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“COMPUTATIONAL EXPERIMENT IN AEROACOUSTICS”

S.F. Timushev, V.N. Gavrilyuk, K.I. Volosenko, A.A. Aksenov

NUMERICAL MODELING OF TURBOMACHINERY TONAL NOISE IN SPACE WITH COMPLEX ACOUSTIC IMPEDANCE BOUNDARY CONDITIONS

INTRODUCTION

- In 2013 the initiative project started aiming to develop a tool for computational studies in aeroacoustics of bladed machines, mainly pumps and ventilators, looking as well on the problem of tonal noise reduction of the air jet engine ventilator (compressor).
- The main features the new method must gain are:
  - accuracy
    - » +/- (3 .. 4) dB would be the perfect result
  - high processing speed
    - » (processing time must comprise an order of few minutes to one hour)
  - possibility to use it directly in the CAD software
  - sufficiently short human time for preparing acoustic input data
    - » (preparation of the acoustic input data should be within 1-2 hours)
  - resolving the problems of acoustic source
  - decomposition of pseudosound and propagating mode

METHOD

- Methods for modeling the turbomachinery noise are mainly based on application of
  - Lighthill's equation
    - M.J. Lighthill 1952 Proceedings of the Royal Society, London A 211, 564-587. On sound generated aerodynamically. Part I. General Theory
  - FW-H equation
    - J.E. Flowcs-Williams and D.L. Hawkings 1969 Philosophical Transactions of the Royal Society A264, 321-342. Sound generation by turbulence and surfaces in arbitrary motion
  - Kirchhoff's theorem
    - FlowNoise (ECIM Ltd) FanNoise (KAIST) /Duck Joo LEE et all, Fannoise2003
  - Lighthill's variation analogy
    - AcuSolve FEM CFD solver Actran/LA FEM acoustics propagation solver FluidConnection CAD integration and meshing softwar /Robert SANDBOGE at all, Fanoise2007
  - RANS+LEE+SNGR
    - Zhu Y.J. at all. NCEJ 2008
  - AVM provides decomposition (M<<1)

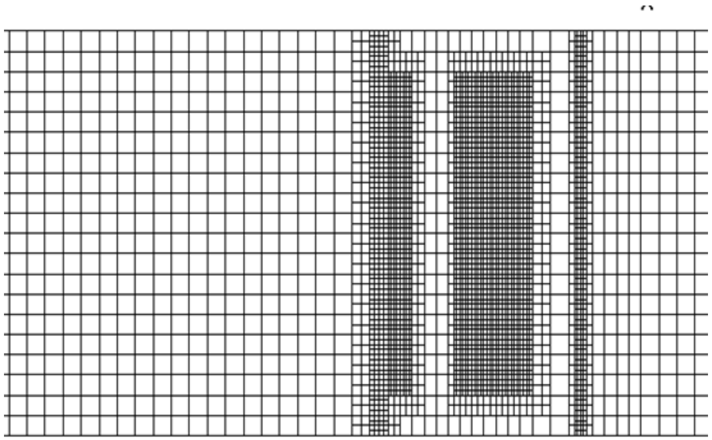
AVM REFERENCES

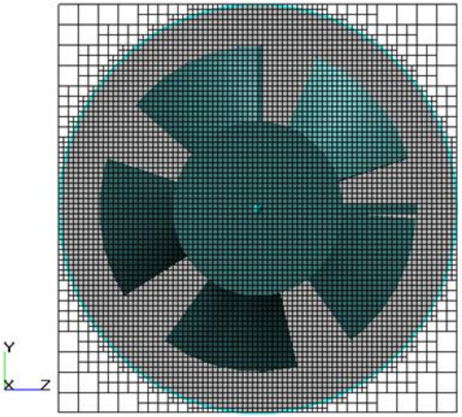
- Артамонов К.И. Термогидроакустичекая устойчивость. М.: Машиностроение, 1982
- Timuchev, S., Illichov, K., Tourret, J. Prediction of BPF pressure pulsation in centrifugal pumps and ventilators with taking into account the effect of machine casing on impeller flow parameters [Prédiction de la pulsation de pression dans les pompes etventilateurs centrifuges prenant en compte l'effet de la carcasse de la machine sur les paramètres d'écoulement dans la roue] Houille Blanche Issue 3-4, 2001, Pages 60-64

