NUMERICAL SIMULATION OF ACTIVE FLOW CONTROL IN TURBOMACHINERY

Dipl.-Ing. Roland Wunderer

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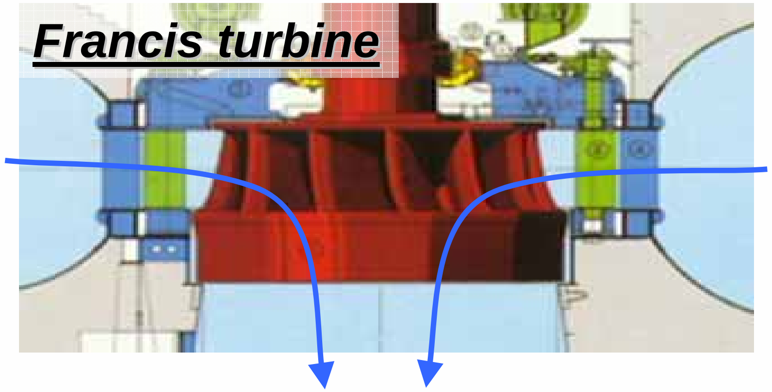
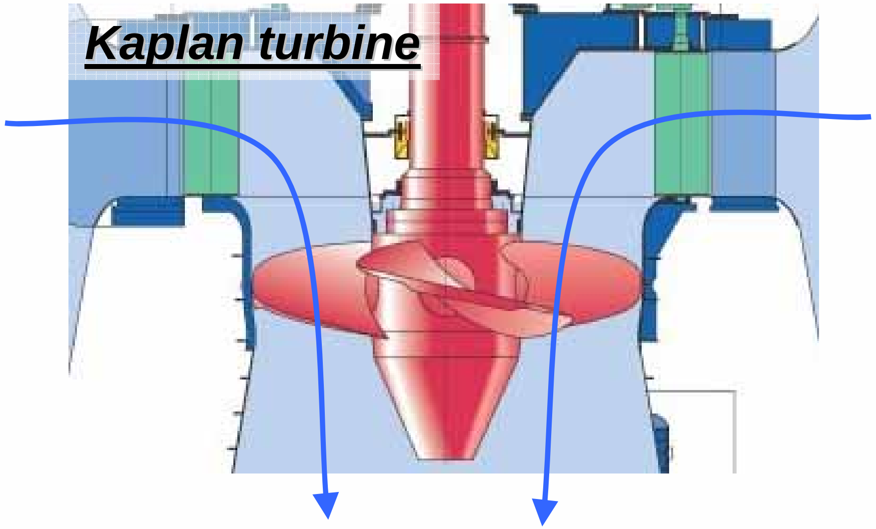
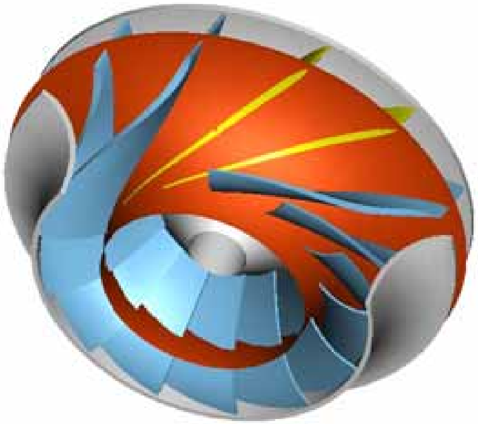
1. Project goals

