THEORETICAL AND EXPERIMENTAL INVESTIGATIONS OF THE AIRCRAFT NOISE SHIELDING BY MEANS OF AIRFRAME STRUCTURES

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25 September 2014

Outline

- Motivation
- Experimental data result
- Calculation methods and approaches
- Comparison of the different approaches
- Conclusions

Motivation

The first estimations of the shielding effect were done in the 1970‘s.

These calculations showed extremely high efficiency of the engine noise shielding. It gave a stimulus to a works which was dedicated to the search of the general arrangement for airplanes with airframe structures shielding noise of the aviation engine

The basic motivation for shielding effect investigation in the first decade of the 21 century was idea that this effect allow satisfy the NASA N+2 (42 EPNdB) and, possibility, N+3 (71 EPNdB) based on Chapter 4 noise reduction requirements.

Experiments performed in the beginning of the 21 century showed that the noise level with shields was higher by 15-20 EPNdB, compared to what was predicted early.

Based on this in TsAGI a row of experimental and theoretical work were done.

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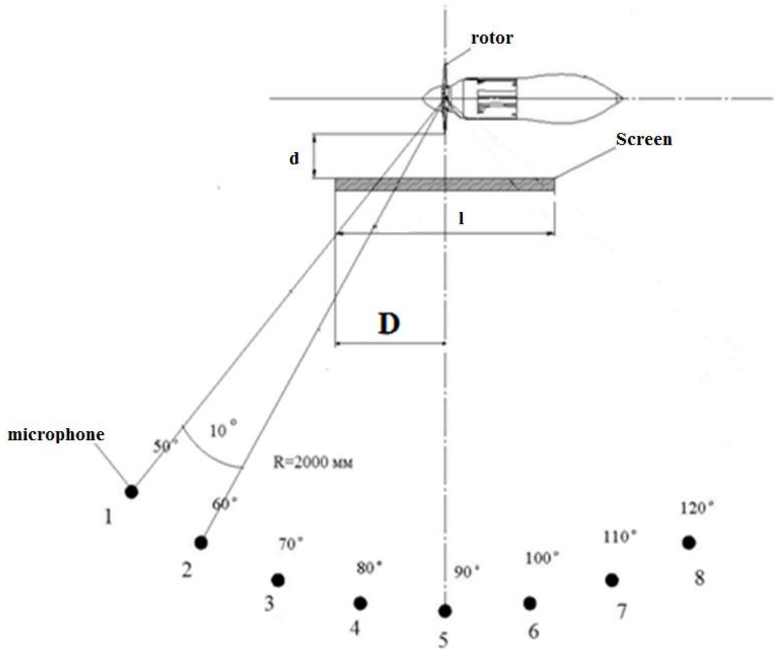
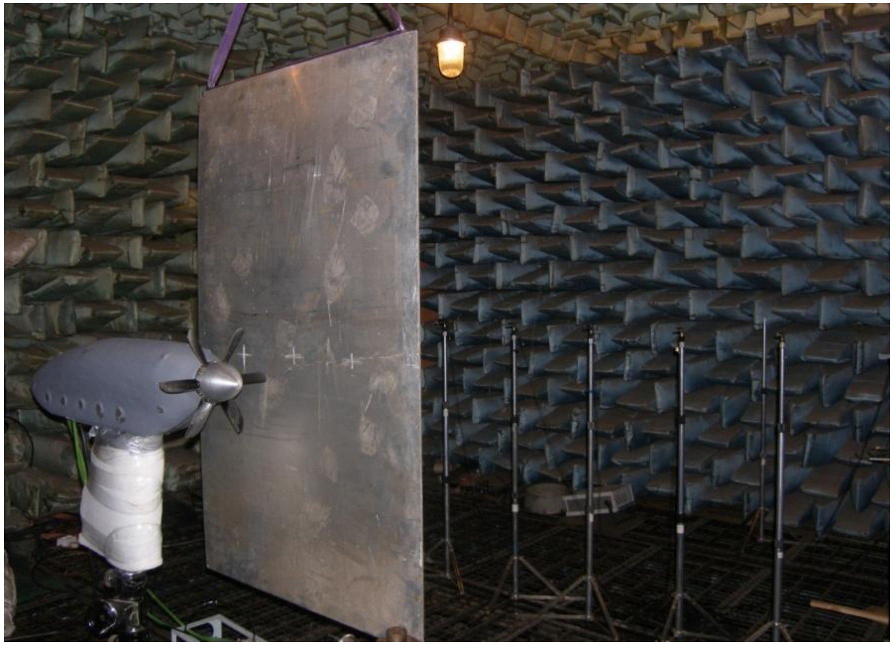
- Experimental data result
    - Propeller noise shielding
    - Jet noise shielding
- Calculation methods and approaches
- Comparison of the different approaches
- Conclusions

Propeller noise shielding by means of metal plate. Experimental setup AC - 2.



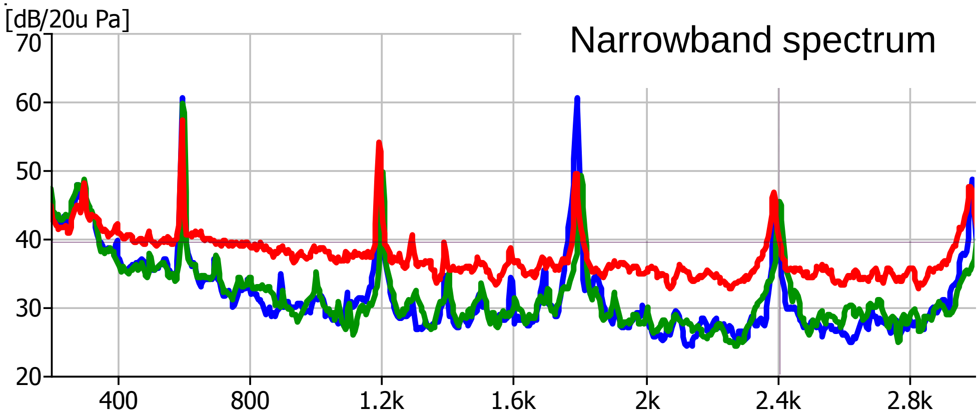


Rotor operating regimes
Rotation: 4500 и 6000 rpm.