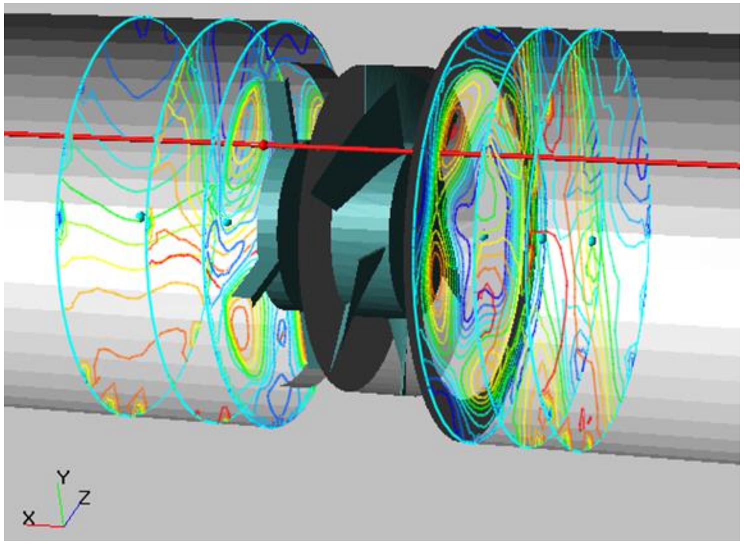
- Timouchev, S. , Tourret, J., Pavic, G. , Aksenov, A. Numerical 2-D and 3-D methods for computation of internal unsteady pressure field and near-field noise of fans (Conference Paper) Noise Control Engineering Journal Volume 54, Issue 1, January 2006, Pages 15-20

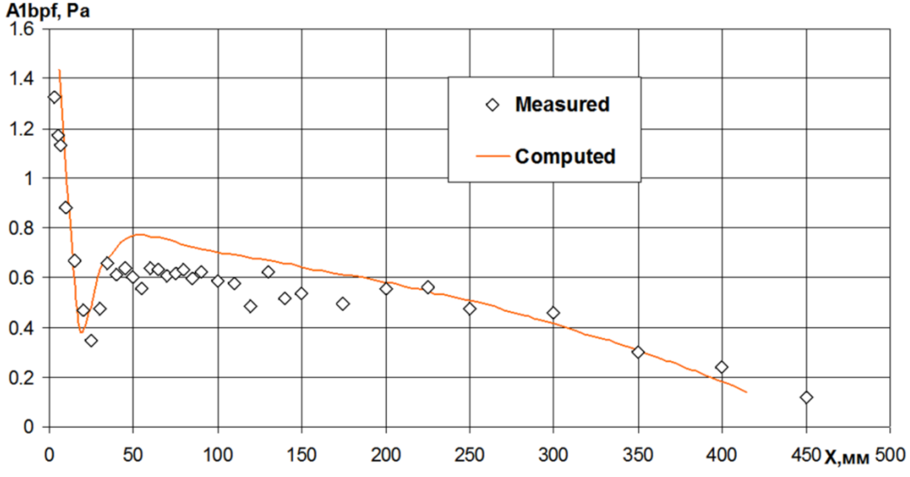
- Klimenko D.V. Thesis for degree of candidate tech.sc . MAI 2016 http://www.mai.ru/events/defence/index.php?ELEMENT_ID=72360

AVM PRESSURE PULSATION COMPUTATION









AS APPROACH

BASIC ASSUMPTIONS

- tonal components at the blade passing frequency (BPF) and its higher and combined harmonics dominate in the pressure pulsations and noise spectra
- BPF and its harmonics are in the low-middle range that results in interference and diffraction of acoustic waves in the presence of complex impedance boundary conditions
- vortex mode (pseudo-sound) zones adjacent to the bladed rotor locally limited in space comparing with the whole volume of the flow path and considered as the boundary tonal noise source
- Mach number << 1 (low subsonic flow)

GOVERNING EQUATION END SOUND SOURSE

- Fourier transformed linearized wave equation with complex variables in the Cartesian coordinate system for adiabatic sound propagation in the irrotational and thermodynamically uniform and steady flow

$$\left(ik + M_j \frac{\partial}{\partial x_j} \right)^2 p = \frac{\partial^2 p}{\partial x_j^2} + f$$

