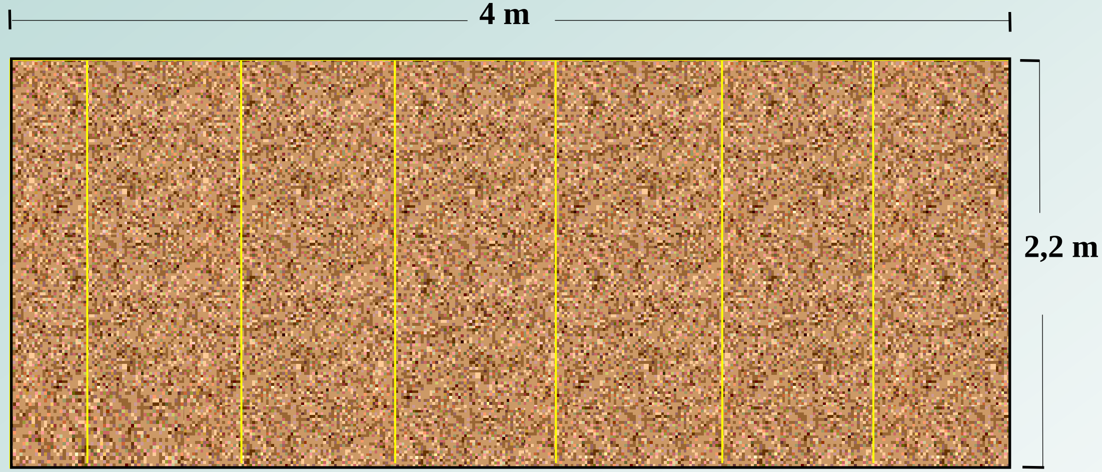
Noise radiation by the cabin wall

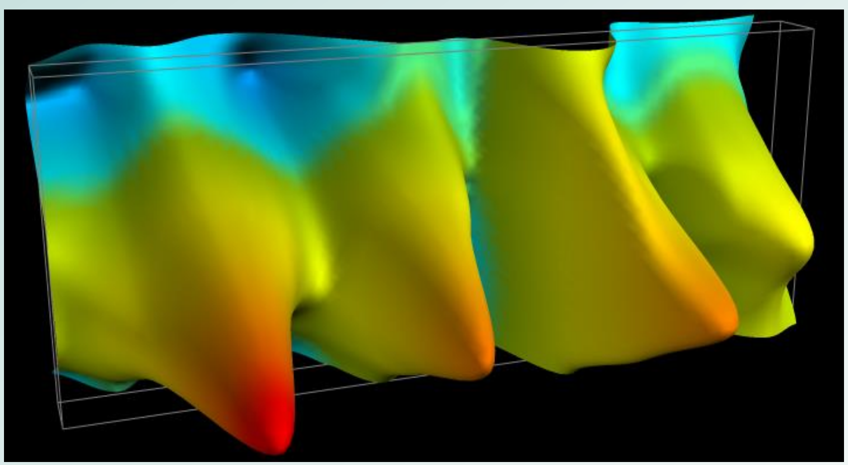


Noise energy flow through the bulkhead

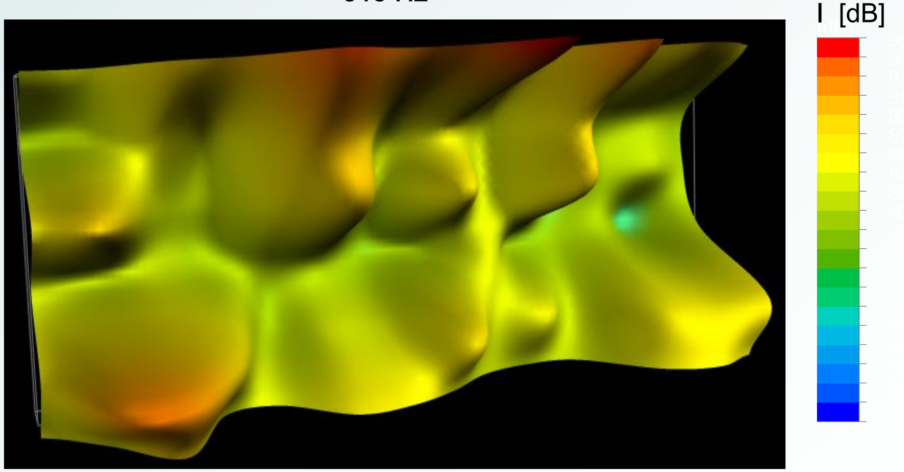
Cabin bulkhed



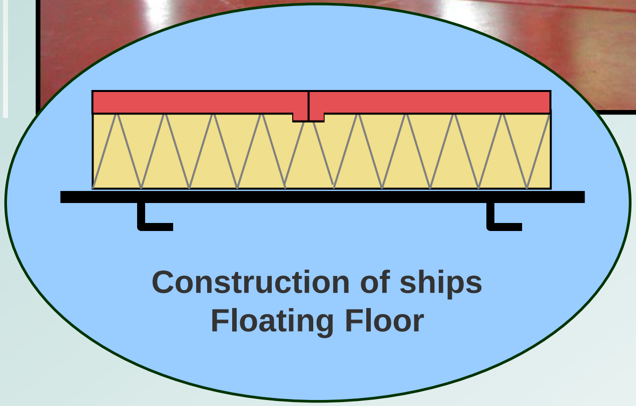
50 Hz



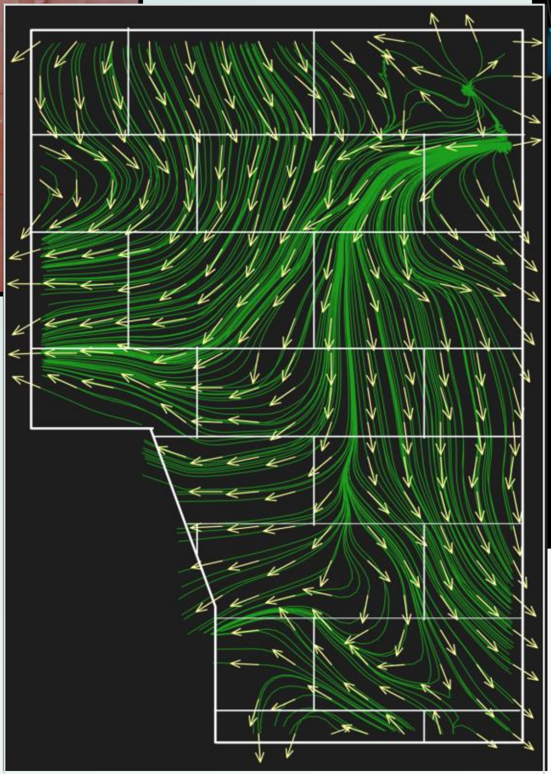
315 Hz

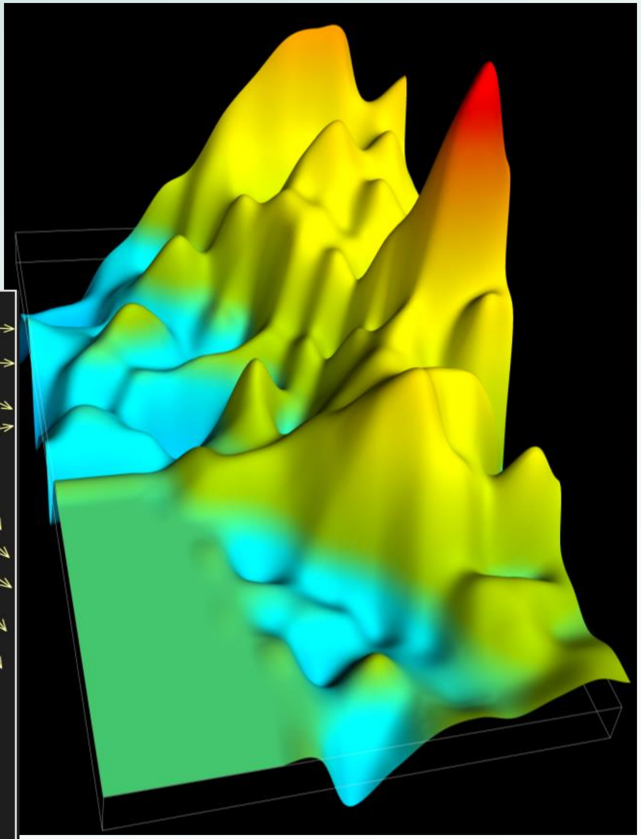


Noise radiation by the „floating floor”