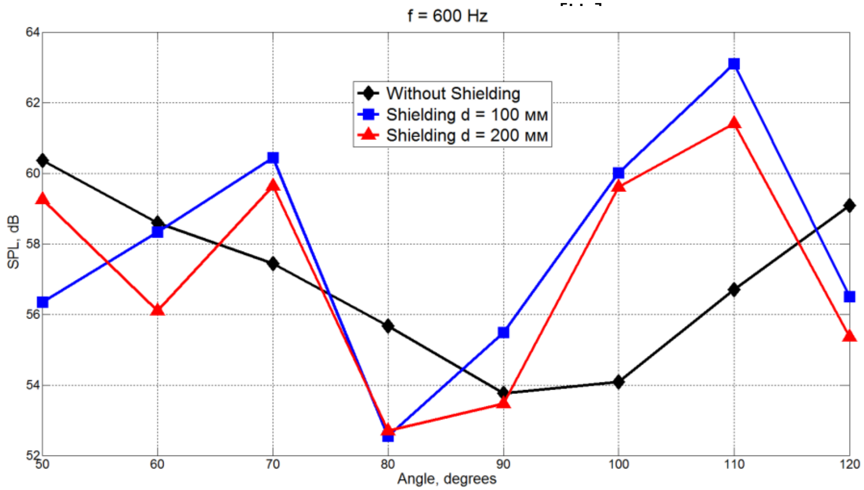
Shielding regimes:
Distance to screen *d*: 100 and 200 mm;

l = 900 mm; D = 450 mm;

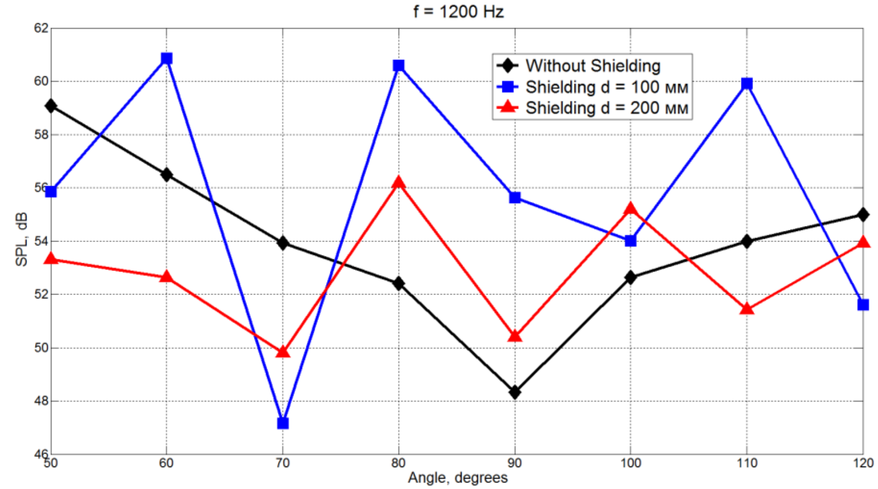
Rotor tonal noise shielding by metal plate



Microphone at angle of 70º degrees, 6000 rpm



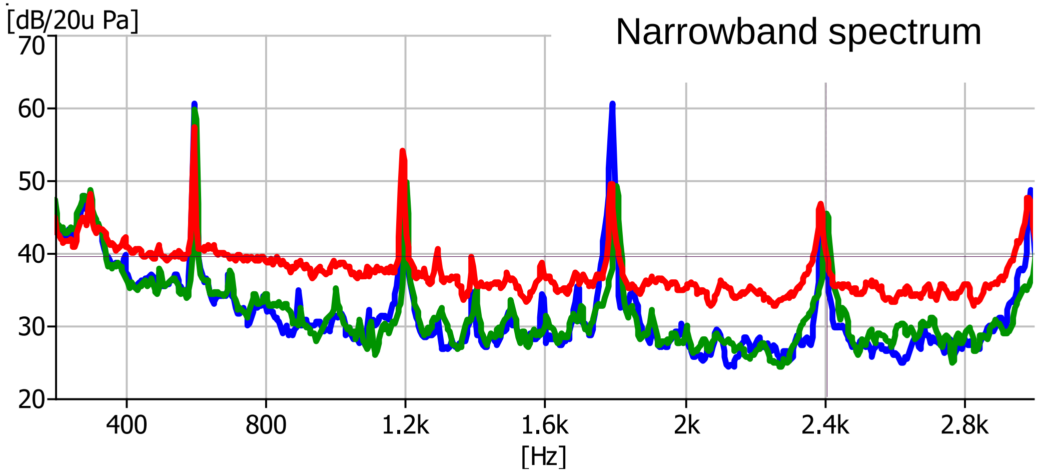
Directivity for first harmonic



Directivity for second harmonic

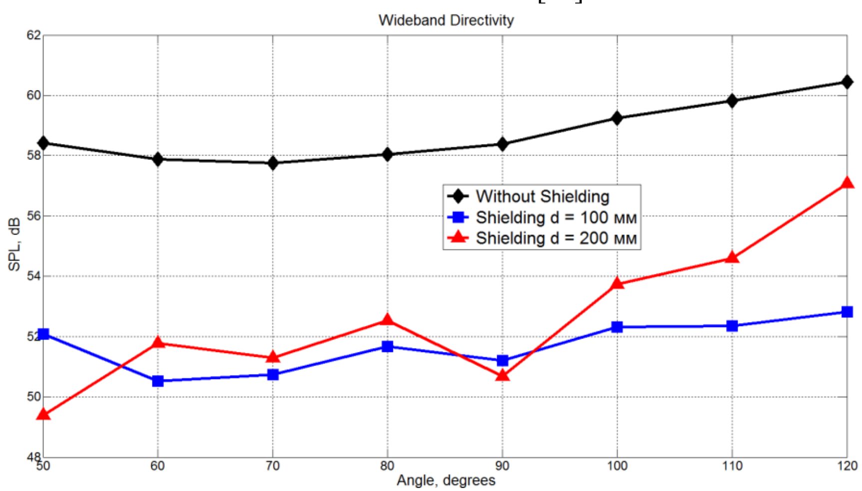
Directivity of rotor tone noise for all investigated operating regimes looks like an interference picture. With respect to free rotor noise directivity occur interchanging zones with maximum and minimum of radiation

Propeller wideband noise shielding by metal plate

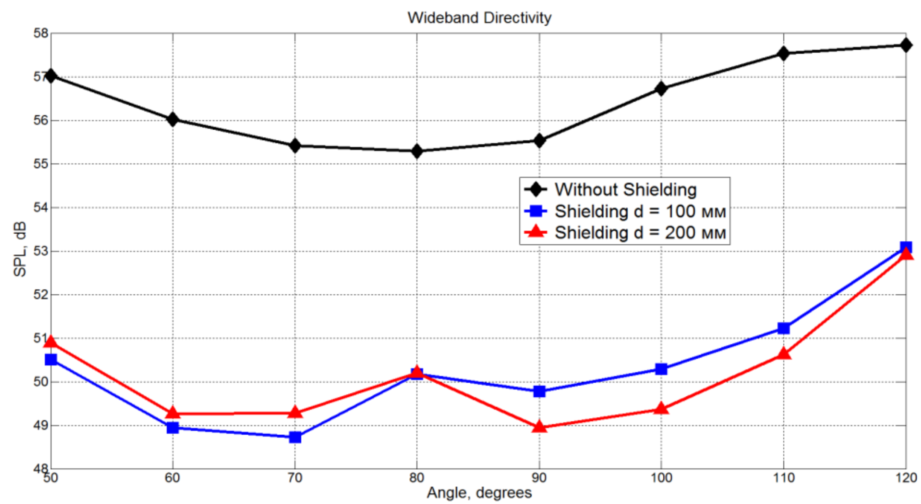


Microphone at angle of 70º degrees, 6000 rpm

Band – 500 Hz.