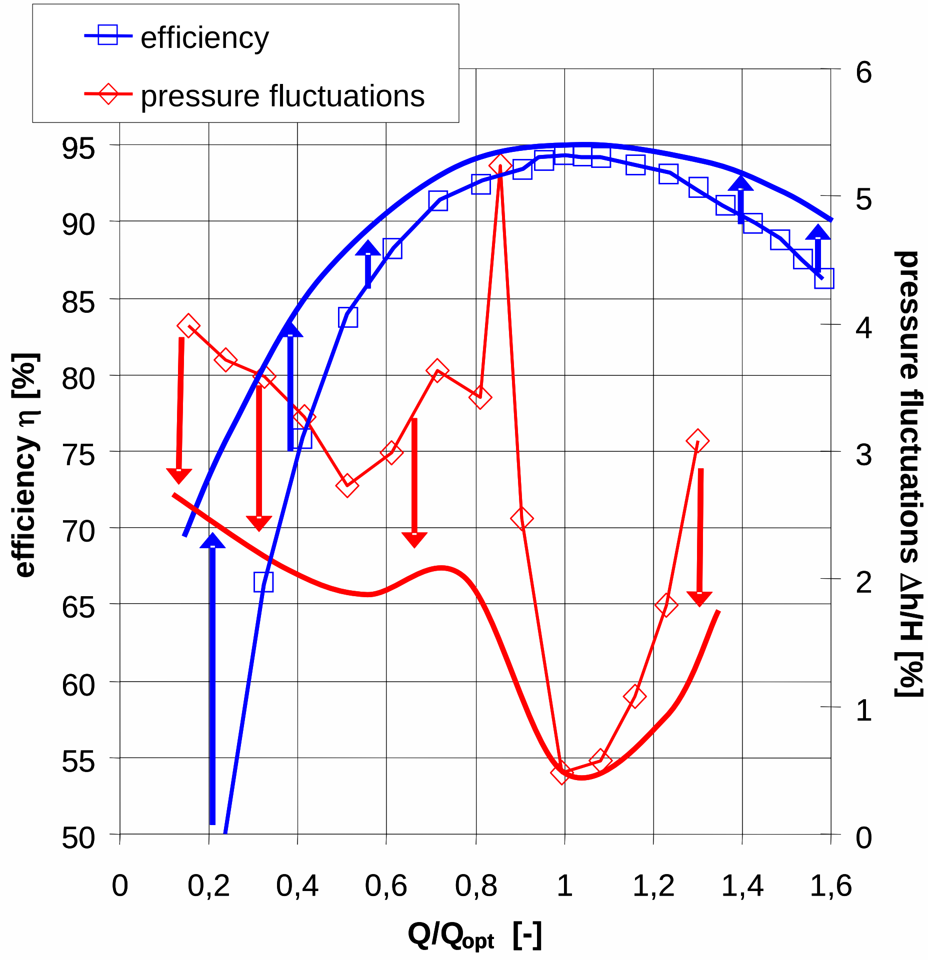






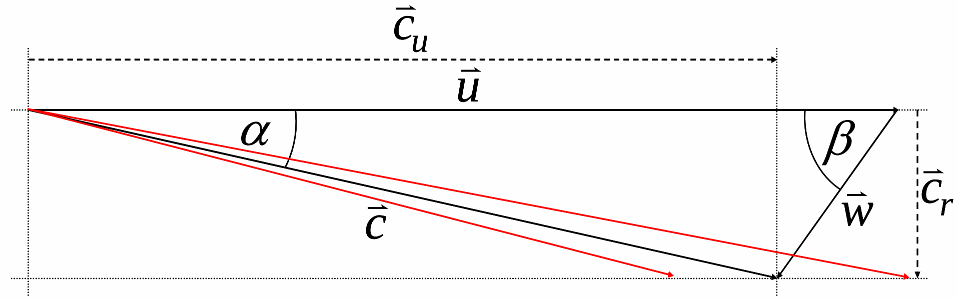
1. Project goals

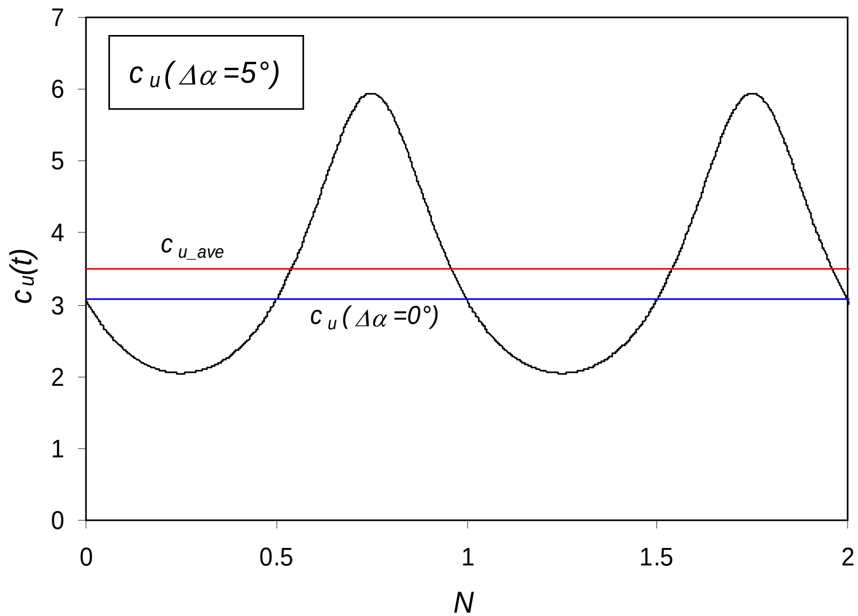
- Improvement of the simulations of turbine flows in part- and overload:
  - *CFD*
- Numerical study of the active flow control regarding:
  - *Affecting the pressure fluctuations on the blade surface.*
  - *Improving the efficiencies in part- and overload operation.*