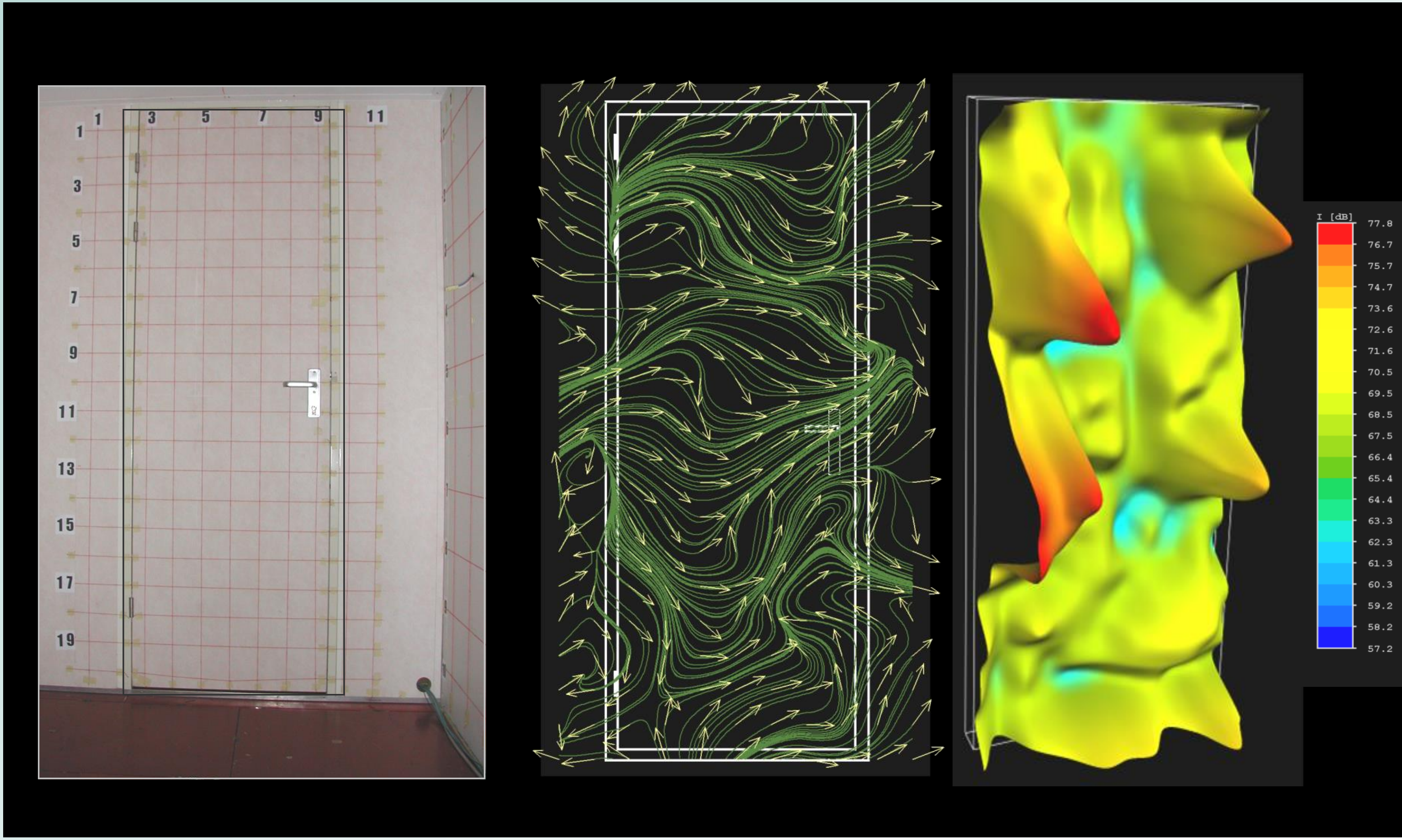


50 Hz

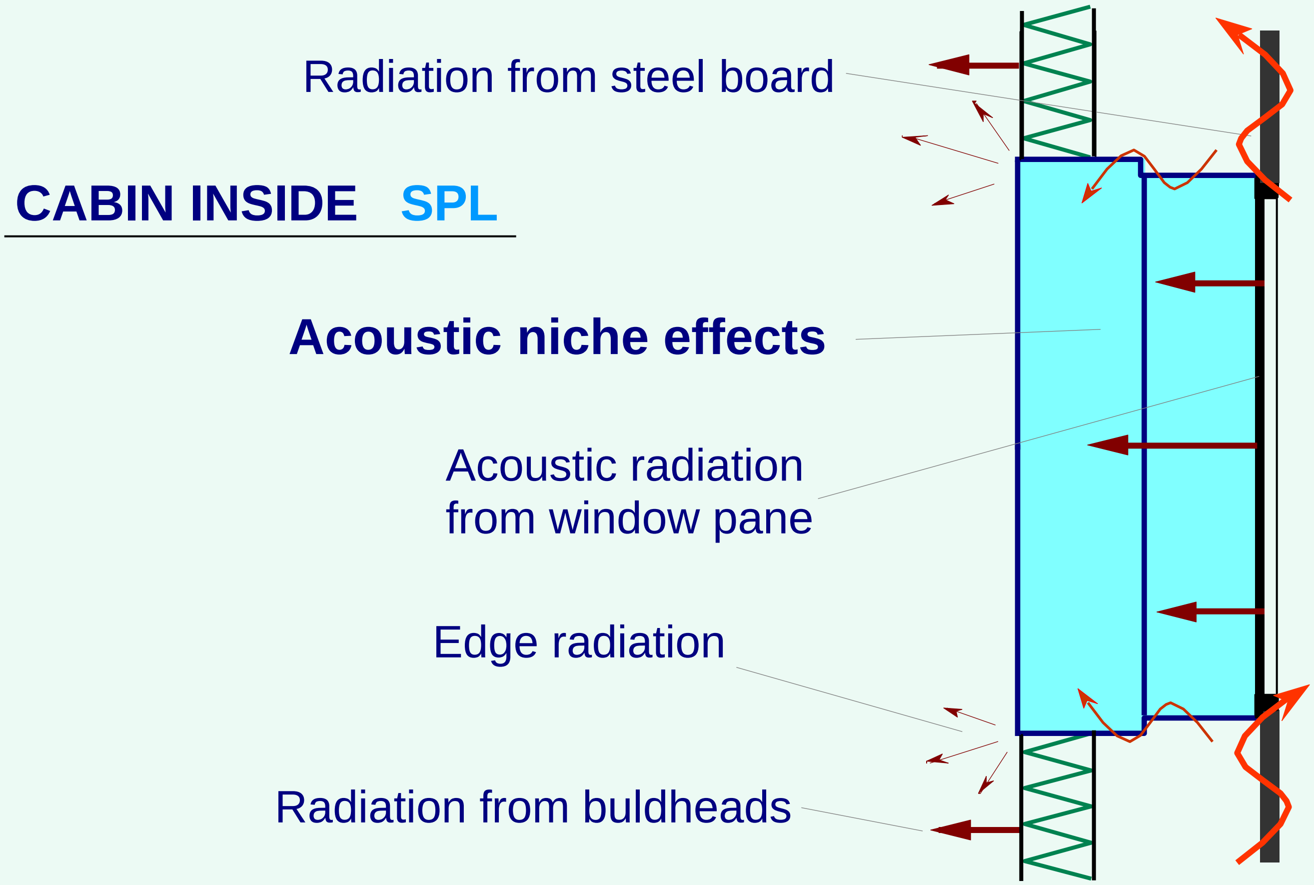