Directivity between first and second harmonic



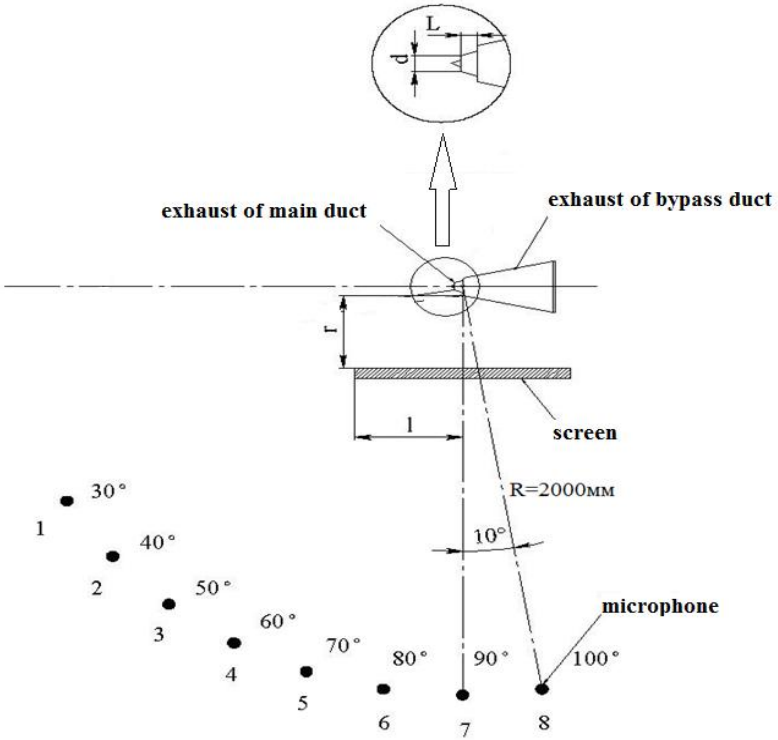
Directivity between second and third harmonic

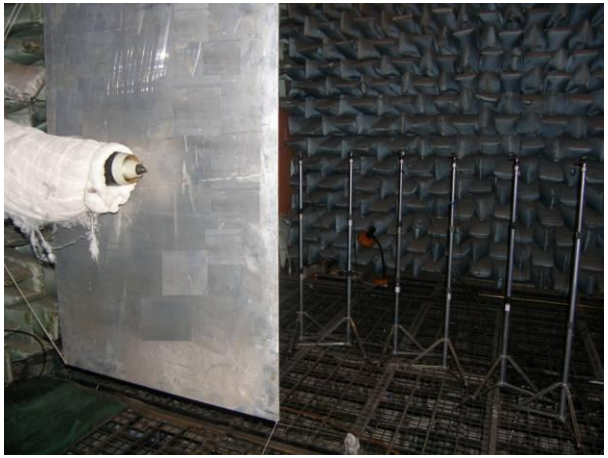
Wideband noise has a high efficiency of shielding and independent from rotor operation regimes

Conclusions for propeller noise shielding by the plate

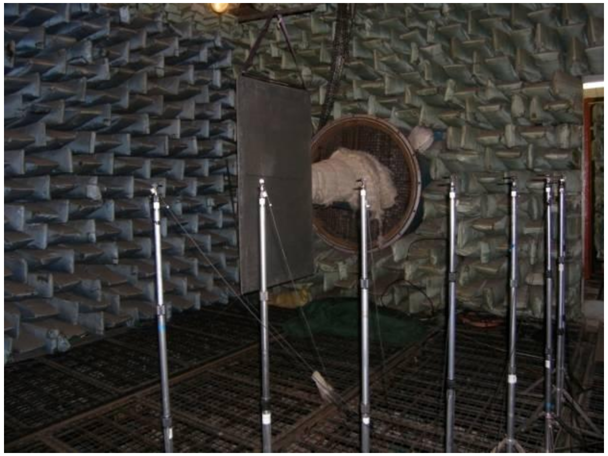
Experimental results showed what tonal and wideband rotor noise have different type of shielding.

Jet noise shielding investigation by means of metal plate. Experimental setup AC – 2.





Metal plate 1500×900×5 mm

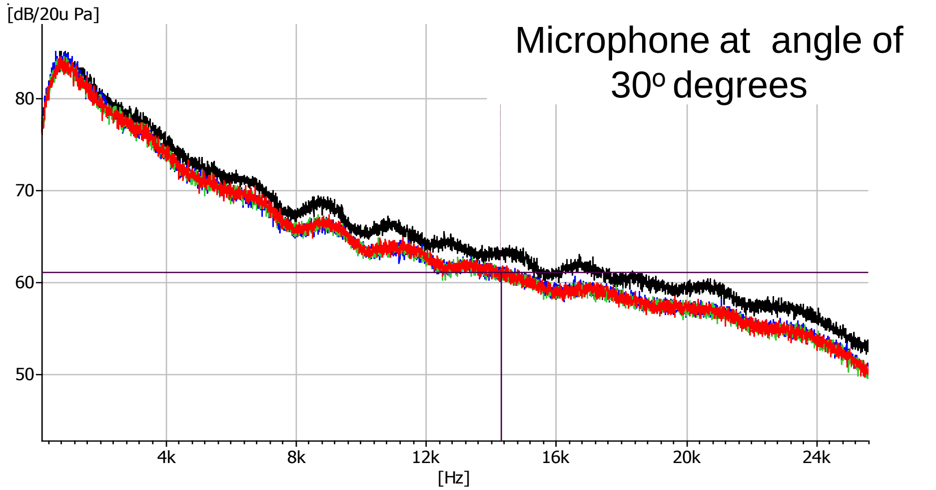


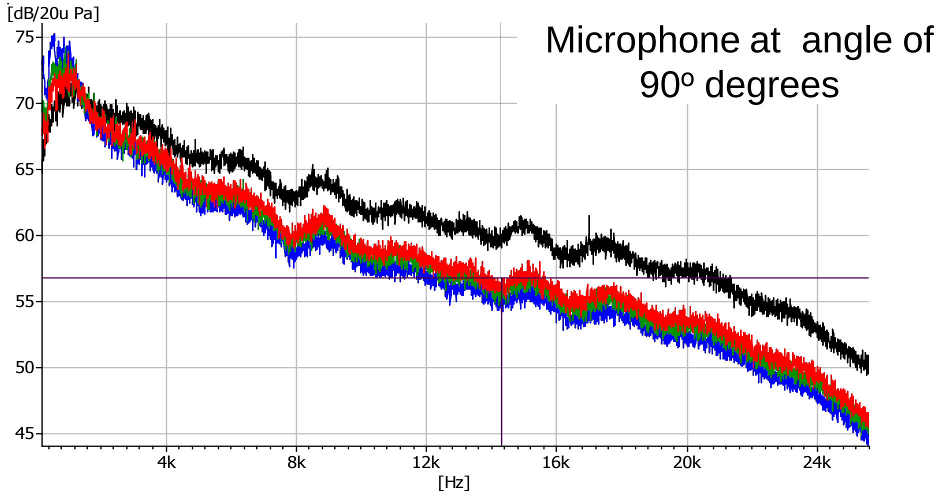
Nozzle operating regimes
V_{out} = 301 m/s, V_{in} = 280 m/s.

Shielding regimes:
Distance to screen *r* : 85 and 170 mm;

l = 245, 285, 365 mm;

Jet noise shielding investigation by means of metal plate . Minimum distance from nozzle to screen.