- ***f*** -- source term determined from the energy relation

$$\frac{1}{\sqrt{2\pi}} \int_S \int_{-\infty}^{+\infty} p(\omega - \xi) u_n(\xi) d\xi \cdot dS = W_l \delta(\omega - \omega_l)$$

- ***W*** -- known sound power (by AVM) at the ***l***– BPF harmonic

BOUNDARY CONDITIONS

- Boundary conditions with the complex impedance for each BPF harmonic in the Mayers' form

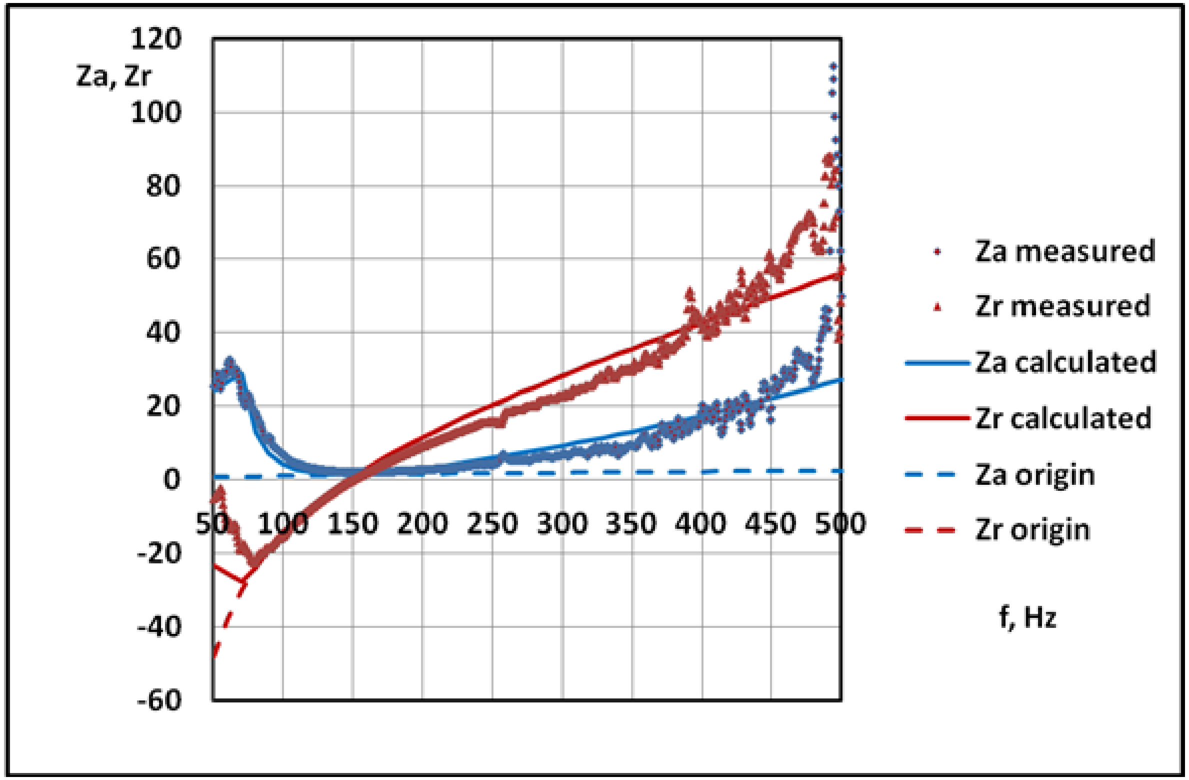
$$iku_j n_j = \left(ik + M_j \frac{\partial}{\partial x_j} - \frac{\partial M_l}{\partial x_j} n_j n_l \right) \frac{p}{\rho c Z}$$