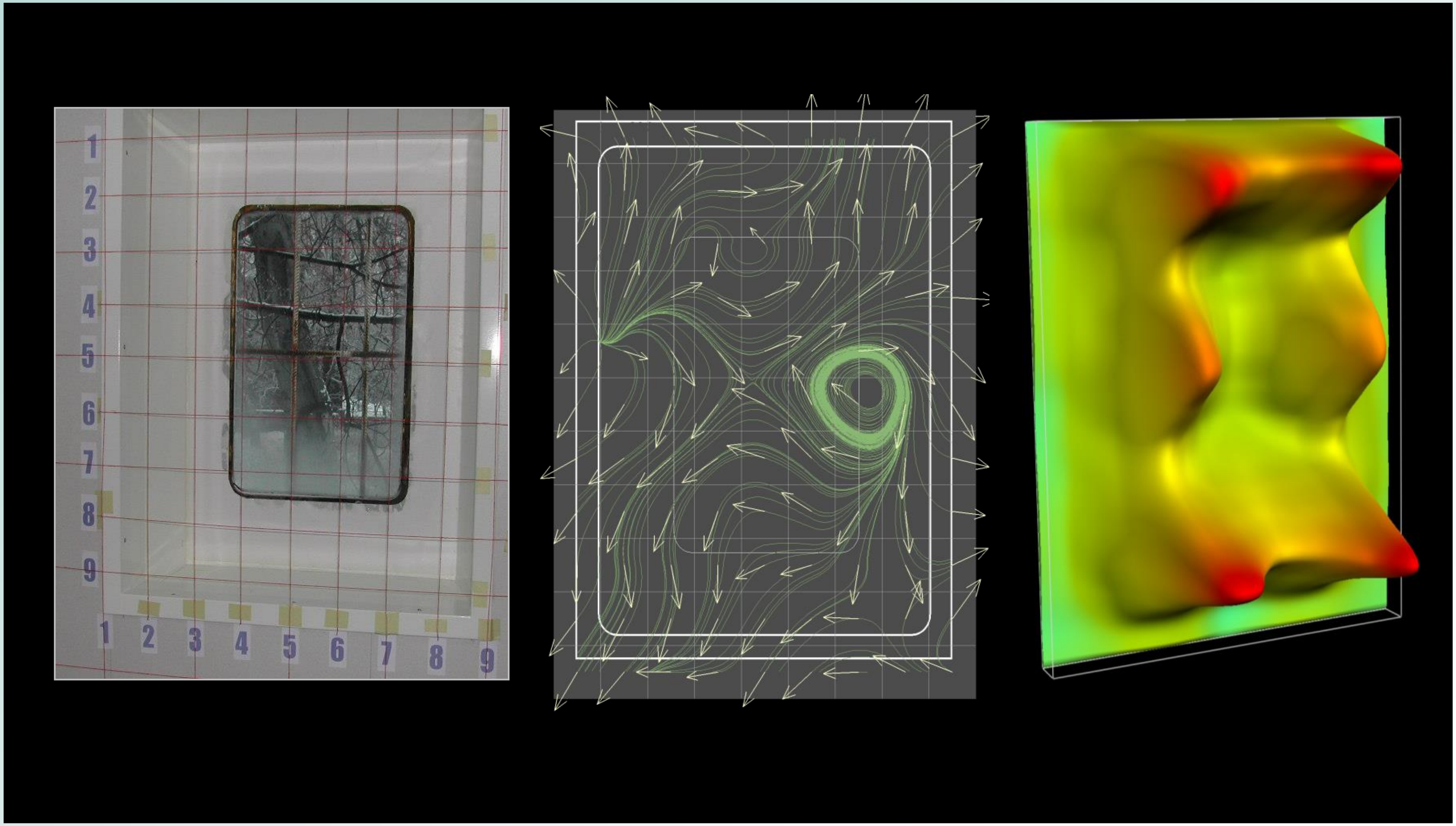
Noise flow through the cabin door



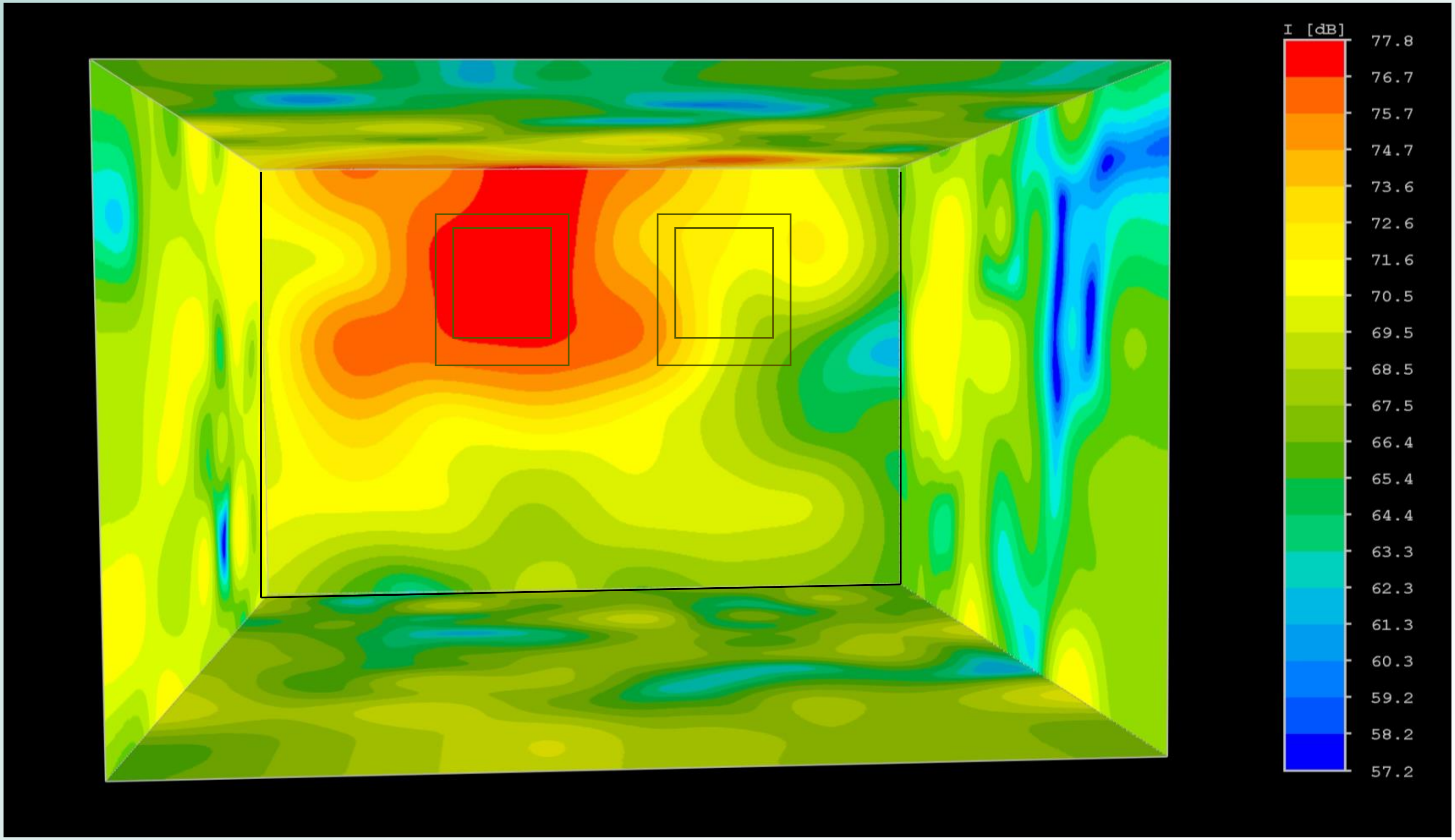
