UNSTEADY FORCES AND FLUTTER IN THE COMPRESSOR OF THE AIRCRAFT ENGINE, NUMERICAL AND EXPERIMENTAL RESULTS

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Fluid-Structure Interaction

- **2D and 3D inviscid and viscous** in-house numerical codes for **flutter calculation** of the twisted rotor blades. (Flutter analysis of real steam turbine of 200 MW and compressor rotor blade of S0-3 aircraft engine. Experimental verifications of obtained numerical results)
- **3D Unsteady forcers of the stage** with vibrating rotor blades in the subsonic, transonic and supersonic inviscid and viscous flow, in-house numerical codes. (Calculations of unsteady forces acting on rotor blades of the several stages in steam turbines and aircraft engines. Experimental verifications of obtained numerical results

3D viscous flutter models

- Sayama et al. 1998
- Weber et al. 1998
- Fransson et al.. 1999 (quasi-3d)
- Chassaing et al. 2001
- Vasanthakumar et al. 2001
- McBean et al. 2002

AEROELASTIC MODEL

- A three-dimensional non-stationary transonic flow of viscous gas through a blade row can be described by a complete system of Reynolds-averaged Navier-Stokes equations.
- The explicit monotonous second-order accurate Godunov-Kolgan finite-volume scheme and moving hybrid H-O structured grid
- The Baldwin-Lomax turbulence model

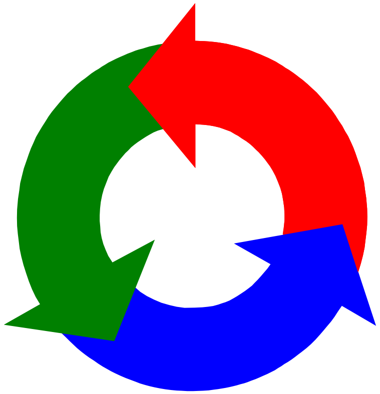
Time Marching

FLOW CODE

STRUCTURE CODE

NEW UNSTEADY FLOWFIELD AT NEW POSITION OF THE MESH

MOVE AERODYNAMIC MESH ACCORDING TO NEW POSITION AND VELOCITY OF POINTS



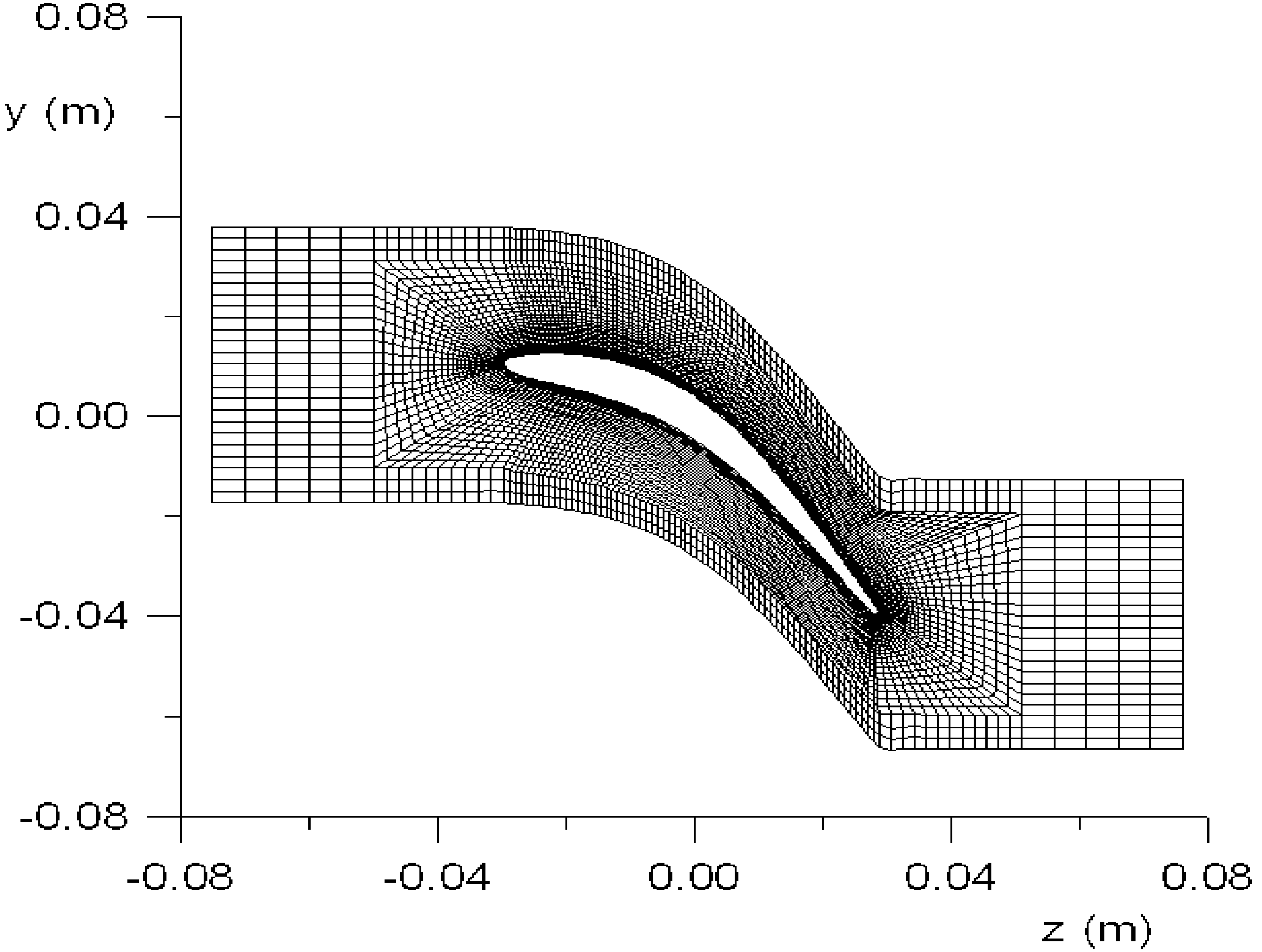
CALCULATE POSITION AND VELOCITY OF THE STRUCTURE AT NEW TIME LEVEL

NEW AERODYNAMIC FORCES ACTING ON THE STRUCTURE

11th Standard Configuration

- consists of twenty vibrating turbine blades
- subsonic case (M= 0.69)
- transonic off-design case (M= 0.99) with a high-incidence inlet flow angle 34 deg upward with respect to the axial direction. and a separation bubble on the suction surface.

Viscous mesh, inner O-mesh, outer structures H grid

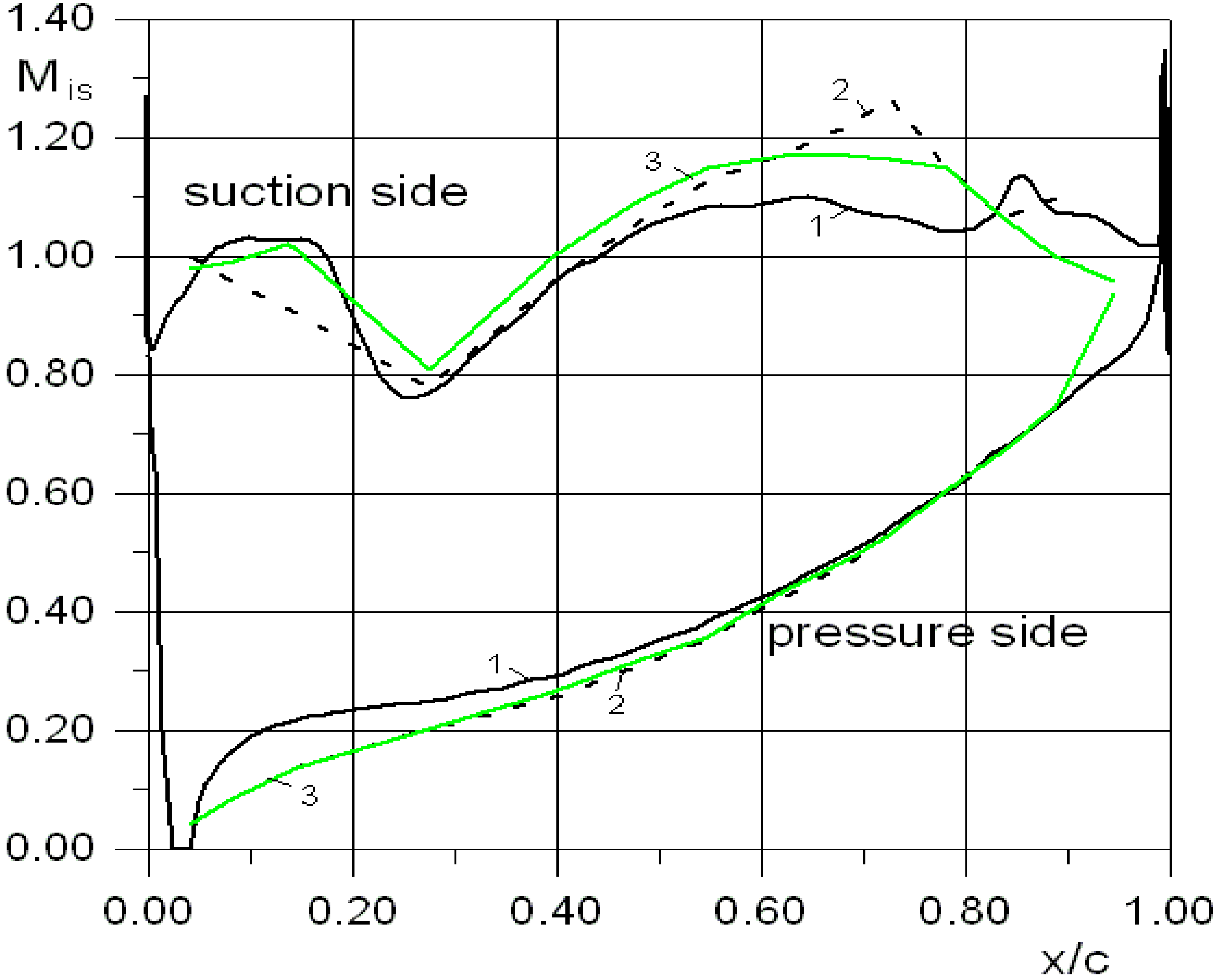


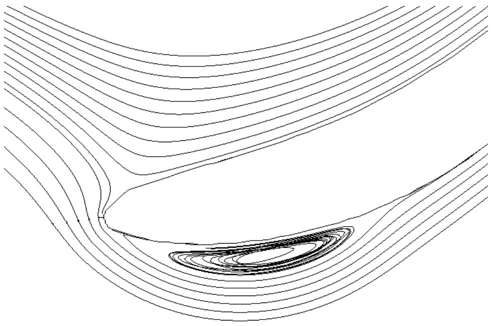
Numerical mesh

- structural hybrid H-O grid 10 000 cells
- The H-grid remains static during calculation.
- The inner O-grid (42 x 213 cells) is deformable in accordance with blade motion.