2. Theoretical basics – Physics

- Problem: Mean angle depends on pitching angle



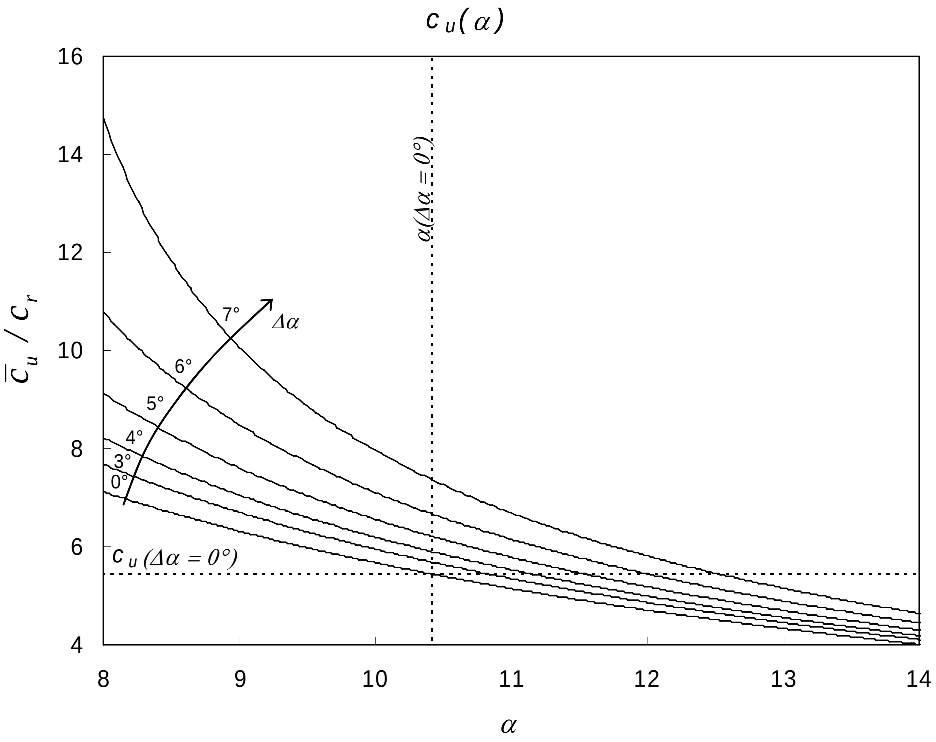


$$\alpha(t) = \alpha_0 + \Delta\alpha \cdot sin(\omega \cdot t)$$

$$c_u(t) = c_r \cdot cotan(\alpha(t))$$

2. Theoretical basics – Physics

- Problem: Mean angle depends on pitching angle

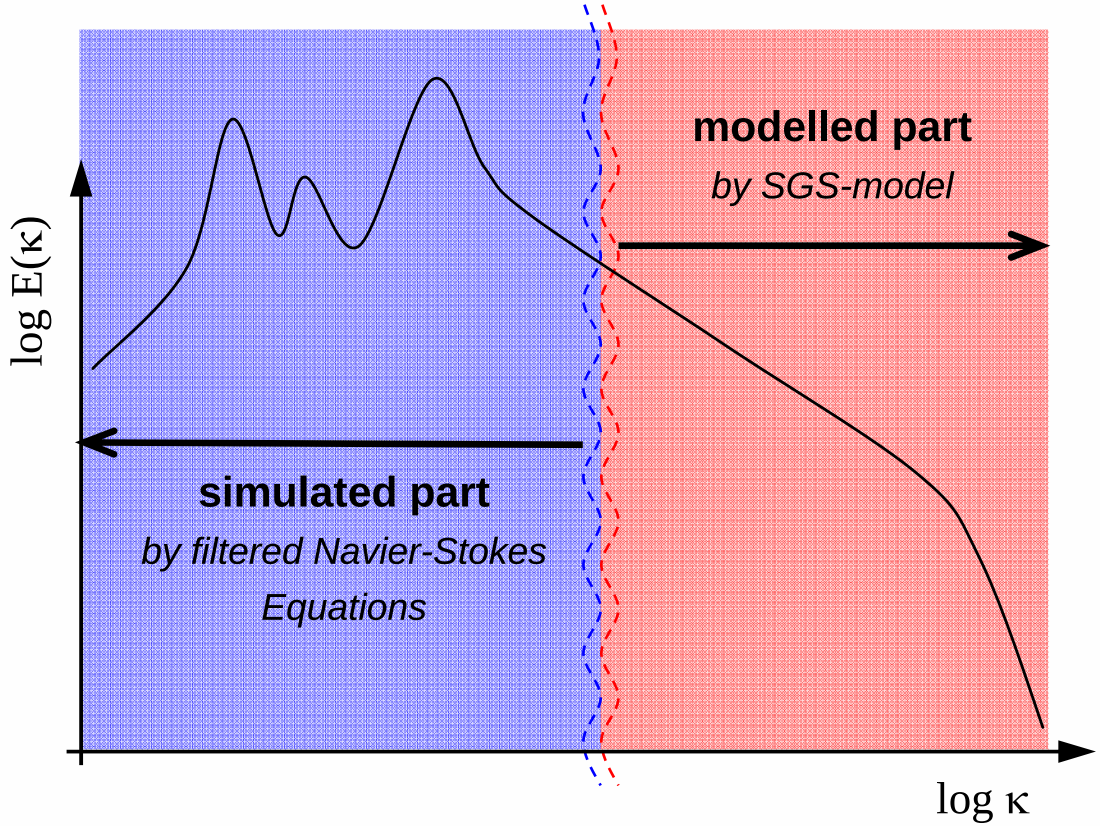


$$\Rightarrow \alpha = \alpha(\Delta\alpha)$$