Noise radiation by the cabin window



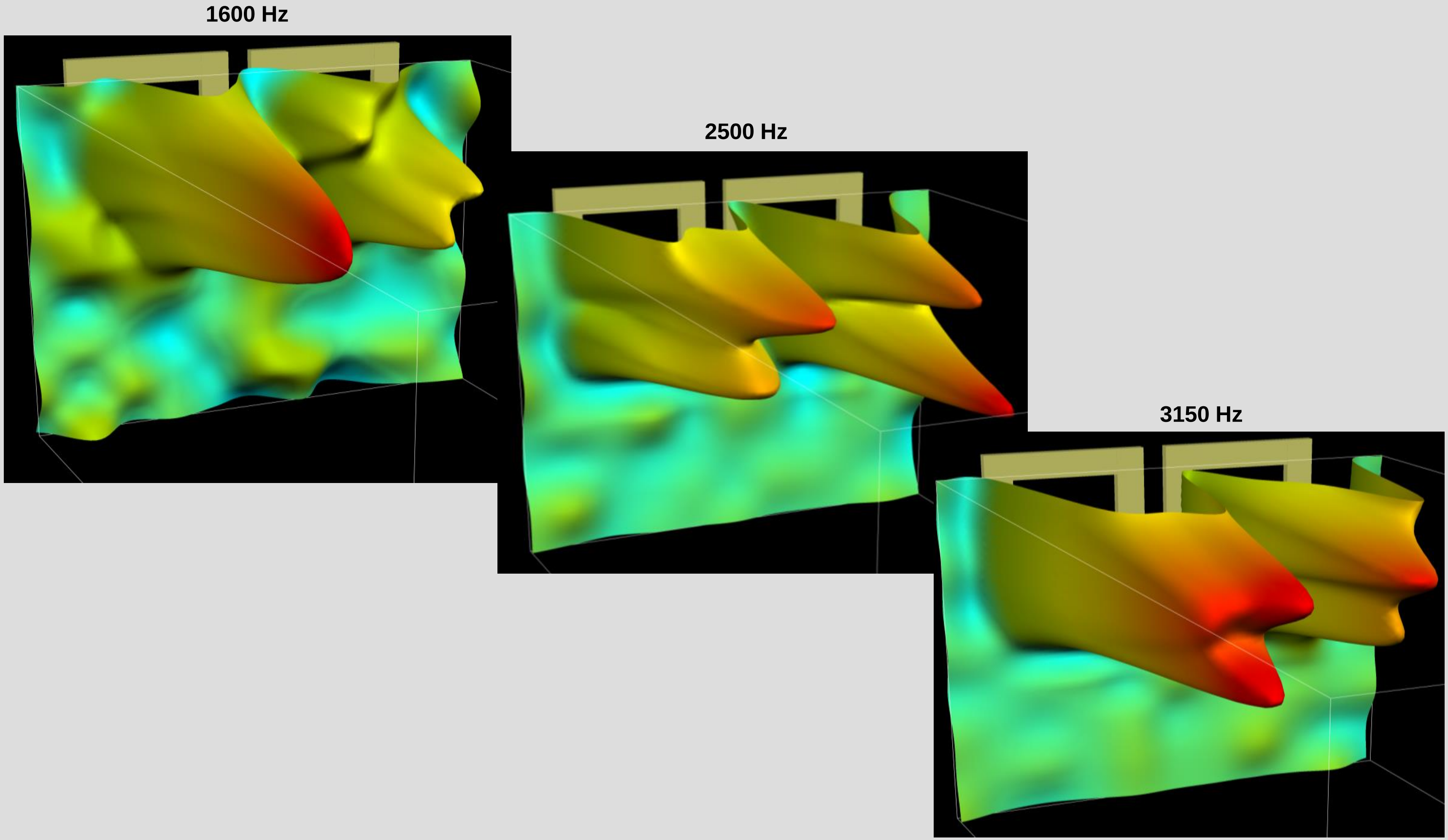
Noise radiation by the cabin window