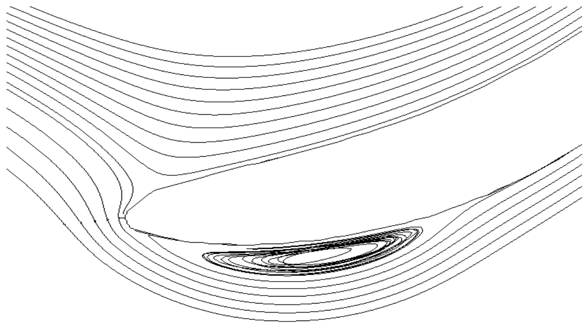
Mach number distribution, midspan, off-design transonic case, M= 0.99,

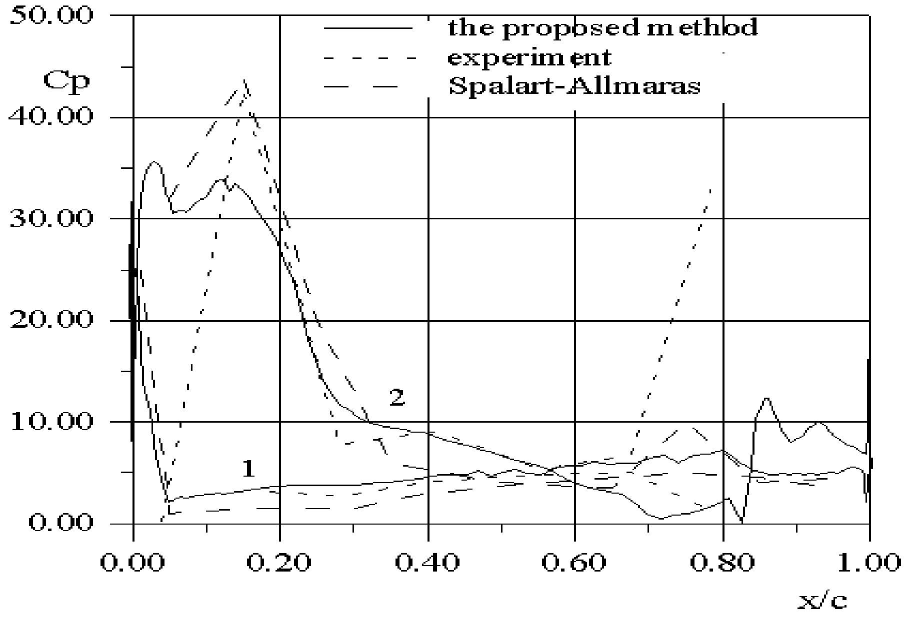
1 – the method proposed; 2 – experiment; 3 –VOLFAP code





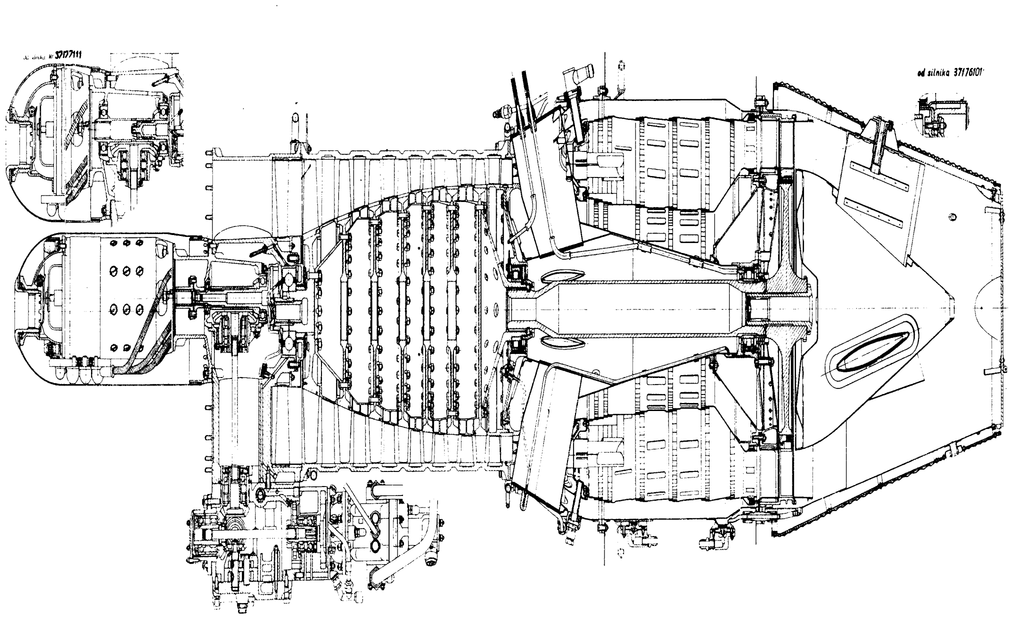
- **2D and 3D inviscid** and viscous in-house numerical codes for **flutter calculation** of the twisted rotor blades. (Flutter analysis of real steam turbine of 200 MW and compressor rotor blade of S0-3 aircraft engine. Experimental verifications of obtained numerical results)



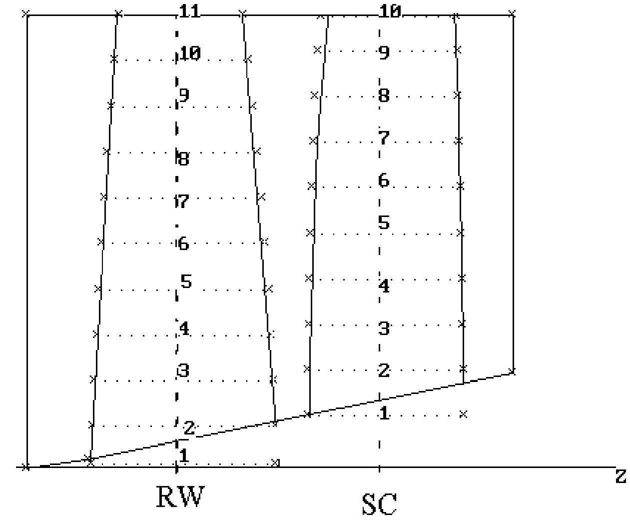


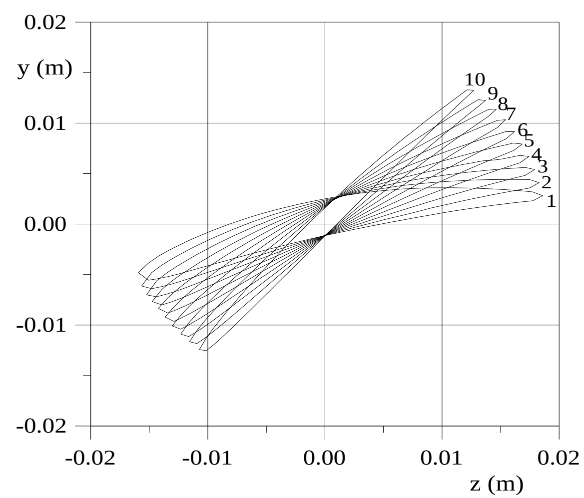
Pressure amplitude distribution over blade surface –
numerical and experimental results for 11th Standard Configuration

- **3D inviscid** in-house numerical codes for **flutter calculation** of the first stage compressor rotor blades of S0-3 engine



SO-3 engine (ISKRA)