- Definition of source for GTP and AJE computational tests

$$J_+(x) = p + \rho c u_j n_j$$

- Grid limitation $\omega h / c < 1$

Determination of acoustic specific complex impedance

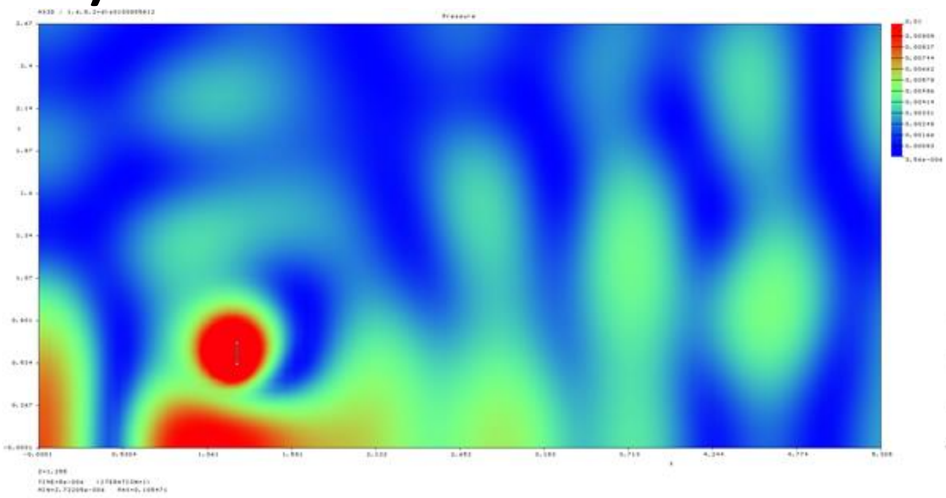


The original model Munin (origin) and the new modified model (calculated) in the case of plates of plas-terboard with a degree of perforation of F = 0.0025, hole diameter d = 5 mm, thickness t = 12 mm and volume length h = 20 mm.

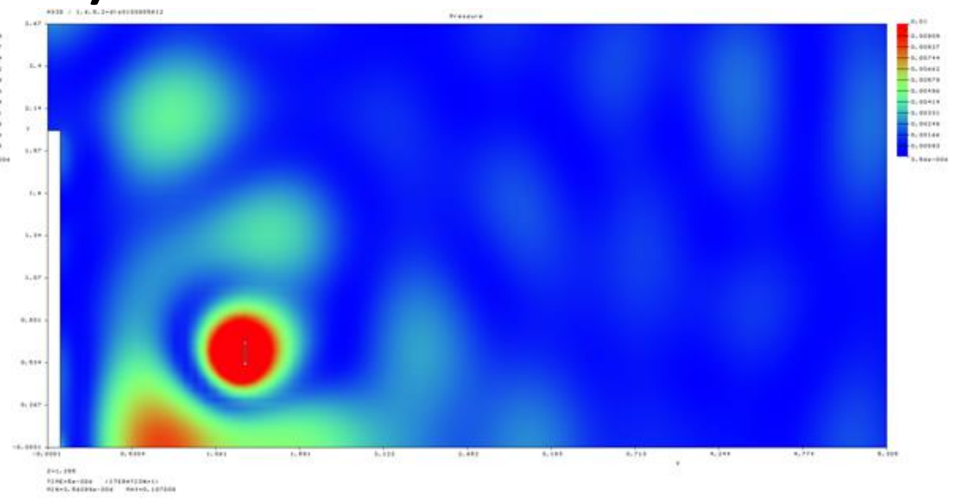
REVERBERATION ROOM

222.5 Hz

a)