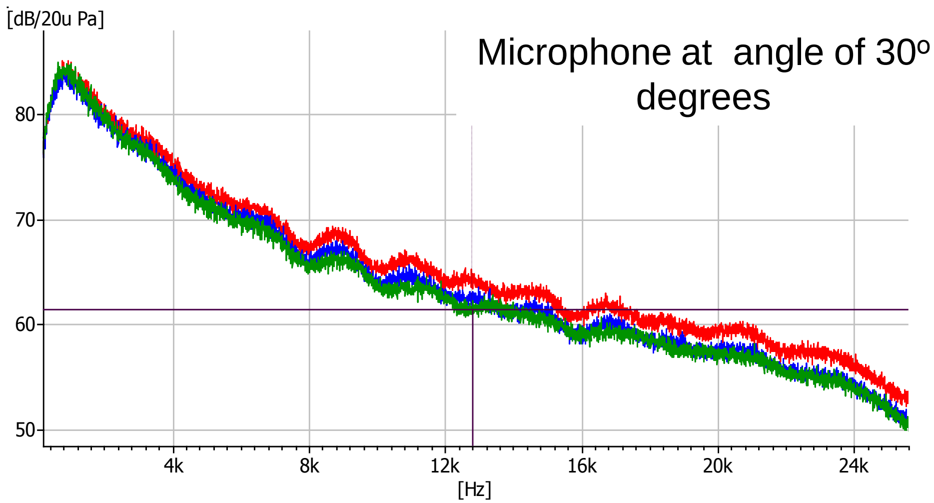


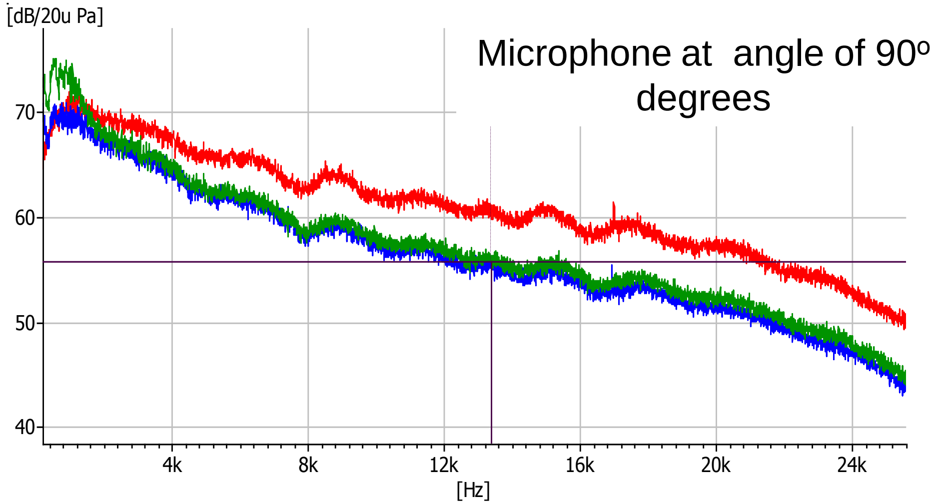


Jet noise shielding (*r* = 85 мм)

No screen (**black curve**),
L = 365 мм (**blue curve**),
L = 285 мм (**red curve**),
L = 245 мм (**green curve**).

Jet noise shielding by means of metal plate investigation . Maximum distance from nozzle to screen tip (maximum shielding).





Jet noise shielding for different r (L = 365 мм).

No screen (**red curve**),
r = 170 mm (**blue curve**),
r = 85 mm (**green curve**).

Conclusions for jet noise shielding by the plate

Experimental results showed what at observation angle 30° degrees shielding efficiency was small and it didn't depended from relative position of the nozzle and screen.

In the geometrical shadow zone (80° degrees and more) different effects was observed. At high frequencies shielding effect was observed. At lower frequencies while screen approached to the nozzle observed the noise amplification.

Outline

- Motivation
- Experimental data result
- Calculation methods and approaches
  - Theories of diffraction
  - Assumption for shielding calculation
- Comparison of the different approaches
- Conclusions

Theories of Diffraction and Shielding Methods Calculation Development
Traditional methods for shielding efficiency calculation

Theories of Diffraction

Geometrical Acoustic Approximation

Geometrical Theory of Diffraction
(J. Keller, 1962)

Kirchhoff Approximation
(Physical Optic Approximation)

Fresnel Approximation

Fraunhofer Approximation

Physical Theory of Diffraction

Geometrical theory of diffraction. Basic assumptions.

$$P_{Total}(\vec{r}) = P_{\mathrm{GA}}(\vec{r}) + P_{Diffr}(\vec{r})$$

Incidence field

Reflected field

$$P_{Diffr}(\vec{r}) = U_0 \frac{e^{ikr}}{r} D(\varphi, \varphi_0, k)$$

D – diffraction coefficient, which depending from incidence angle, observation angle, wave number and local geometrical characteristics of the scattering body. Diffraction coefficient calculating based on solution of the diffraction canonical problem.

U_0 – amplitude of the incidence field at the point of diffraction.

Based approximation for engine noise shielding

Usually aviation engine gas turbine as noise source replacing by point monopole source with directivity measured in far field.

The total field calculated by means of Kirchhoff or Fresnel approximation.

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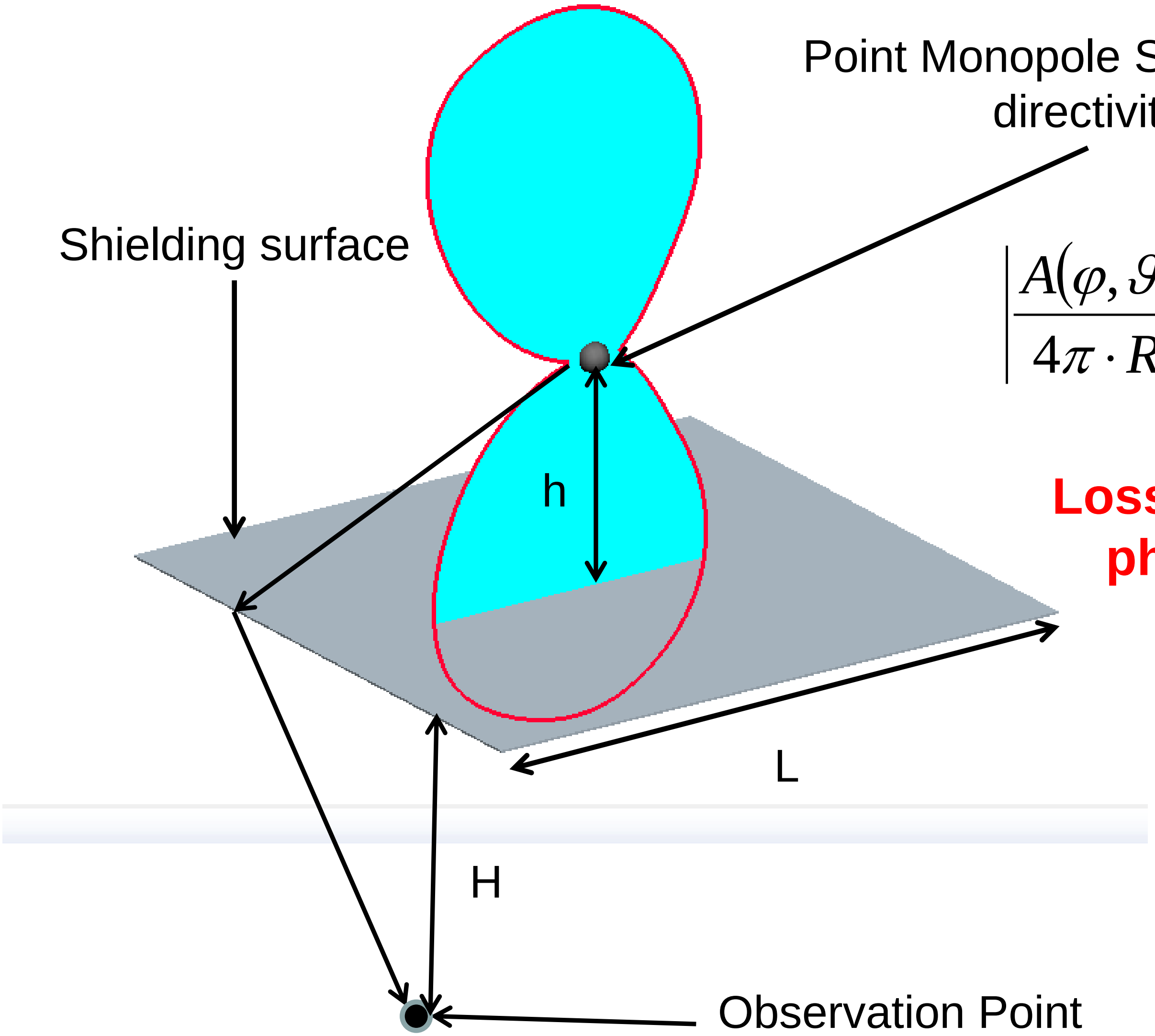
- Comparison of the different approaches
    - Directivity point source
    - Multimonopole source
- Conclusions