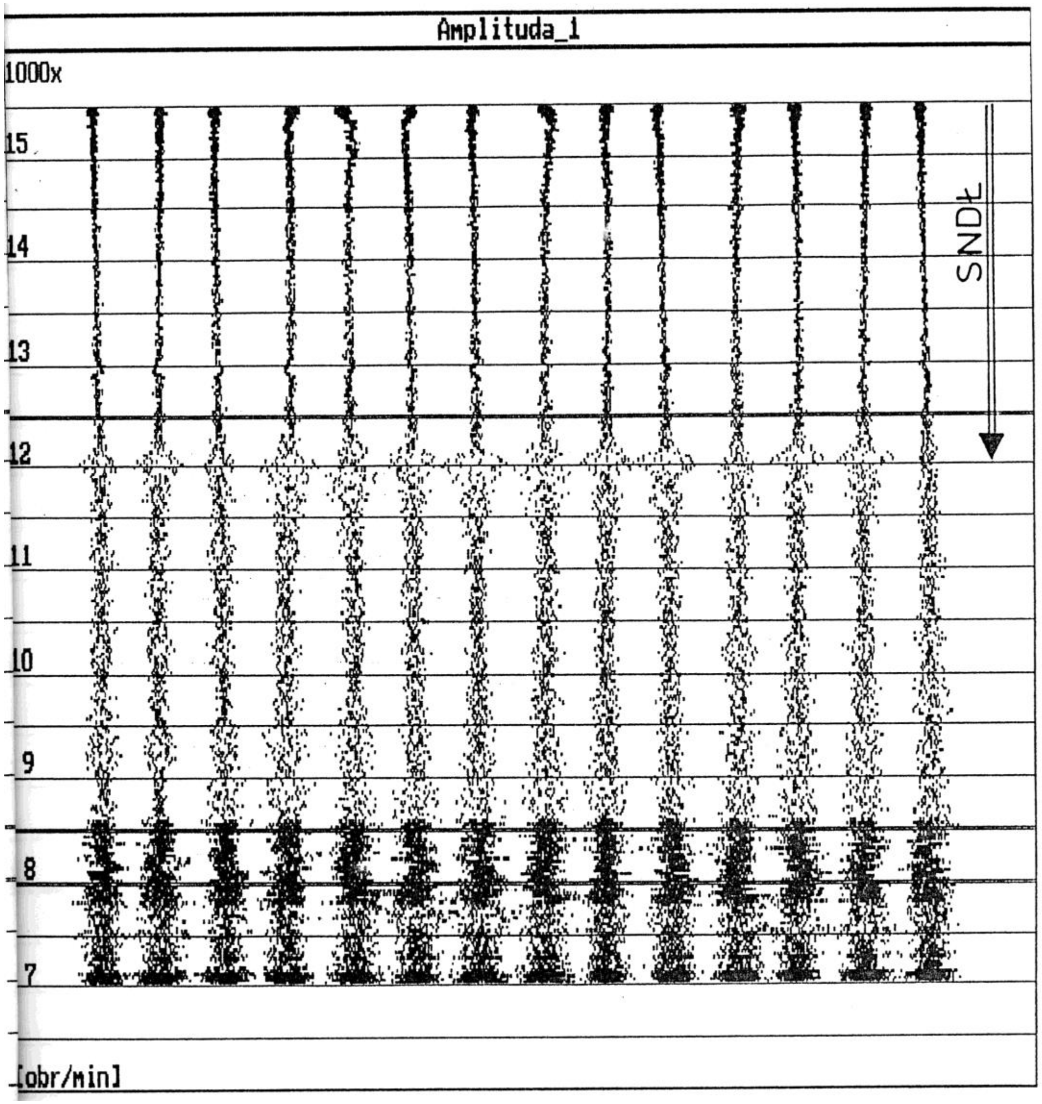




1st stage Finite Volume mesh

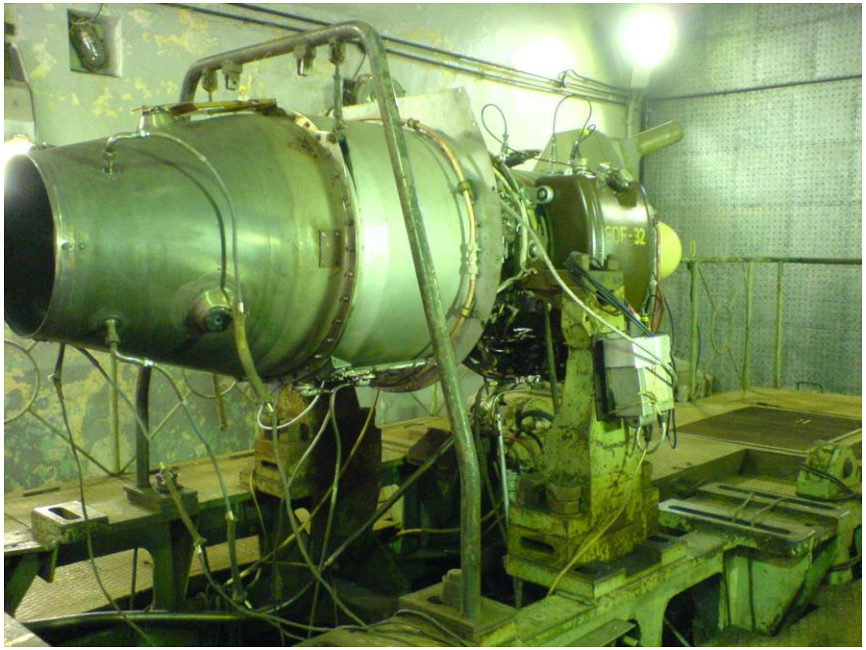
• Tip-timing , I stage S0-3 compressor

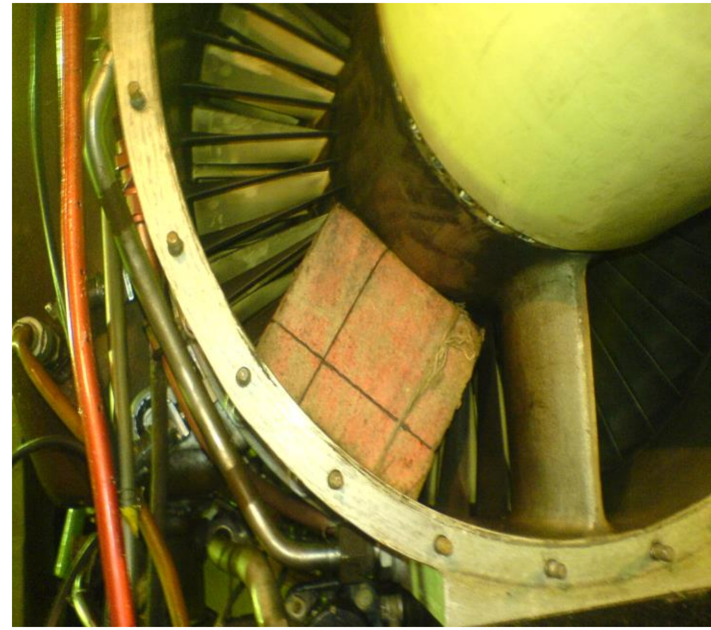
SO-3 engine
(ISKRA)



Air Force Institute of Technology, Warsaw

- **Tip-timing , I stage S0-3 compressor**





SO-3 engine
(ISKRA)

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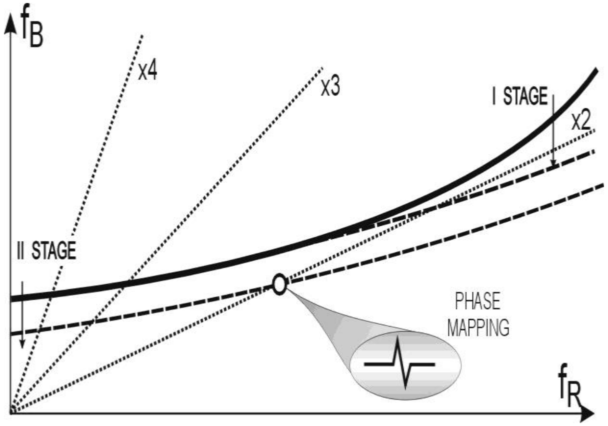
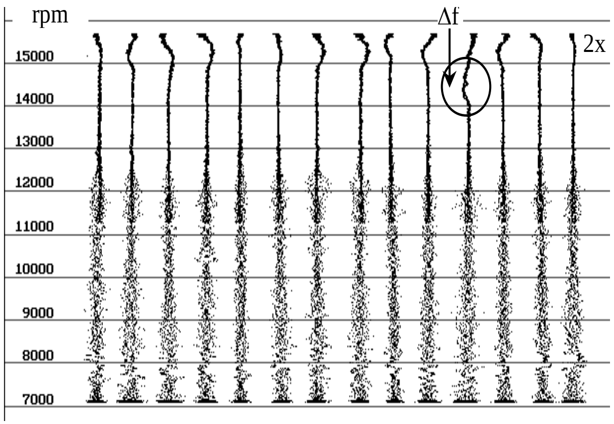
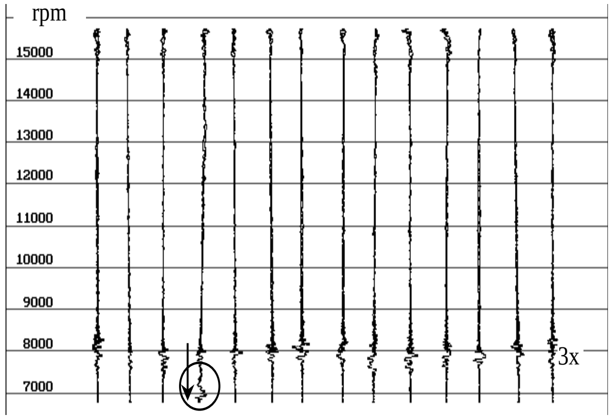
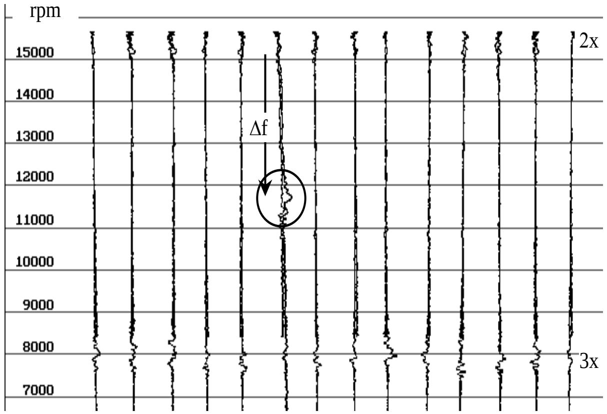
- **Tip-timing , I stage S0-3 compressor,**
- **crack propagation**