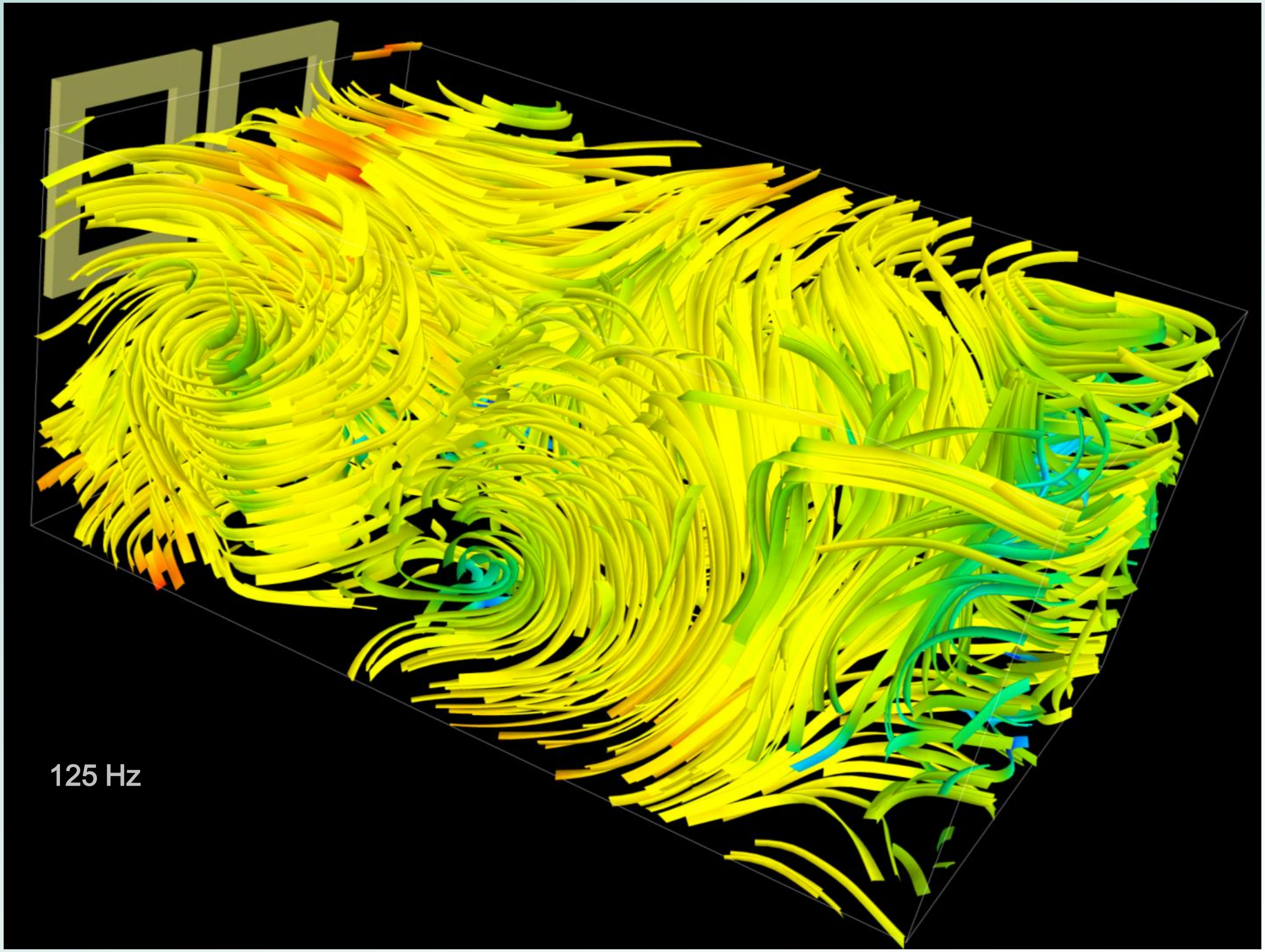
Intensity distributions on the ship cabin partitions