b) ***Z* = 0.1-0.5i**

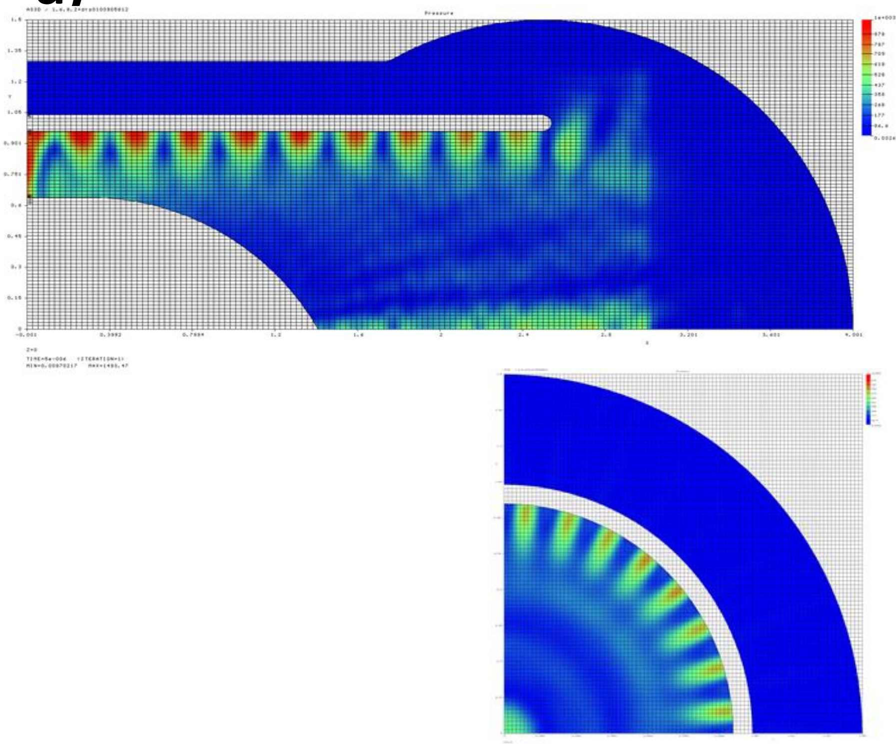


Fan VN-2 noise intensity level in the central plane of reverberation room in absence of SAS (a) and in presence of SAS (b)

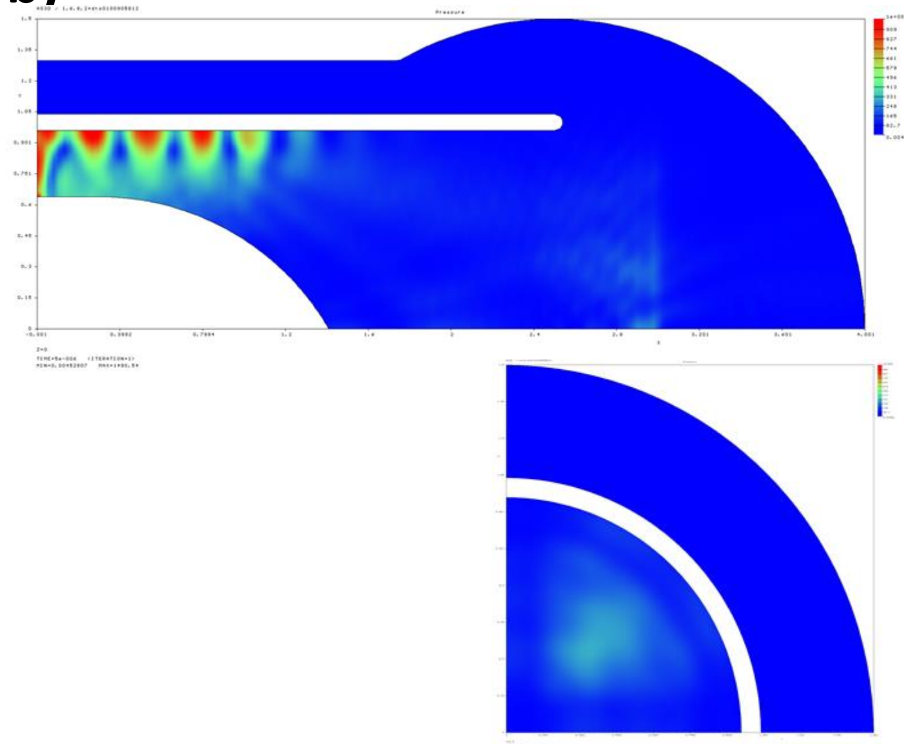
APPLICATION OF SAS IN GTP

2100 Hz

a)



b)