Rotating stall





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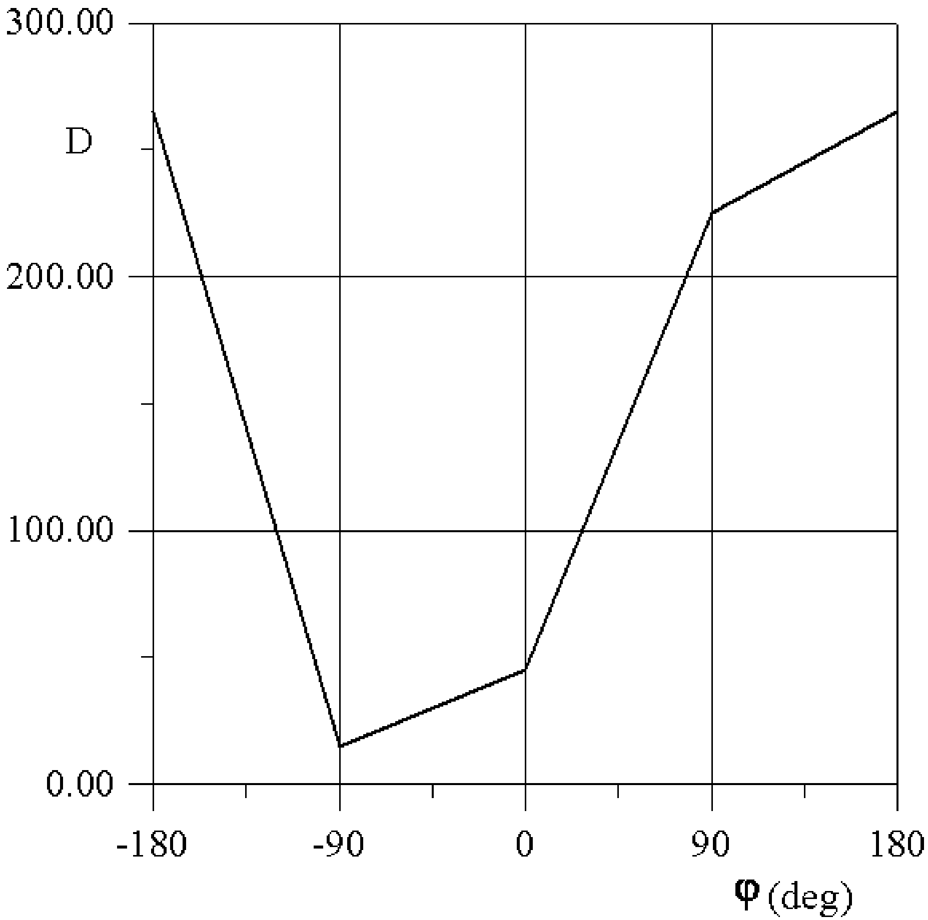
- **3D inviscid** in-house numerical codes for **flutter calculation** of the first stage compressor rotor blades of S0-3 engine

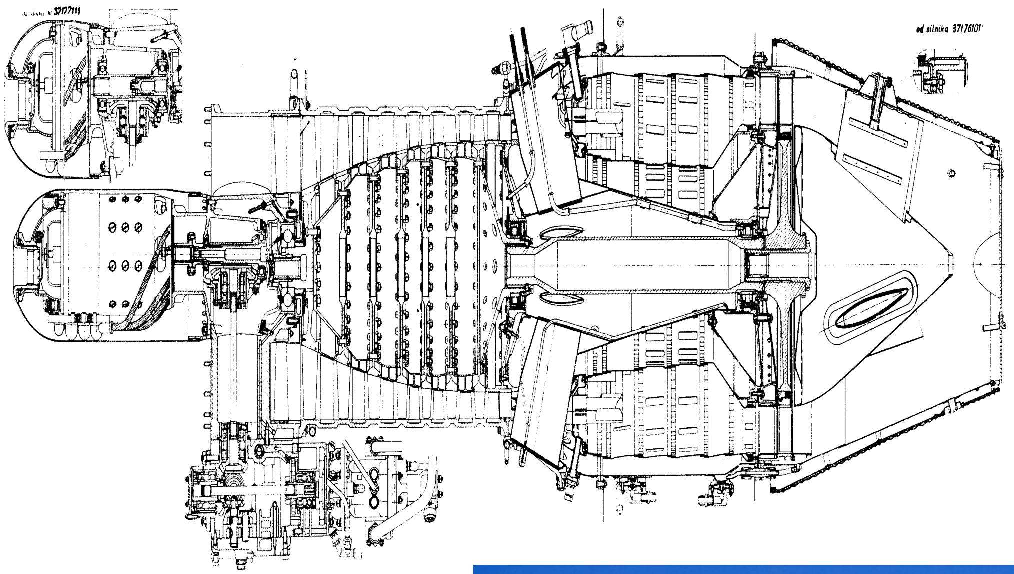
SO-3 engine
(ISKRA)



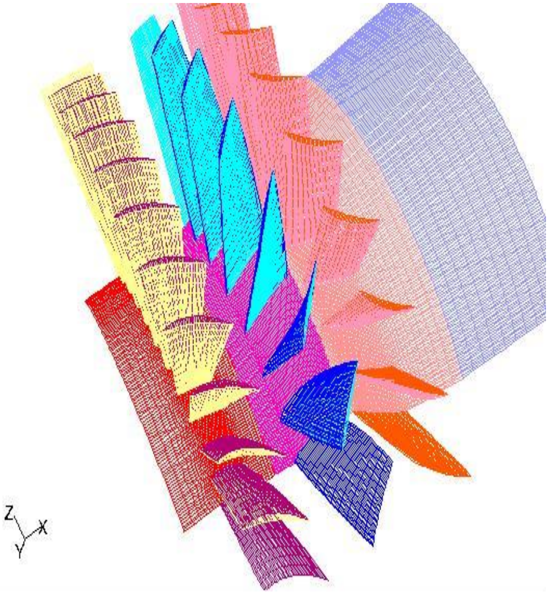
Aerodamping coefficient n=15400 rpm

1st stage Finite Volume mesh

- **3D Unsteady forcers of the stage with vibrating rotor blades** in the subsonic, transonic and supersonic inviscid and viscous flow, in-house numerical codes. (Calculations of unsteady forces acting on rotor blades of the several stages in steam turbines and aircraft engines. Experimental verifications of obtained numerical results



SO-3 engine (ISKRA)_

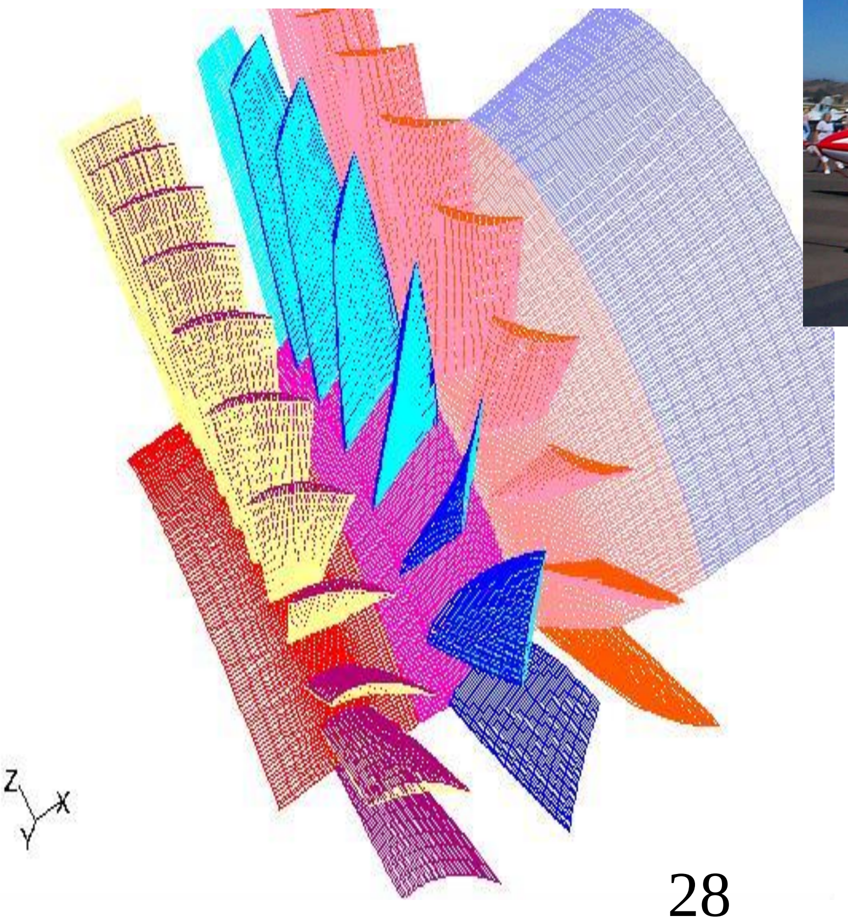


1st stage Finite Volume mesh

Clocking research in compressor to reduce the blade loading

- the **unsteady forces and displacements** of the rotor blade in a one and a half first stage of the compressor SO3 engine is presented for different clocking positions.
- The first rotor **blade vibration** has also been considered.