Traditional model for non compact source shielding calculation



$$\left|\frac{A(\varphi,\vartheta)}{4\pi\cdot R}\right|^2$$

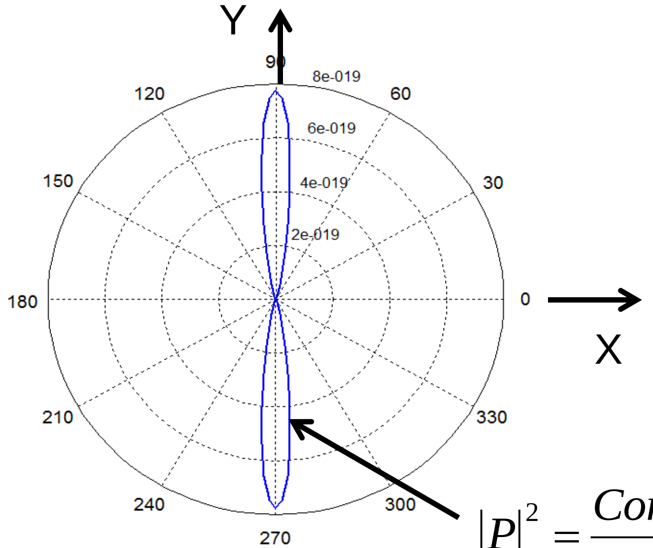
Loss information about phase distribution!

h = 2.2 m

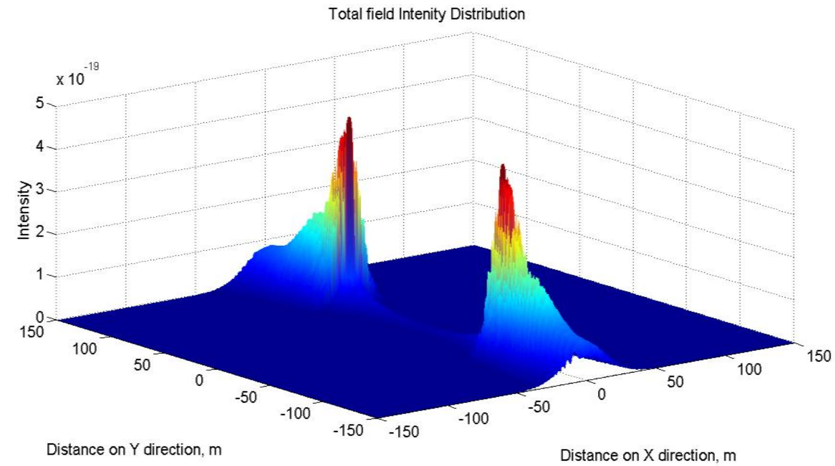
H = 50 m

L = 6 m

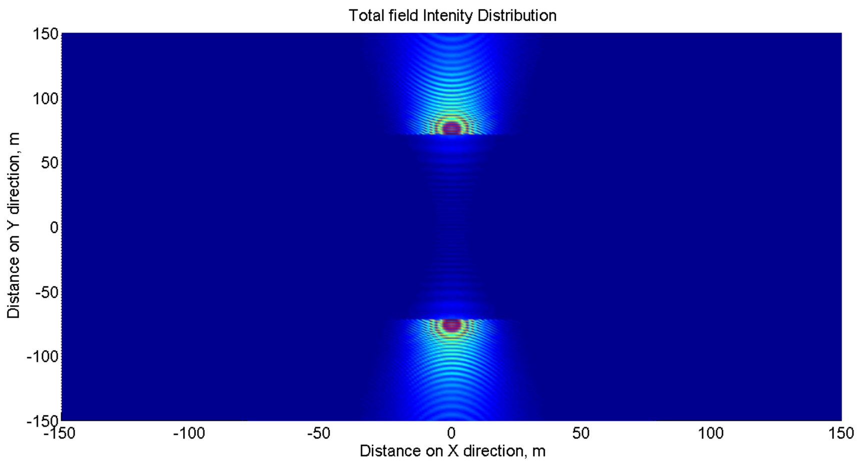
Calculation results for rotor tone noise shielding
Directivity point source model

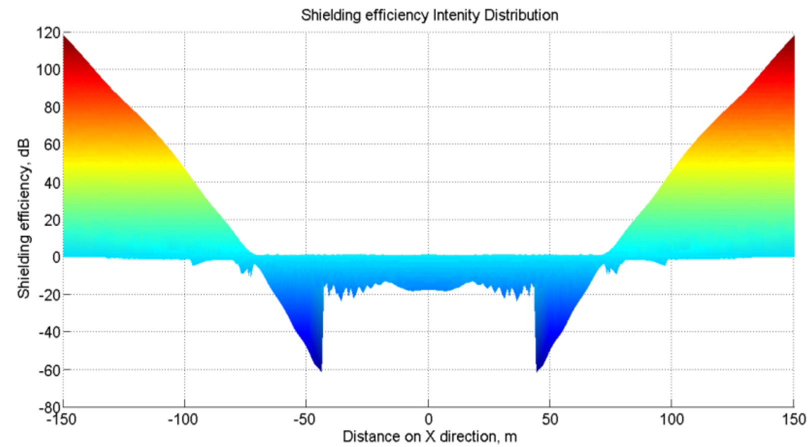


$$|P|^2 = \frac{Const \cdot \left(\sin^{50}(\varphi)\right)^2}{16\pi^2 \cdot R^2}$$