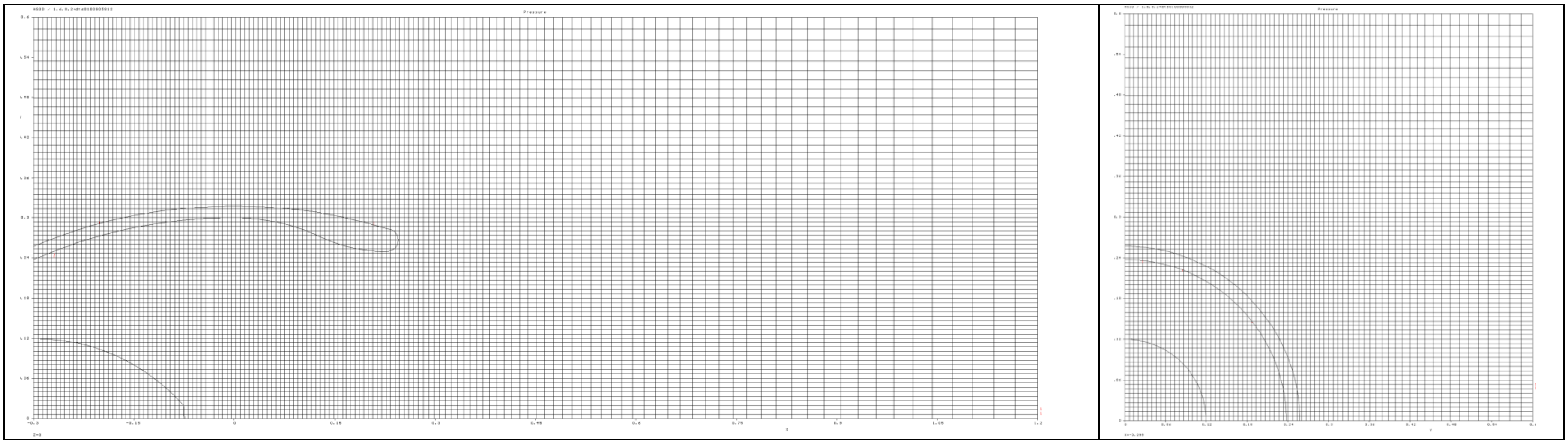


Pressure pulsation amplitude in the mid-section and inlet cross-section without SAS (a) and with SAS Z = 4.0 - 4.0 i (b).

SAS OPTIMIZATION

Im Z \ ReZ	0.8	2	4	6	8
1			-3.52		
-0.5	-2.82	-3.94	-4.35	-4.04	-3.60
-2			-5.13		
-4			-5.39		
-5			-4.99		
-8			-3.08		