The view of the compressor stage-S03 engine



34

28

44

Flow Model 3d Inviscid

- The ideal gas flow around multiple interblade passages (with periodicity on the whole annulus) is described by the unsteady 3D Euler equations in conservative form;
- Explicit monotonous second - order accurate Godunov – Kolgan, finite - volume scheme and moving grids;

Flow Model 3d Viscous

- A three-dimensional non-stationary transonic flow of viscous gas through a blade row can be described by a complete system of Reynolds-averaged Navier-Stokes equations.
- The explicit monotonous second-order accurate Godunov-Kolgan finite-volume scheme and moving hybrid H-O structured grid
- The Baldwin-Lomax turbulence model

Structural Model

- In the structural analysis the modal approach is used
- The natural frequencies and modal shapes of the blade were calculated by using 3D finite element model

In the structural analysis the modal approach is used

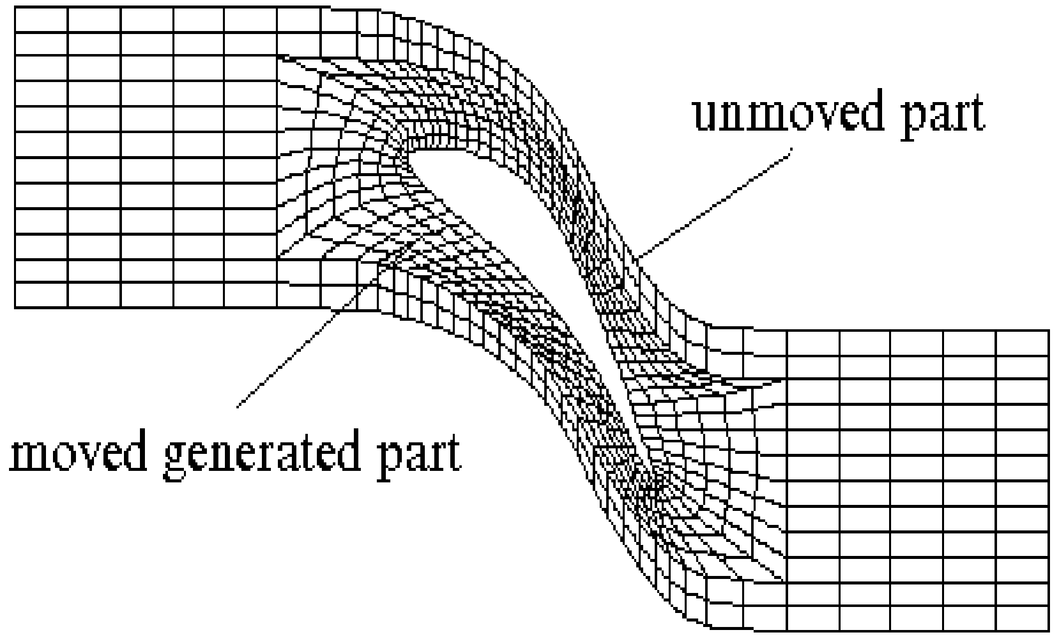
$$\mathbf{u}(x,t) = \mathbf{U}(x,t)\mathbf{q}(t) = \sum_{i=1}^{N} \mathbf{U}_i(x)\, q_i(t),$$

$$\ddot{q}_i(t) + 2h_i\dot{q}_i(t) + \omega_i^2 q_i(t) = \lambda_i(t)$$

$$\lambda_i = \frac{\iint\limits_{\sigma} p\overline{U}_i \cdot \overline{n}^{\circ}\, d\sigma}{\iiint\limits_{v} \rho \overline{U}_i^2\, dv}.$$

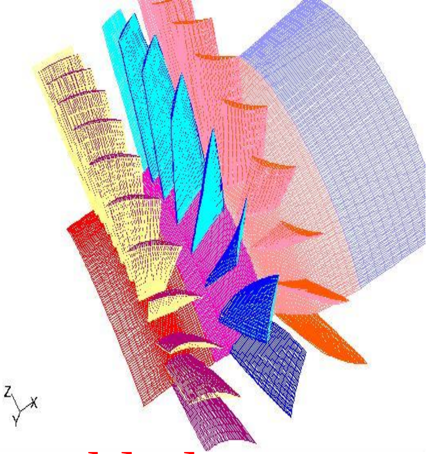
The unsterady grid generation –rotor blade

outer H-grid stationary



inner H-grid is rebuilt in each iteration

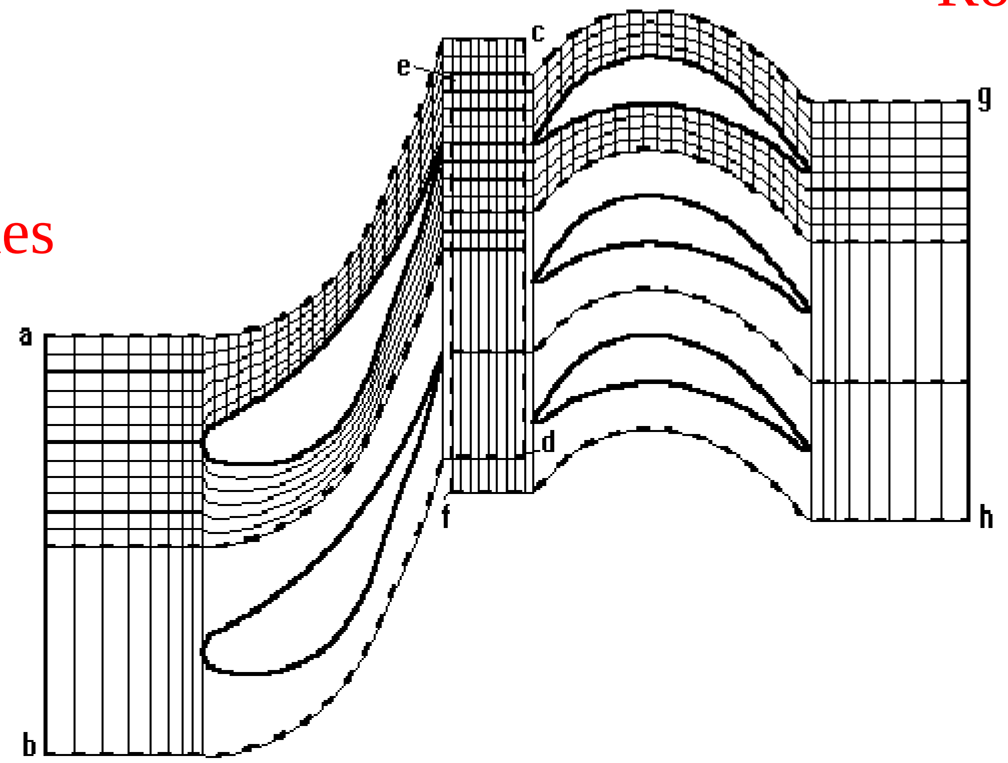
The difference grid



common part (efcd)

Rotor blades

Stator blades



S1 11*49*75

S0 11*41*85

R 11*61*79

Number of iterations 75600, time step 2.5575E-7s, time 20 hours

- **Natural frequencies of the rotor blade (L=0.103 m), n=15400 rpm**
- **ω_1 = 540 Hz**
- **ω_2 = 1620 Hz**
- **ω_3 = 2160 Hz**
- **ω_4 = 3240 Hz**
- **ω_5 = 4320 Hz**
-
- **the excitation frequency n z = 256 * 35 [Hz] = 8960 [Hz] , nominal 15400 rpm - inviscid code**
- modal damping ξ_1 =0.001, ξ_2 =0.001, ξ_3 =0.0011, $\xi_3 = \xi_4 = \xi_{10}$.