Noise radiation by the cabin wall with 2 windows



Intensity field (*streamlines*) in the crew cabin



Mapping of noise with laser techniques:

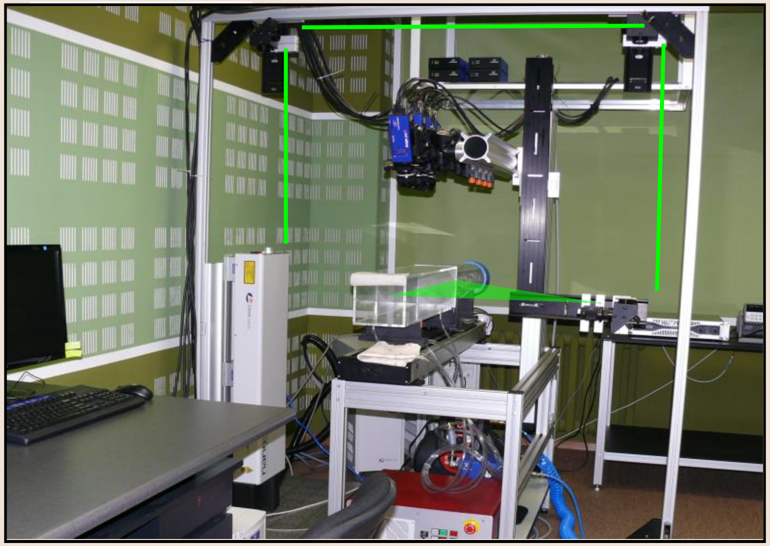
1. **Particle Image Velocimetry, PIV**
2. **Laser Doppler Anemometry, LDA**

PIV and LDA laboratory

PIV system – LaVision Gmbh

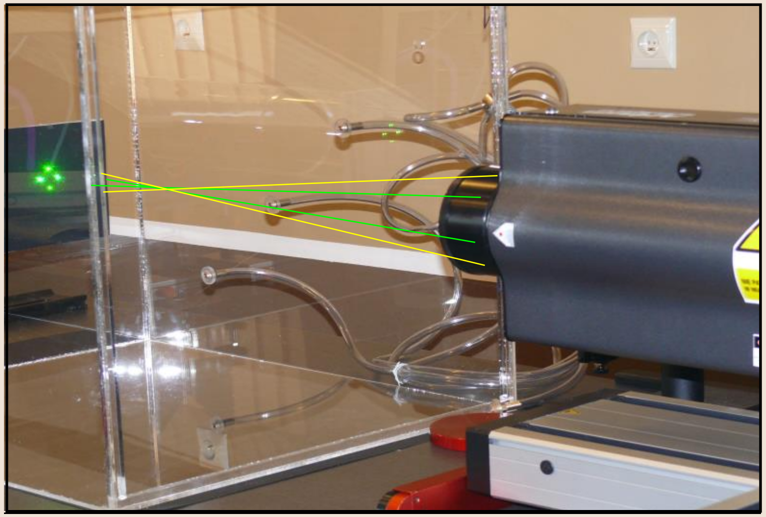
Nd:YAG Double-Pulse Laser
2 x 325 mJ, 532 nm, 15 Hz
Sheet Forming Optics (50 x 50mm)

- **Imager Pro X 4M CCD Cameras** (4)
  2048 x 2048 p., 7,4 µm, 14 Bit, 14f/s,
  Schaimpflung mounts (4)
- **Calibration Kits** *(50 x 50, 33 x 300 mm)*
- **3D Trawerse Unit** *(1m x 1m,x 1m)*
- **Aerosol Generator** *(DEHS)*
- **Computer System with software:** *DaVis v. 8.11, 2D, 3D Stereoscopic PIV, 3D3C Tomo PIV*



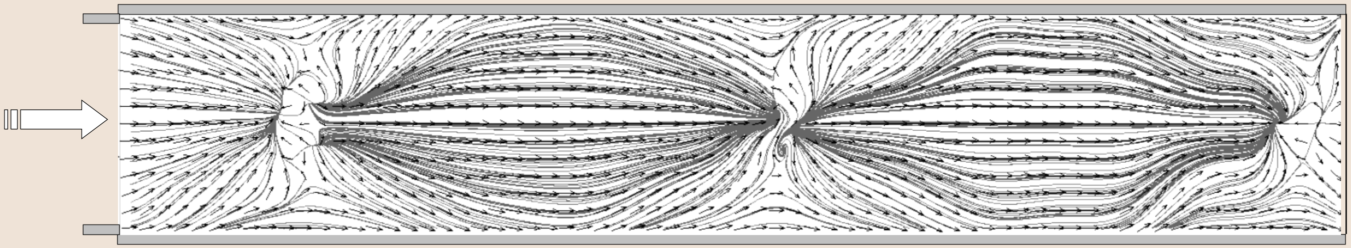
LDA system – Artium (USA)

- **Two Diode Pumped Laser** *(DPSS)*
  300 mW- green, 300 mW- yelow
- **2D Transceiver system** *t. LDV-200 TR*
- **Advans Signal Analyzer**
- **Automated Instrument Menagment System**
- **Spinning Calibrator Device**
- **3D Trawerse Unit** *(0,9m x 0,9m x 0,9m)*
- **Aerosol Generator** *(DEHS)*
- **Computer System** *and software*

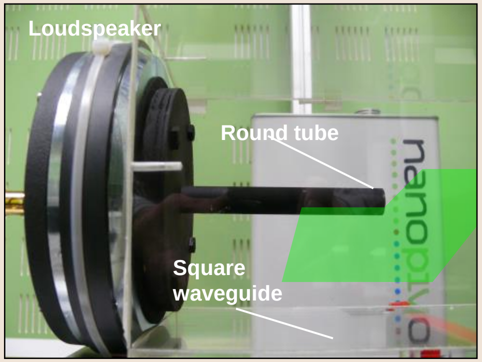


Acoustic flow inside a square waveguide

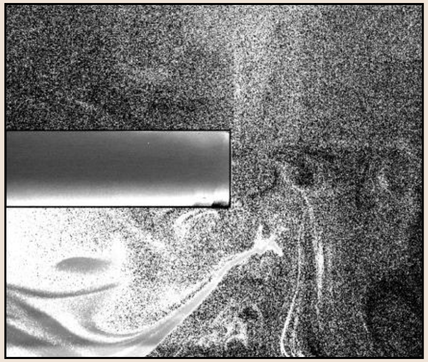
Image of acoustyic standing wave inside a square duct