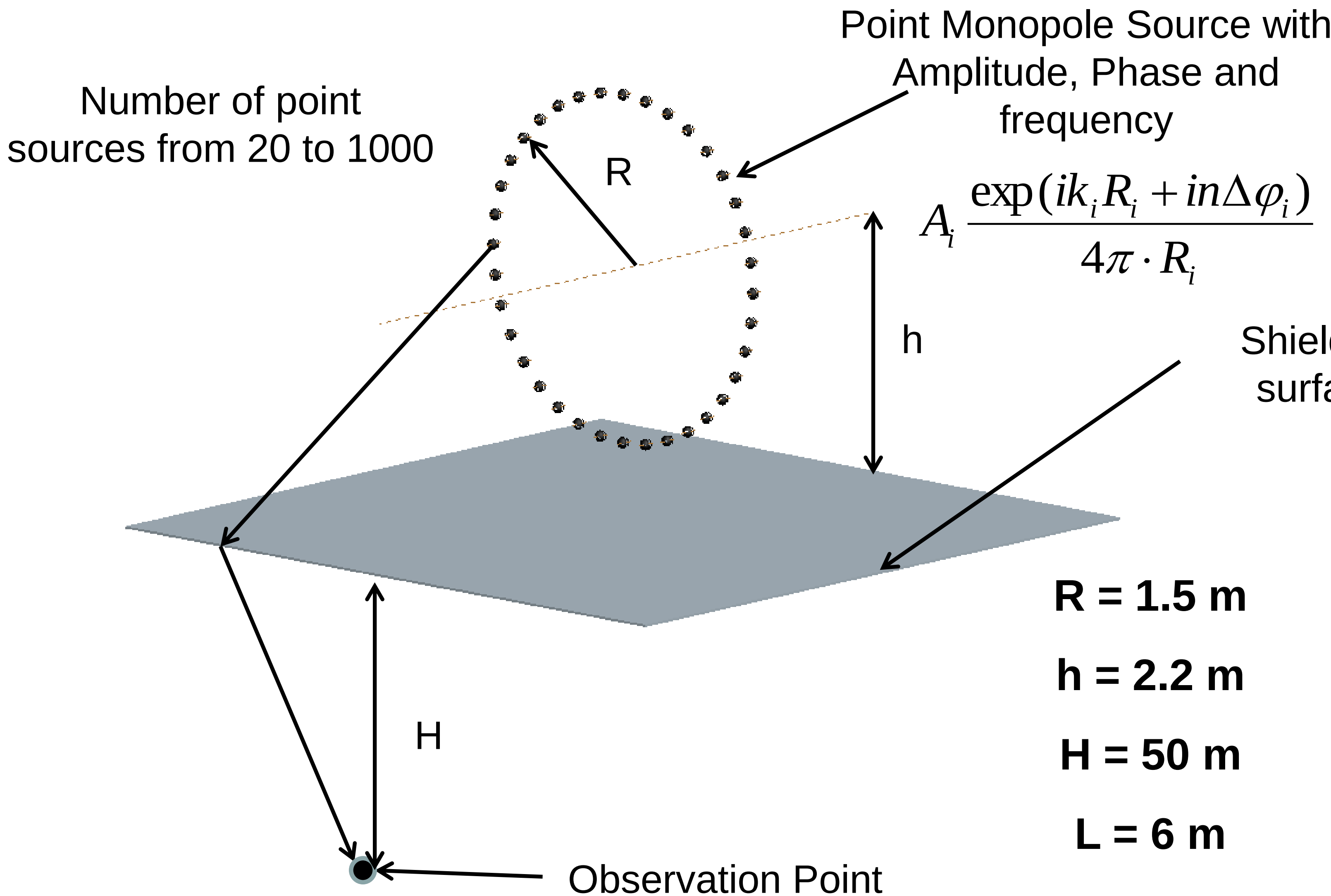


Frequency = 1 kHz





Multimonopole source model for propeller noise analysis



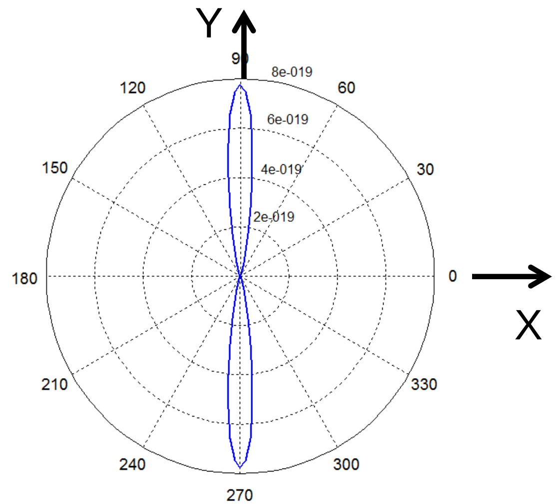
R = 1.5 m

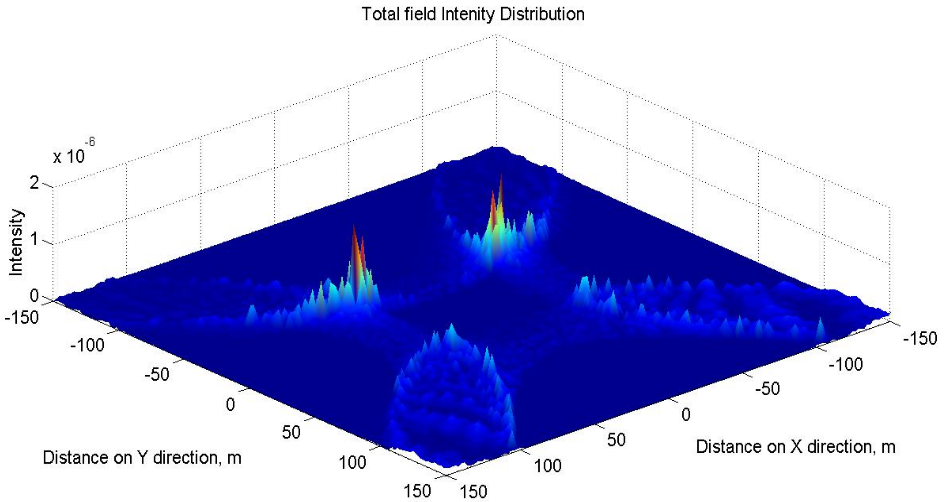
h = 2.2 m

H = 50 m

L = 6 m

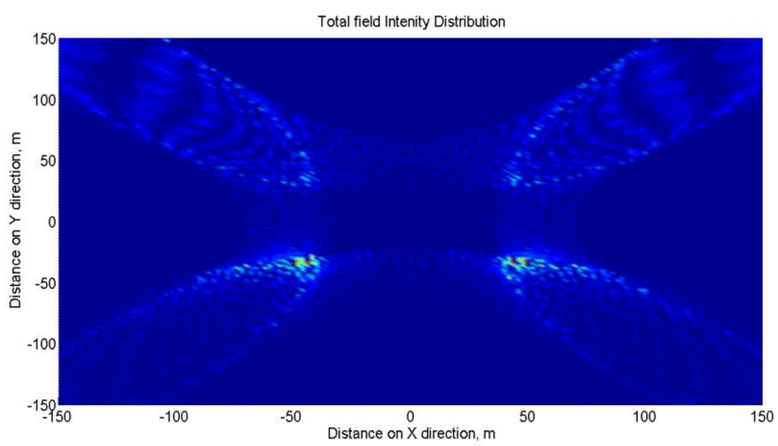
Calculation results for propeller tonal noise shielding
Multimonopole source model (non compact source)