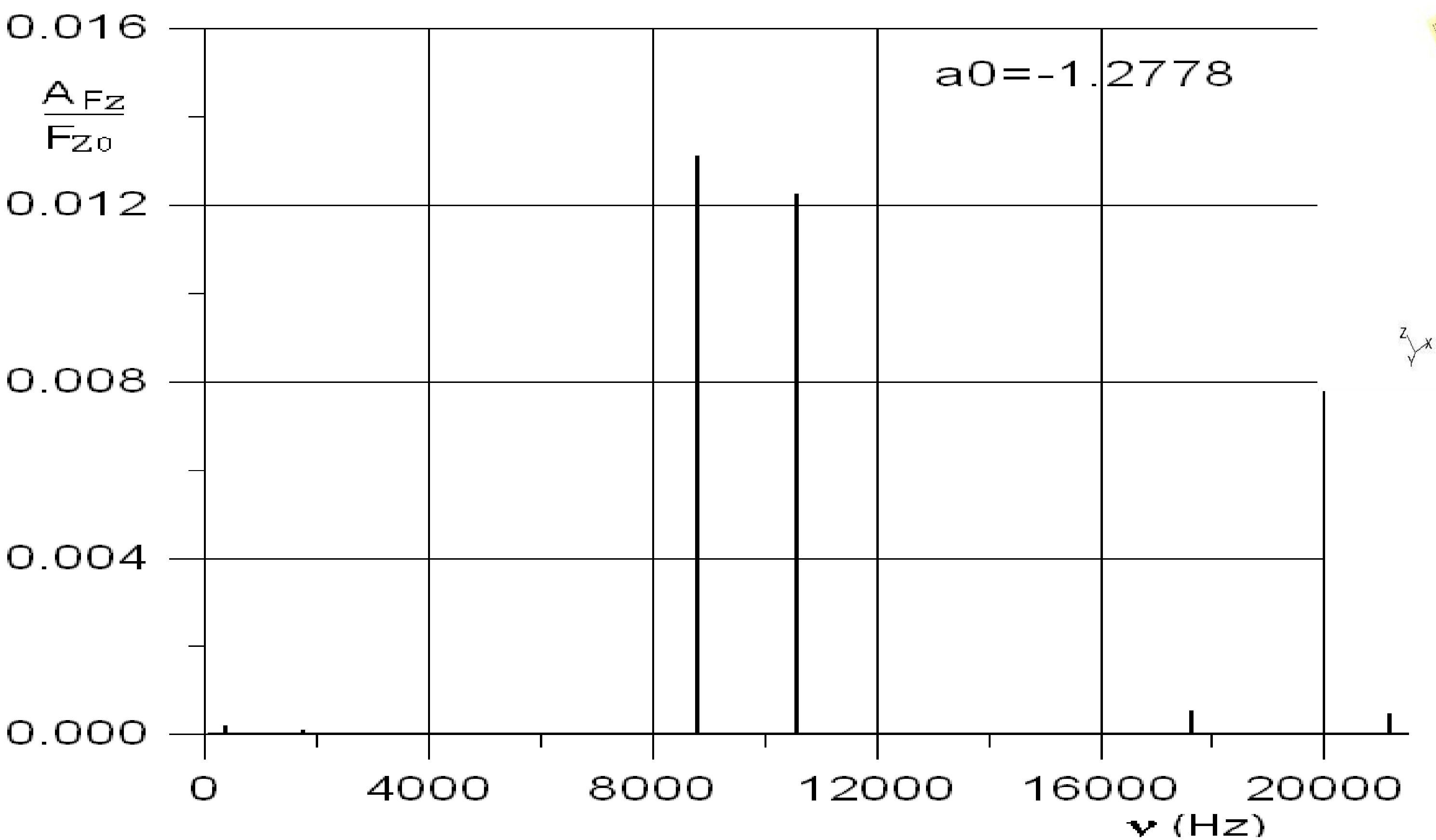
Clocking positions

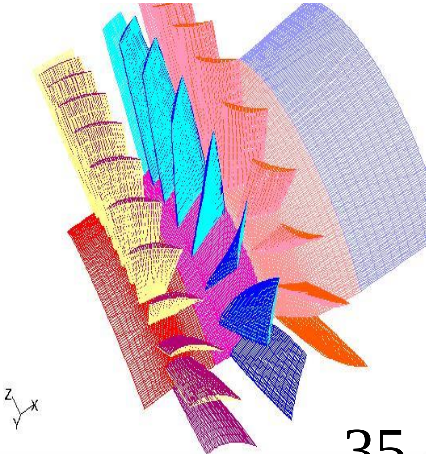
- At clocking 1 the trailing edge of the S0 stator blade is aligned along the turbine axis with the leading edge of the rotor and the trailing edge of the rotor being aligned with the leading edge of the S1 stator (1/3 of the S1 stator pitch from the blade leading edge in the direction of the rotor rotation).
- The second clocking position was obtained by rotating the first stator by 1/3 of the vane pitch.
- The third clocking position was obtained by rotating the first stator by 2/3 of the vane pitch. At clocking 3 the trailing edge of S0 stator blade is aligned with 1/7 of the S1 stator pitch from blade leading edge.

The averaged values of unsteady loads acting on the rotor blade in the root, mid and peripheral sections for **clocking 1**

L	Fy, N	Fz, N	M, N*m
0.05	-5.75	-1.28	-0.016
0.5	-7.41	-4.13	-0.037
0.95	-7.57	-7.89	-0.057

The amplitude frequency spectrum of aerodynamic load for root layer **(clocking 1),** axial force Fz