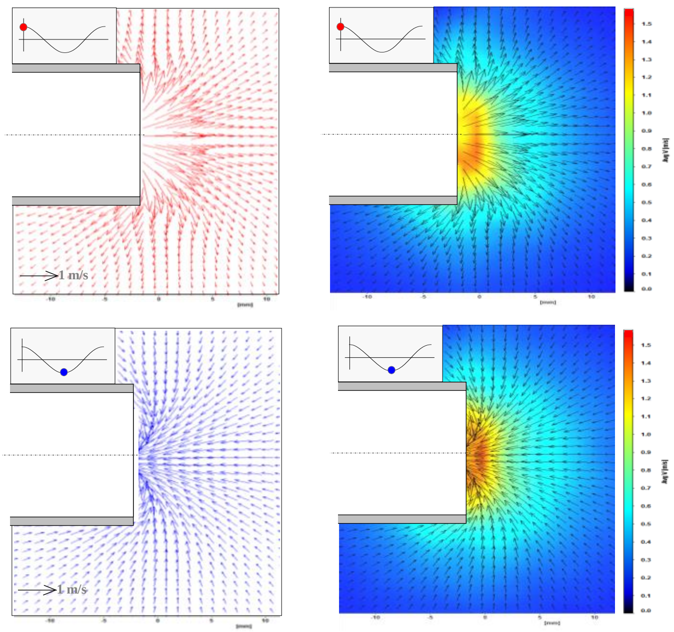
Acoustyic flow field around a outlet of circular tube



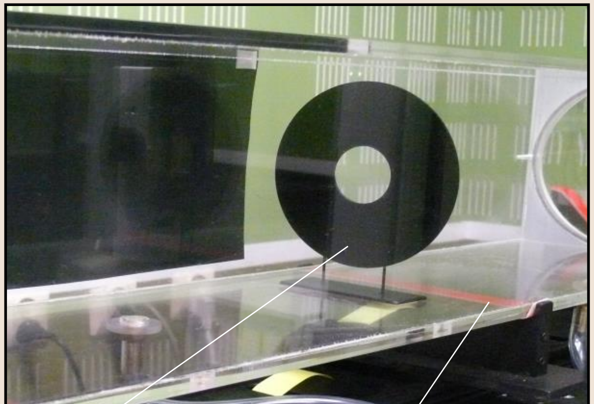
Seeding particle flow in laser light



Phase relation of acoustic flow outside a tube (700 Hz)



Acoustic flow inside a square waveguide

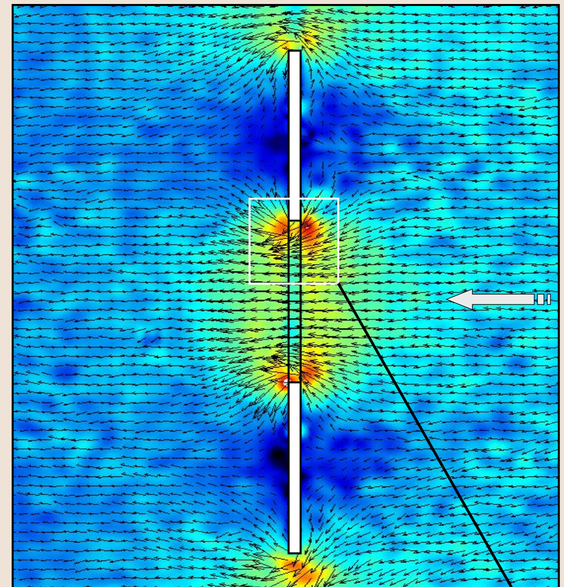


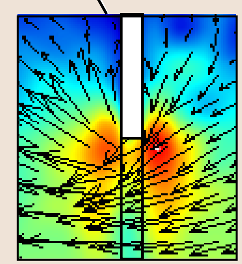
Circular disk:

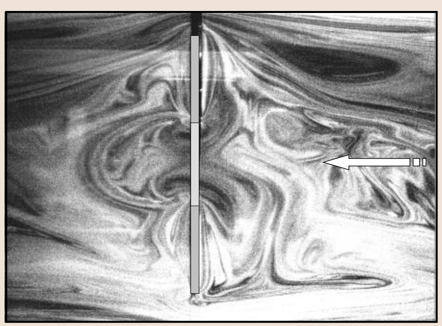
diameter - 120 mm
thickness - 1.2 mm
hole - 38 mm

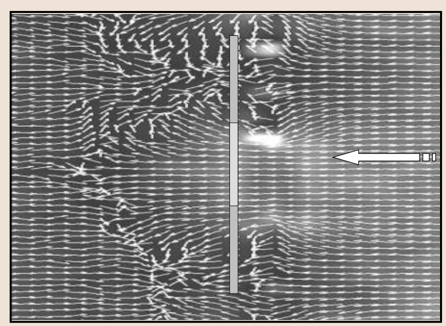
Waveguide:

square - 150 x 150 mm
length - 750 mm
active signal - tone, 530 Hz









CONCLUSIONS

- The sound intensity analysis for 3D vector fields formed in real crew cabin, can to see the normally invisible effects of shipboard noise.

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- With „Seeing the Invisible" acoustics wave we can easily make contact with the designers and engineers who should be implemented technically noise abatement on ships.

CONCLUSIONS

- **The sound intensity** analysis for 3D vector fields formed in real crew cabin, can to see the normally invisible effects of shipboard noise.
- With **„Seeing the Invisible”** acoustics wave we can easily make contact with the designers and engineers who should be implemented technically noise abatement on ships.
- Our innovative methods of acoustic **research with a SI, A-PIV, A-LDA measurements** significantly expanded all the acoustic diagnostic systems using for ships machines and equipment.

THANK YOU

FOR YOUR ATTENTION !

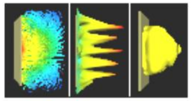
Summing up our research possibilities …

New experimental techniques to optimal research at reducing noise on ships and offshore platforms.