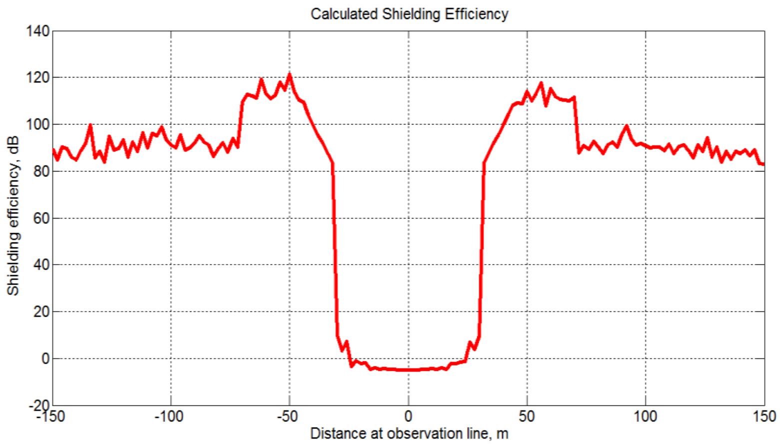




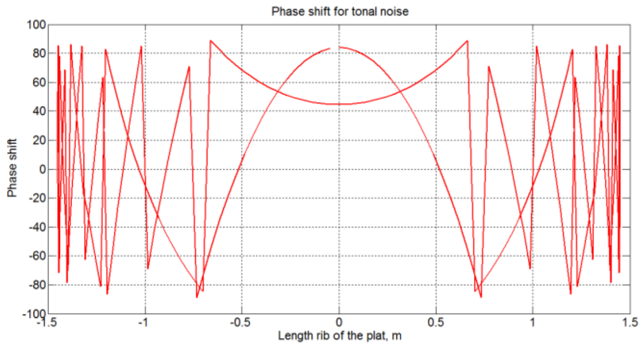
200 sources, n = 50

Frequency = 1 kHz

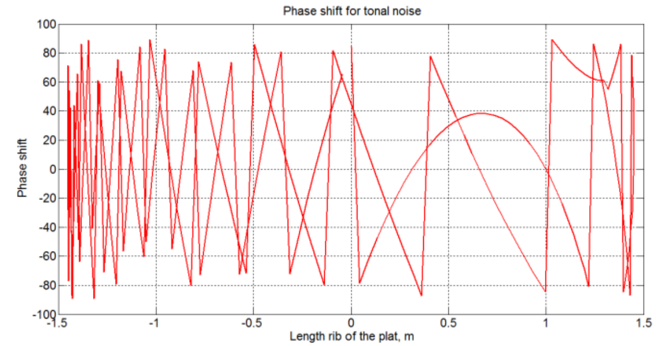




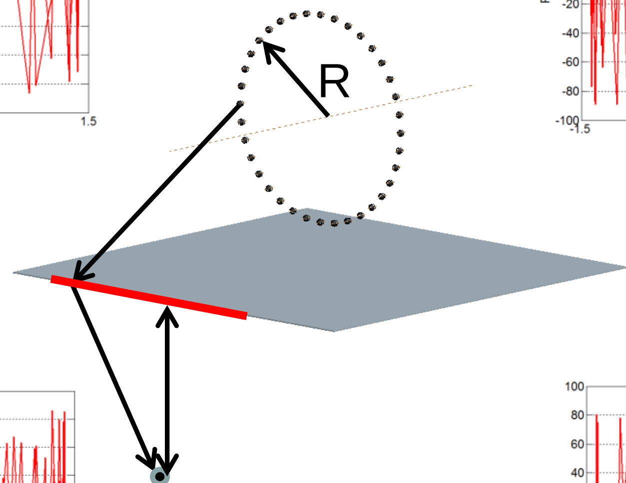
Phase shift for tonal (f=1 kHz) and wideband (1/3 octave with 1 kHz centerbody frequency) noise at point X=100 m, Y=0 m



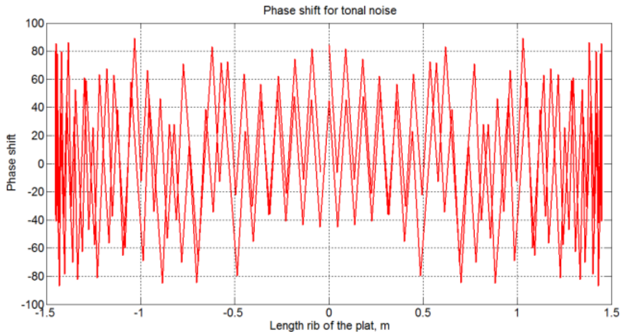
200 sources; n = 0



200 sources; n = 10



$$P_{Diffr}(\vec{r}) = U_0 \frac{e^{ikr}}{r} D(\varphi, \varphi_0, k)$$

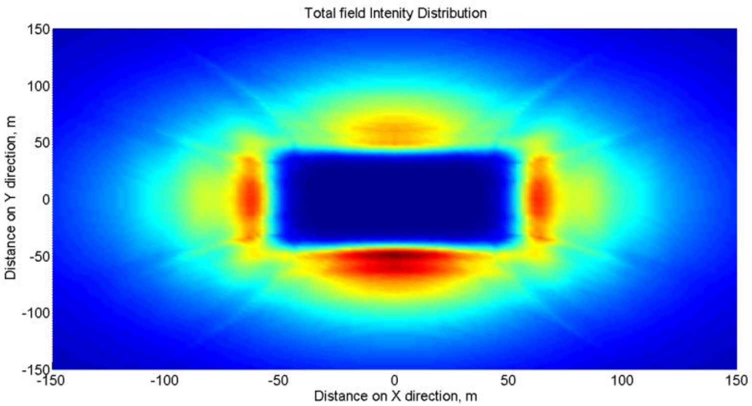


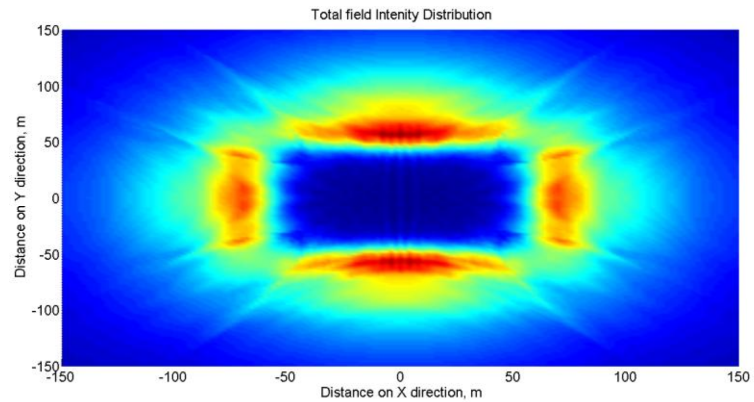
200 sources; n = 50

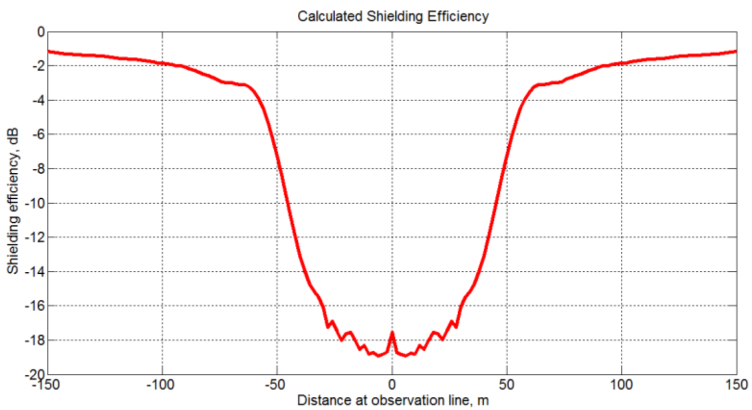
Wideband noise. 200 sources, 100 averaging