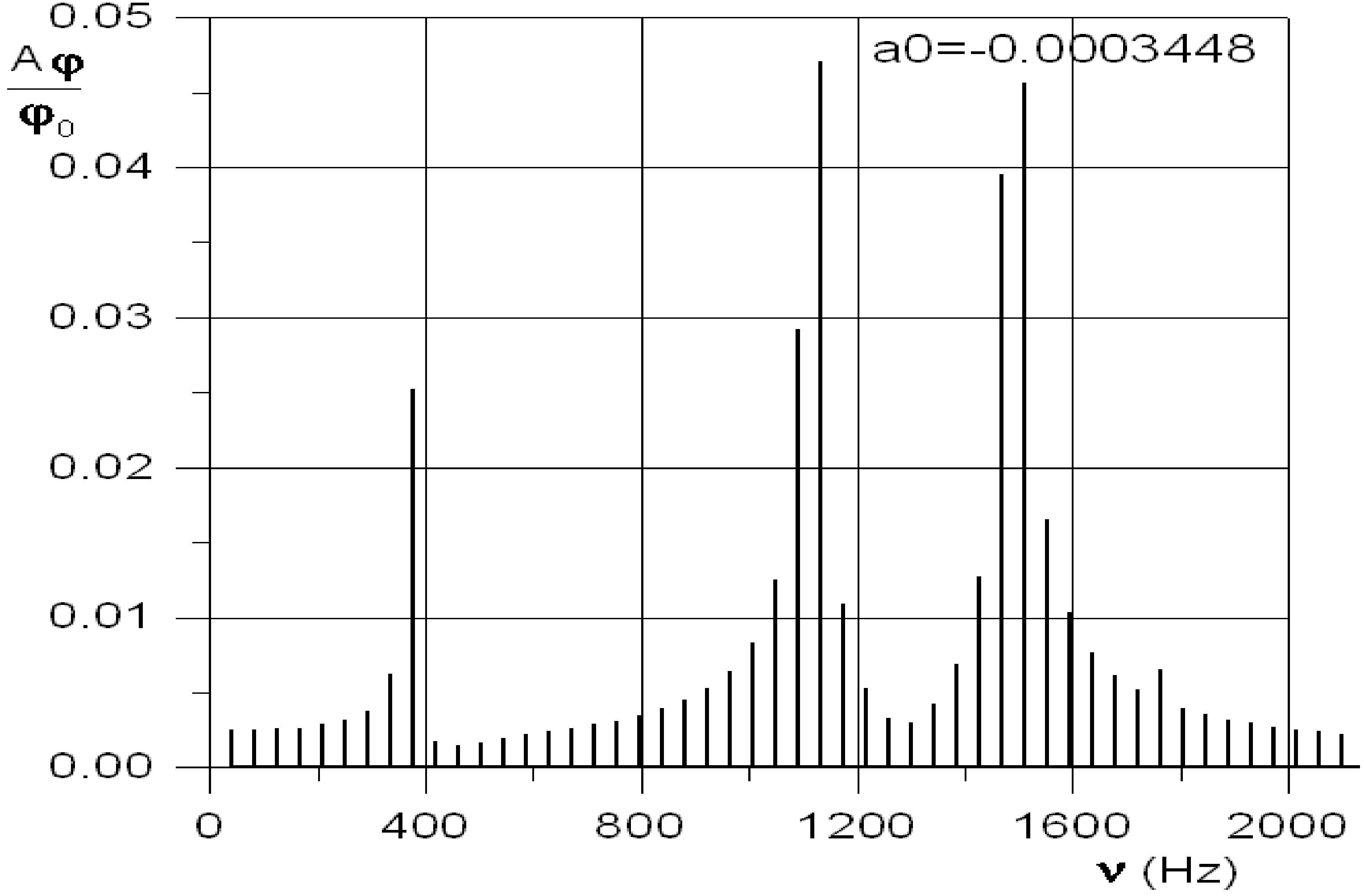
35

42

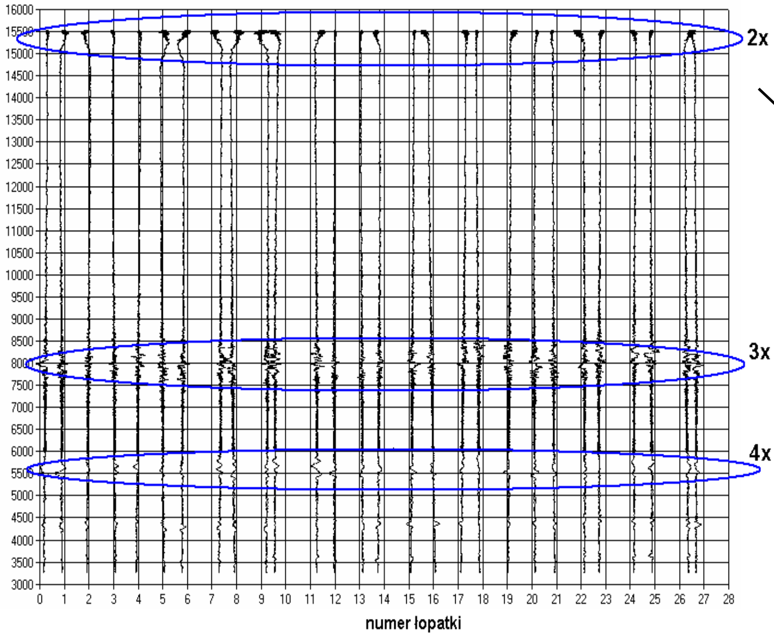
256×35=8960Hz

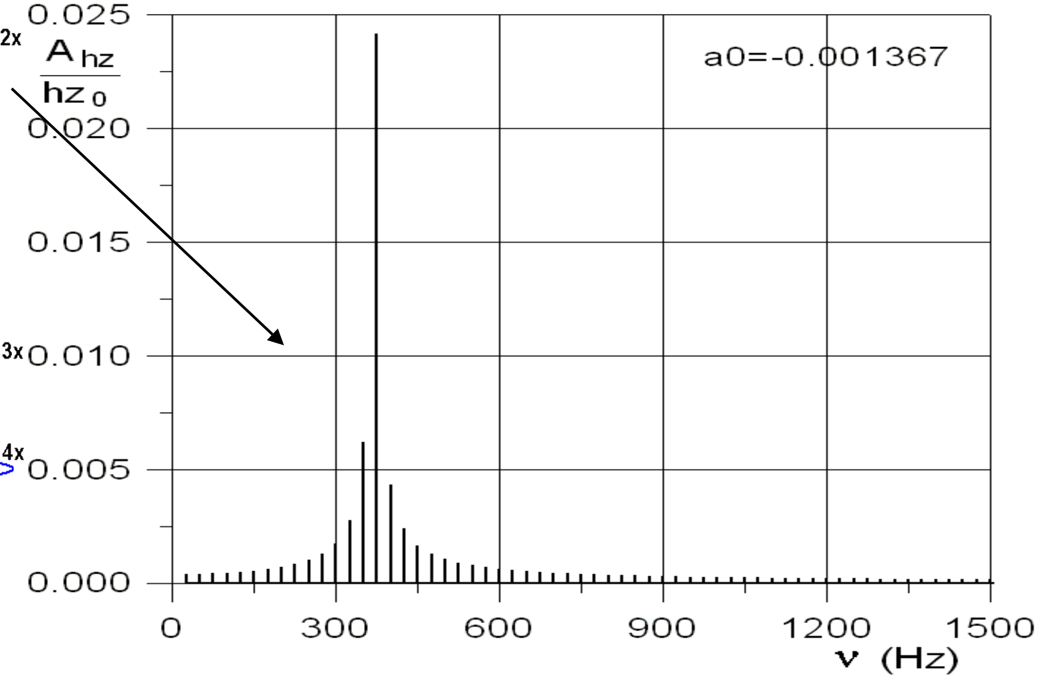
256×42=10752 Hz

The amplitude-frequency spectrum of blade rotation angle oscillations at the root layer, clocking 1



- **3D Unsteady forcers of the stage with vibrating rotor blades** in the subsonic, transonic and supersonic inviscid and viscous flow, in-house numerical codes. (Calculations of unsteady forces acting on rotor blades of the several stages in aircraft engines. Experimental verifications of obtained numerical results

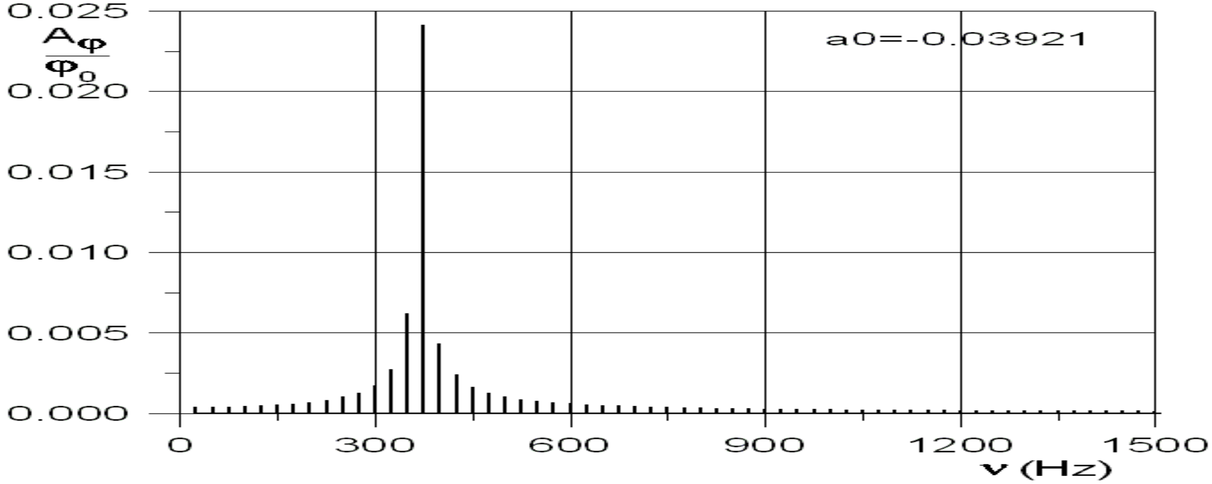


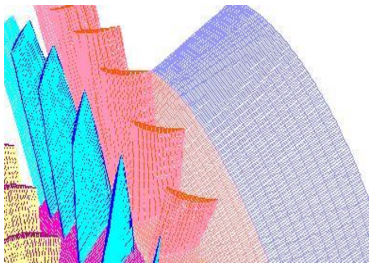


Experimental results, rotor blade displacements

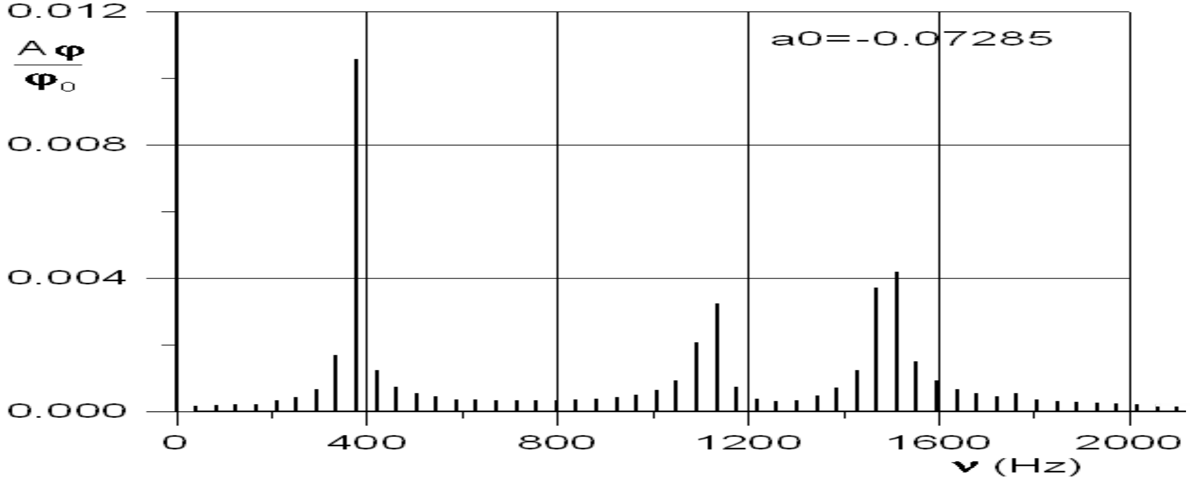
Harmonics of displacements of the 1st stage rotor blade

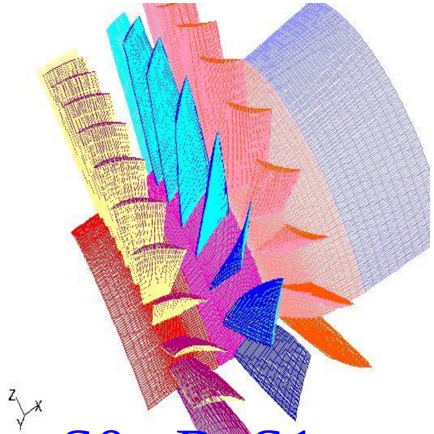
The amplitude-frequency spectrum of blade rotation angle oscillations at the peripheral layer, ***clocking 1***





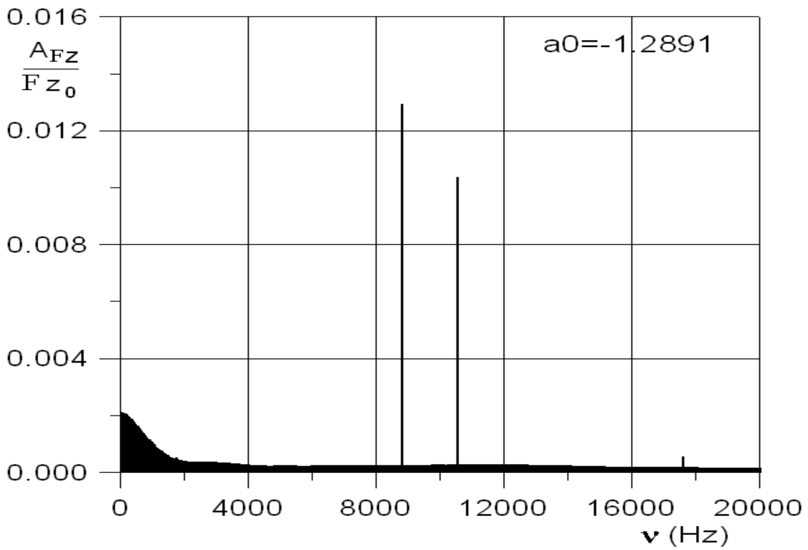
R S1



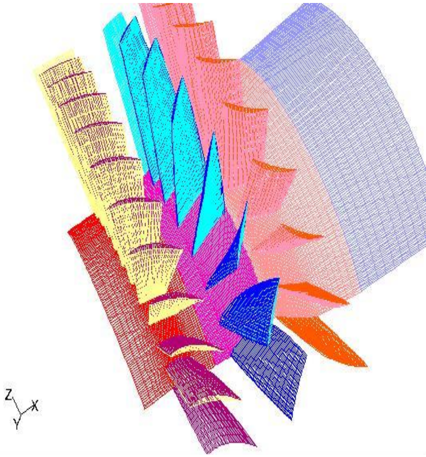


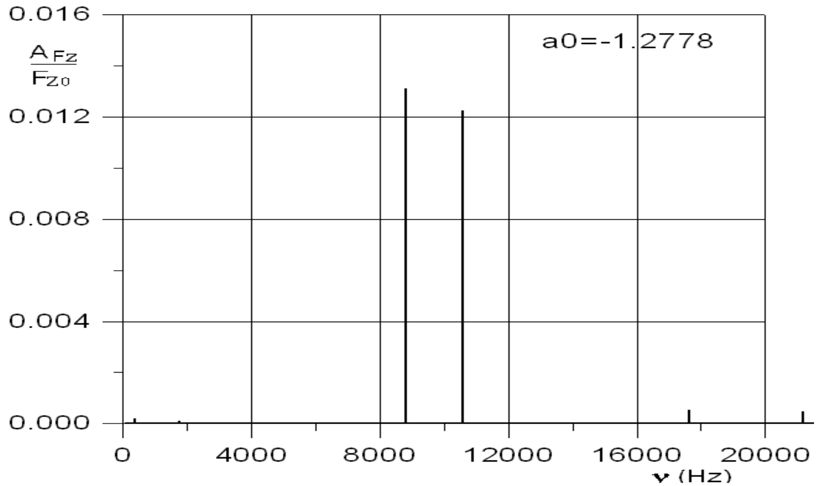
S0 R S1

The amplitude frequency spectrum of aerodynamic load for root layer (clocking 2 and 3), axial force Fz