Ship design and investigation equipment for crew protection against noise

Stefan Weyna,
Applied Vibroacoustic Dep., West Pomeranian University of Technology, Poland, weyna@zut.edu.pl

ACOUSTIC RESEARCH USING SOUND INTENSITY (SI) MEASUREMENT



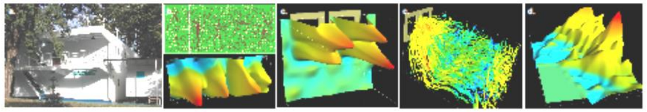
Acoustic wave radiated by the vibrating plate described as a wave shape, streamlines and intensity isosurface

The applied research technique is the vector distribution analysis of acoustic fields generated by sources in the real-live conditions and the creation of spatial visualization of the acoustic wave response to the obstacles in the way of its propagation. Experiments are carried out laboratory research and in industrial conditions using a new method for analysis of the acoustics wave flow as the acoustic energy or noise flux in the real sound field. To the study of the wave acoustics flow, own post-processing program called "SIWin" is used. The distribution acoustic field is presented graphically on the 2D plane or in 3D space as a sound intensity maps, acoustic energy flux lines, shapes of the traveling acoustic wave or as a spatial distribution of intensity izosurfaces. Based on the measurement data we also can create animations of the actual forms of wave motion.

The presented methods visualize the results of acoustics flow and interpret the shapes of the traveling wave, the effects of vortex rotation and the collapse of the wave on obstacles. Even for acousticians, it is a hitherto unknown form of experimental investigations of vector visualization of the flow of events in the acoustic wave like flows in fluid mechanics. The new testing methods improve and develop modern diagnostic techniques used to the machinery and mechanical appliances conducted with acoustic methods. They become a very useful tool in optimizing the choice of technical methods for the noise abatements on the workplace. They also have a crucial importance in the validation of computer simulations, which often differ significantly from results recorded in the real machinery work conditions.

SOUND INTENSITY AND LASER ANEMOMETRY IN SHIP ACOUSTICS RESEARCH

Direct measurements of sound intensity representing the flow of energy in sound fields has revolutionised acoustical metrology. It is now possible to measure the sound power output of individual noise sources of all forms and sizes in their operational environments. In-situ measurements can be achieved even when sources operate in the presence of other comparable powers, a process impossible with conventional instrumentation. Investigations carried out with sound intensity measurement techniques may be compared against those made by classical methods. Based on the research with intensity technique and using selected presentation methods, we can demonstrate results of vector space distribution of the acoustic field in the area adjacent to the ship partitions. This enables one to obtain significantly new information related to energetic acoustic fields in the vicinity of vibrating ship partitions which, in turn, affect the noise distribution inside the cabin. For instance, we can present results of the transmission loss measurements together with flanking transmission for ship bulkheads and partitions with doors and windows.



Ship Acoustics Laboratory (a) and sample results of the SI measurement: noise radiated by the cabin wall (b), cabin windows (c) and by the cabs floor (d)

For the purpose of ship pipe installation noise research we also use the Laser Anenometry Technique. The most widely applied laser methods for acoustics flow measurements are doubtlessly the Acoustics-Particle Image Velocimetry (A-PIV) and the Acoustics-Laser Doppler Anemometry (A-LDA). Both of these methods have been used in the measurement of vectors sound fields. Laser anemometry is a method which allows to made the non-intrusive instantaneous measurement of acoustic velocity in the field. The non-intrusive property of the laser measurements methods represents the greatest advantage against other methods using sensors for acoustic flow measurements. The proposed study provides objective information about noise generation by acoustics flow around obstacles and inside a ducts in order to improve physical understanding of noise generated by these flows and to provide well documented test cases to validate theoretical Computational Fluid Dynamics (CFD) and Computational Aero-Acoustics (CAA) models.

Laboratory of Acoustic Imaging Laser Anemometry (PIV and LDA) and some of investigation results of acoustic flow in duct

Our proposed program is directed to enrich knowledge to better understanding of the noise generated by the air condition installations, turbo-machinery, pump, fans, pipe installations and other ships devices (HAVAC systems), and to identify more effective ways of its reduction. As in the case of applications of the sound intensity method and laser acoustics anemometry a large role in the analysis of the results plays a graphical visualization of the test results. For this purpose for post-processing analysis the SIWin own program, LaVision – FlowMaster, proper orthogonal decomposition (POD) and Tecplot will be used.

We have extensive experience in research on ships and well equipped laboratory with set of sound intensity and laser anemometry systems. We are well prepared to conduct research of noise abatement on ships and offshore platforms using these innovative measurement techniques.

APPLIED VIBROACOUSTICS DEPARTMENT

Research activity

MARTEC ERA-NET Maritime Technologies

SHIP ACOUSTICS LABORATORY

Investigations on natural size ship cabins end equipment under real dynamic excitation

with emphasis on :

- vibroacoustic investigation in dynamic conditions (testing technology and construction) for the natural size ship cabin built inside a mock-up superstructure,
- vibroacoustic characteristics for separate natural size cabin partitions (bulkheads, ceilings and floors) or walls with windows and doors : structure borne and air borne transmission loss (with flanking transmission),
- characteristics of: insertion loss, sound radiation efficiency, velocity level difference factor, impact sound insulation factor, etc.
- measurements of vibration and noise level of ship mechanism and noise inside ship accommodations (structureborne and airborne noise with flanking transmission), measured on board or during trial trip,
- measurements of acoustic power radiated by cabin partitions using *Sound Intensity Method*, with mapping of spatial intensity vector distribution and with visualization of acoustic energy streamlines paths.

All acoustic parameters are measured according to International Standards (IMO, ISO, NORDTEST etc.) or - since no international standard exist - according to a method developed by our Applied Vibroacoustic Dept.

APPLICATION OF "SI " MEASUREMENT

- direct determination of sound power of sources,
- measurement of sound energy transmission through partitions,
- identification and location of different acoustic sources; main and local (vectors field distributions),
- noise control and measurement of transmission loss, sound absorption, specific acoustic impedance, etc.,
- measurement and graphical presentation of the sound energy flow in near and far acoustic fields,
- graphically mapping scattering, interference or reflected acoustic waves in real environmental fields,
- experimental study of power flow vector fields inside and outlet of the acoustic ducts

End-users:

- shipyards (shipbuildings or maintenances) and design offices,
- shipping institutions,
- research institutions.

Looking for ***RESEARCH PARTNERS*** …

European Commission

European Research Area

International EU Project (HORISON 2020)

MARTEC ERA-NET Maritime Technologies

ERA-NET/MARTEC II, Call 2014

„New experimental techniques to optimal reducing noise on ships and offshore platforms”