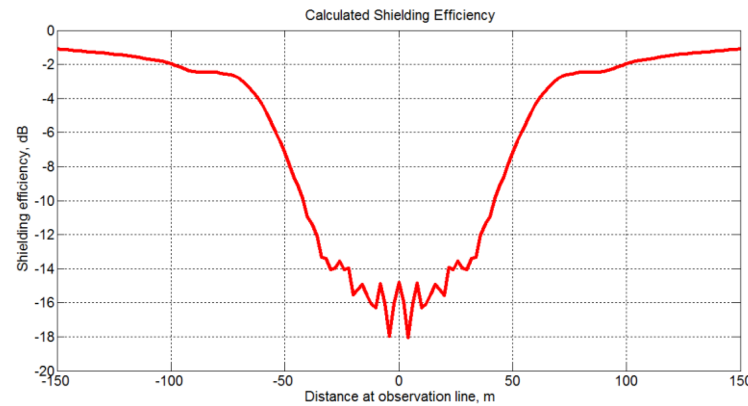
Calculation results for wideband rotor noise shielding

1000 sources; 10 averaging





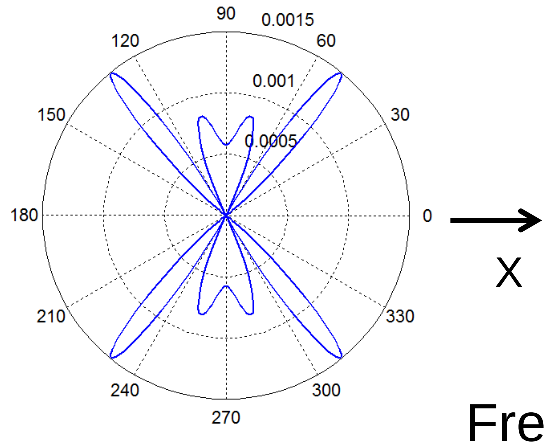


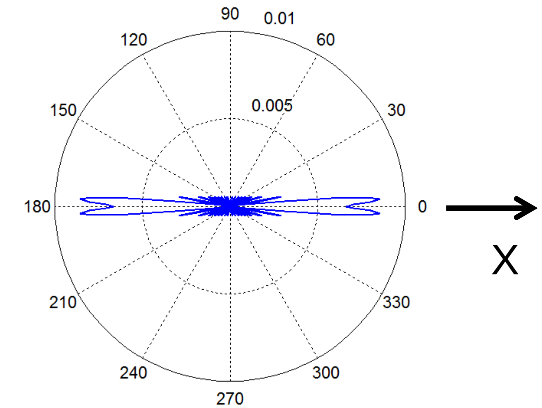


1 octave waveband with centerbody frequency 1 kHz

1/3 octave waveband with centerbody frequency 1 kHz

Calculation results for rotor tonal noise shielding
Non compact source model. Asymmetry effect.

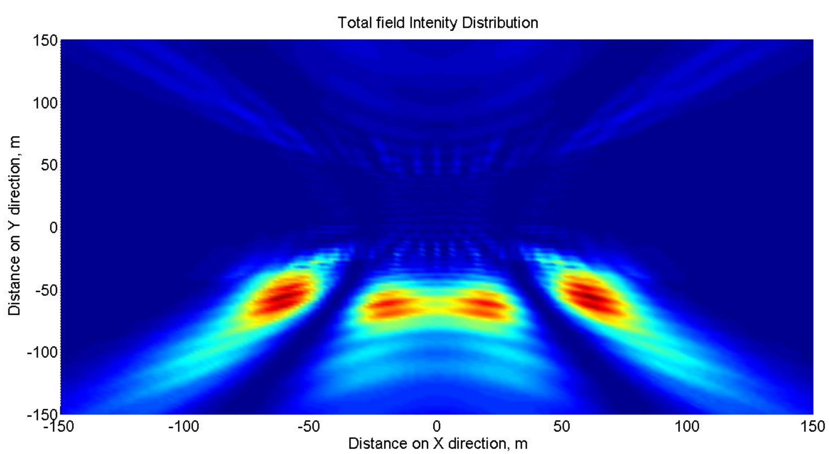


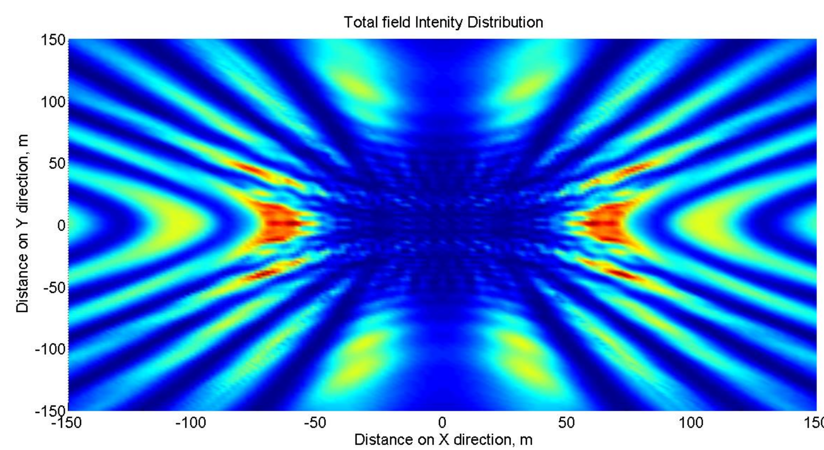


Frequency = 1 kHz

100 sources, n = 20

100 sources, n = 1





With growth of number sources and n asymmetry effect grows too

Conclusions

Modeling of the non compact source by means of point source with measured in the far field directivity led to the significant errors.

For shielding efficiency calculation aimed on external noise reduction needs to use efficient theory of diffraction and high quality model for full description (amplitude and especially phase) of the near acoustic field.

Analysis of the multimonopole model for tonal propeller noise showed asymmetry effect while shielding calculated. This asymmetry depending from phase shift between sources.

Propeller wideband noise shielding for multimonopole model showed depending from the band and insignificant depending from number of sources.

Jet noise shielding is a another difficult problem and we will be investigating it further.

We will developing GTD to account for flow and boundary layer.

THANK YOU
FOR YOUR ATTENTION!