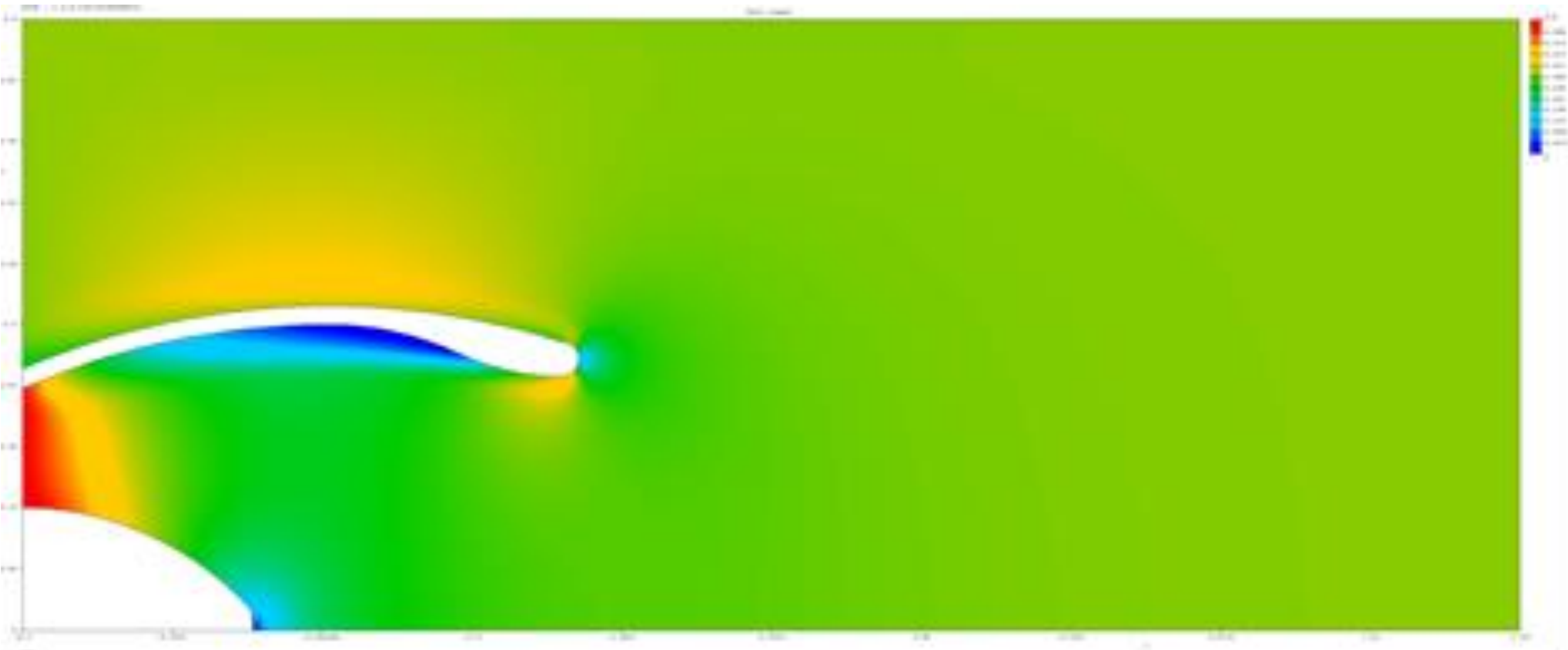
Application of SAS in AJE



Air intake .
M=0.3
16 blades
BPF=2100Hz
Grid(140 x 72 x 72) number of cells 709207

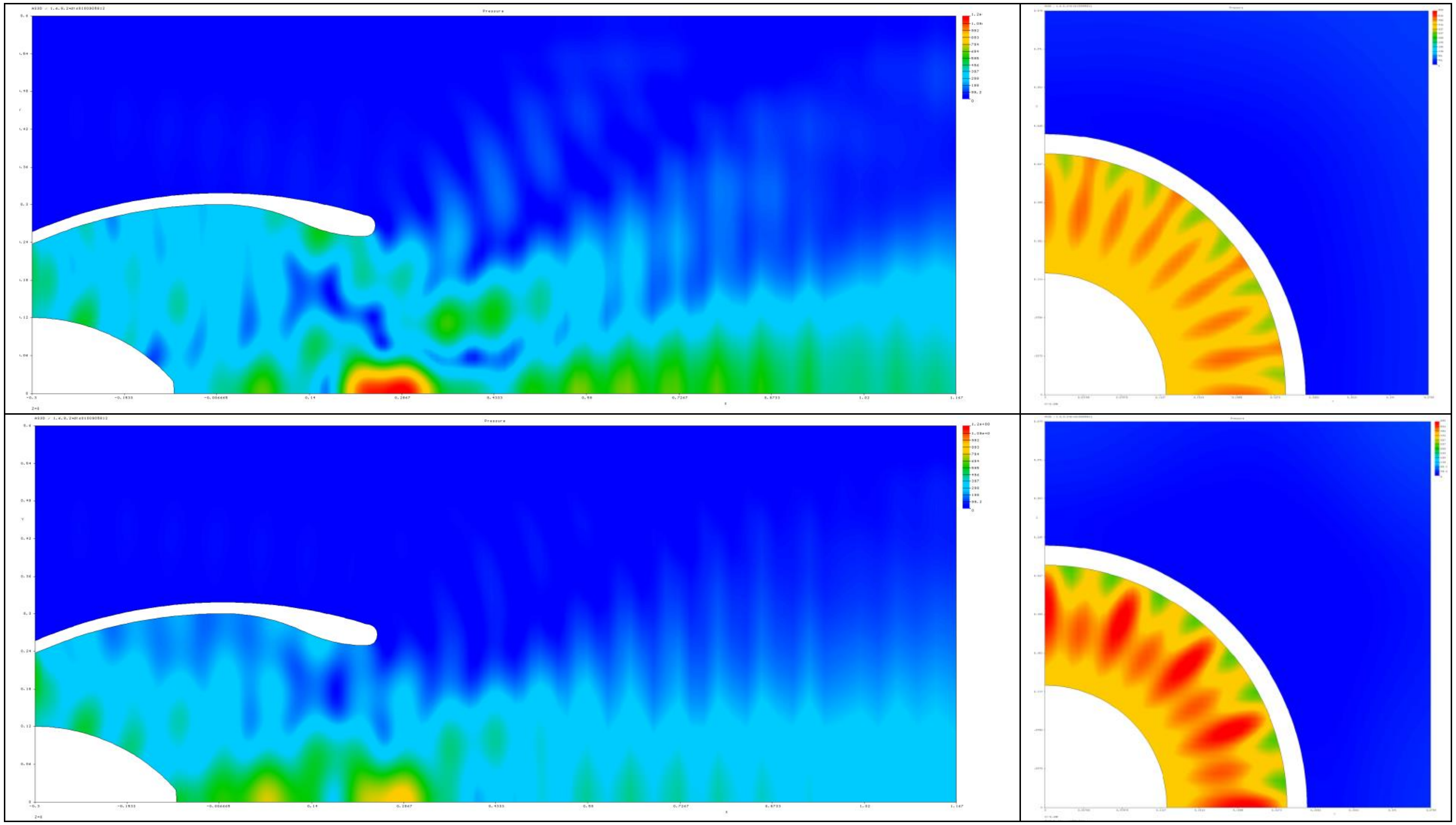
$$J_+ = 1000 \cdot \left[1 + \cos(16\phi)\right]$$