Clocking 3





Clocking 1

256×35=8960Hz

256×42=10752 Hz

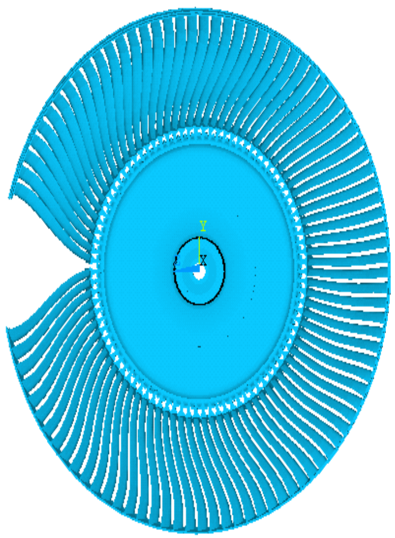
Structure calculations

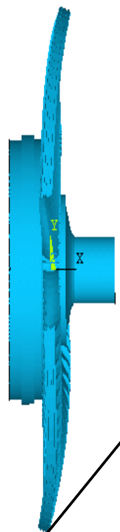
- **Forced vibration of shrouded bladed discs with shroud discontinuity**. (Experimental verifications of obtained numerical results)
- Free and forced vibration of **several bladed disc on the shaft** in steam and gas turbines. (Experimental verifications of obtained numerical results)

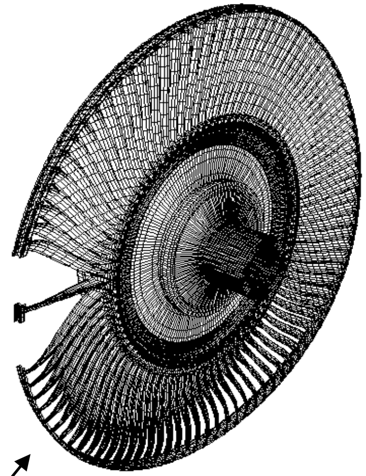
Conclusions

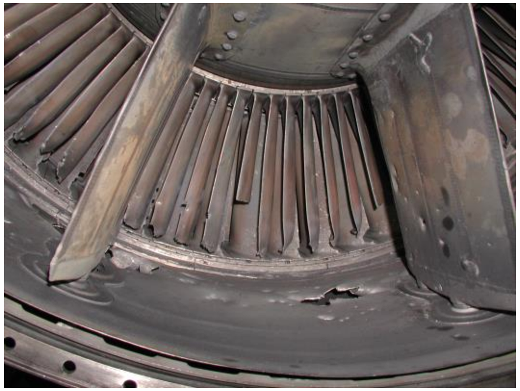
- A partially - integrated method based on the solution of the coupled aerodynamic-structure problem is used to calculate **unsteady 3D inviscid flow** through mutually moving S0 stator, rotor and S1 stator in the compressor stage of an S03 engine with the rotor blade rotating at n=15400 rpm.
- In the considered compressor stage wake interaction caused by different stator clocking positions did not appear to induce any significant changes in rotor generalized forces. Thus it may be ignored from the aerodynamic point of view.
- The **harmonic spectrums of vibrating blade** generalized displacements varied depending on the clocking position.

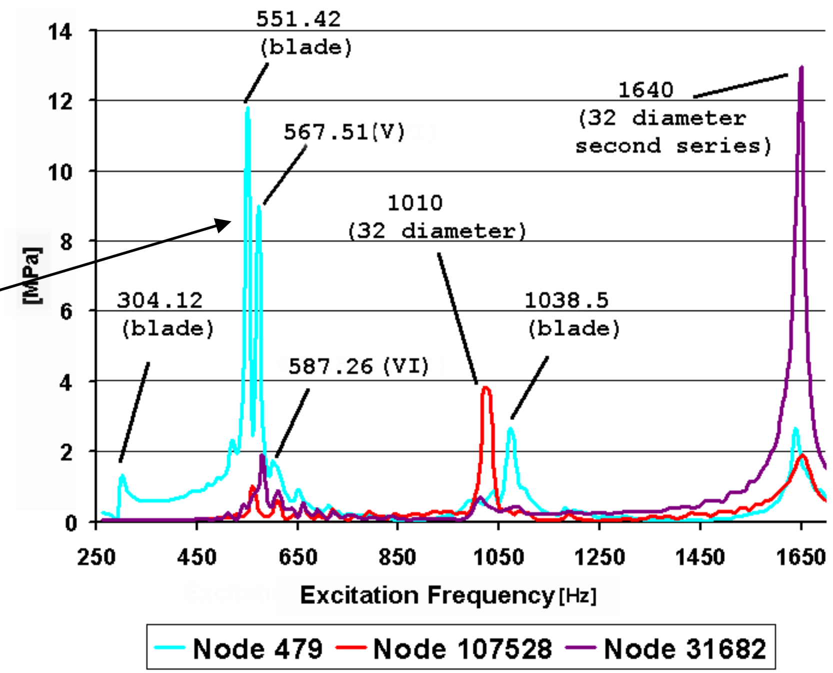
- **Forced vibration of shrouded bladed discs** with **shroud discontinuity**. (Experimental verifications of obtained numerical results)







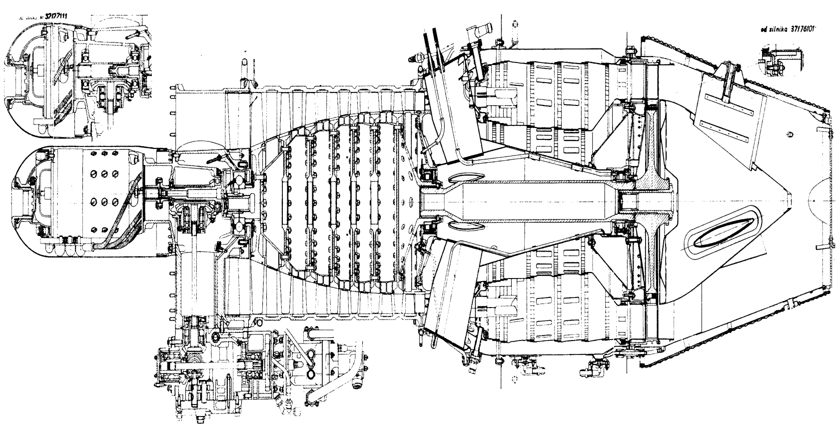


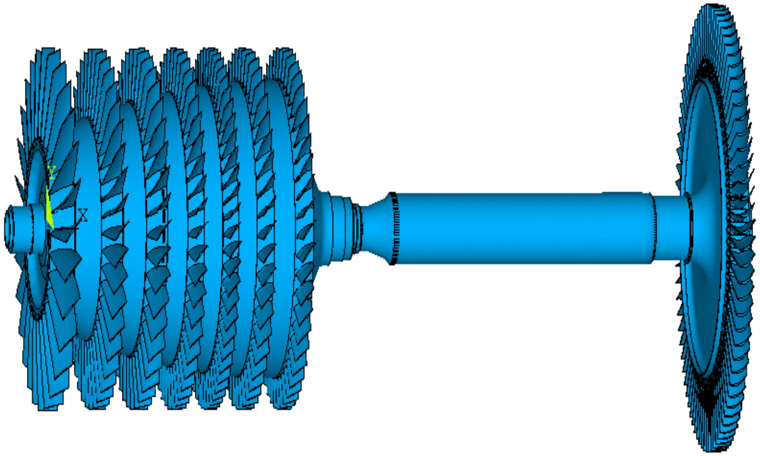


Blade response

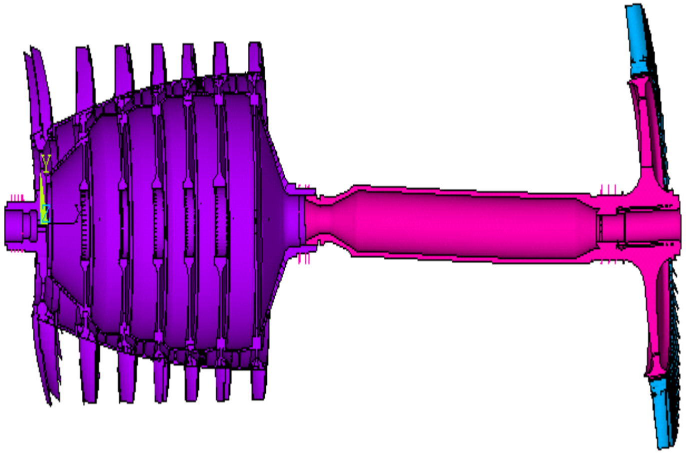
SU-22

- Free and forced vibration of **several bladed disc on the shaft** in gas turbines –S0-3 engine (ISKRA) . (Experimental verifications of obtained numerical results)





FE Model



Coupling effects

Conclusions

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