Mach number



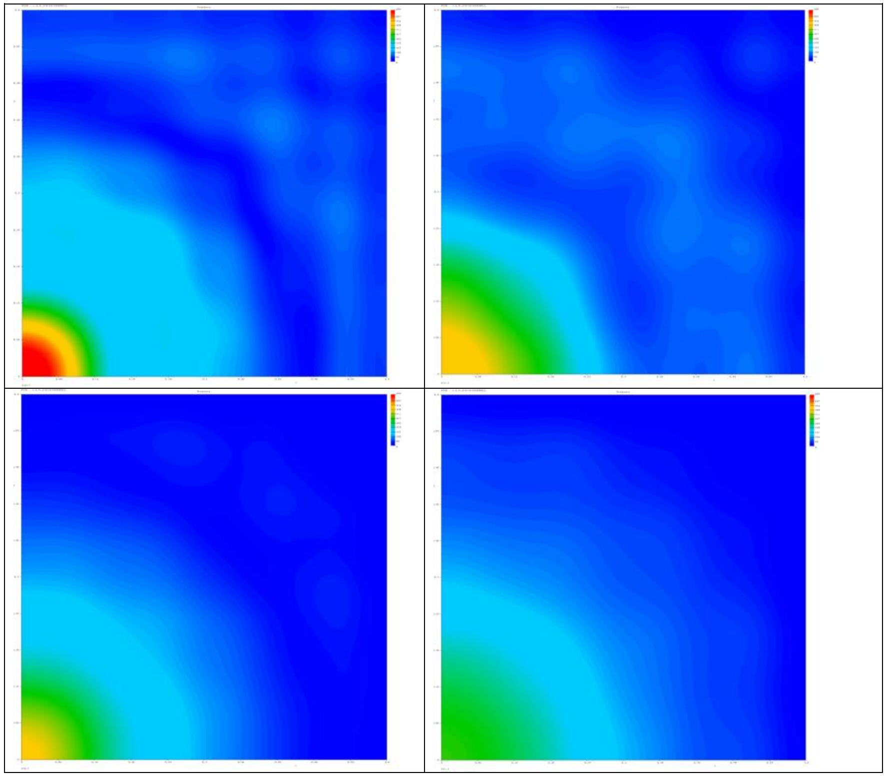
Scale from 0 to 0.5

SAS effect 1



Amplitude of pressure pulsations (left, scale 0 – 1200 Pa) (right, scale 0 – 600 Pa). Upper- no SAS, bottom- SAS **Z=4-0.5i**

SAS effect 2



Amplitude of pressure pulsations in cross sections from air intake x=0.7 m (left) and x=1.1 m (right) (scale 0 – 600 Pa). Upper- no SAS, bottom- SAS **Z=4-0.5i**

SAS effect 3

	NO SAS	SAS Z=4-0.5i
SPL	*24.1 W*	*5.73 W*
Noise reduction		6.24 dB

Computations completed with i7 3.2 GHz CPU

Processing time for

- the steady flow task -- 16 min.
- the acoustical task --24 min.

CONCLUSION

- The AS method of modeling acoustic fields is very efficient in terms of minimization of computer and human resources
- AS can be used for optimization of impedance characteristics and location of SAS
- AS +AVM are waiting for the customer actual validation/application case