$$\bar{c}_u = c_r \cdot \left[\frac{1}{\sqrt{\alpha_0^2 - \Delta\alpha^2}} - \frac{1}{3}\alpha_0 - \frac{1}{90}\alpha_0 \cdot \left(2\alpha_0^2 + 3\Delta\alpha^2\right) \right]$$

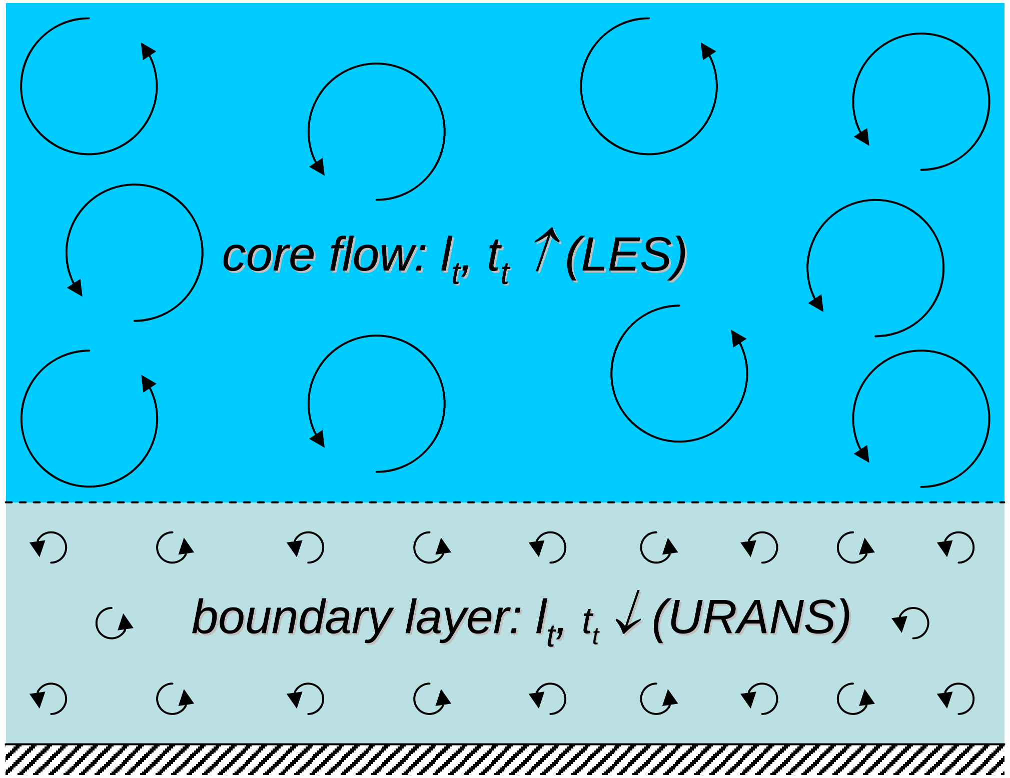
3. Theoretical basics – Numerics

- Modelling turbulence – LES



3. Theoretical basics – Numerics

- Modelling turbulence – Hybrid modelling



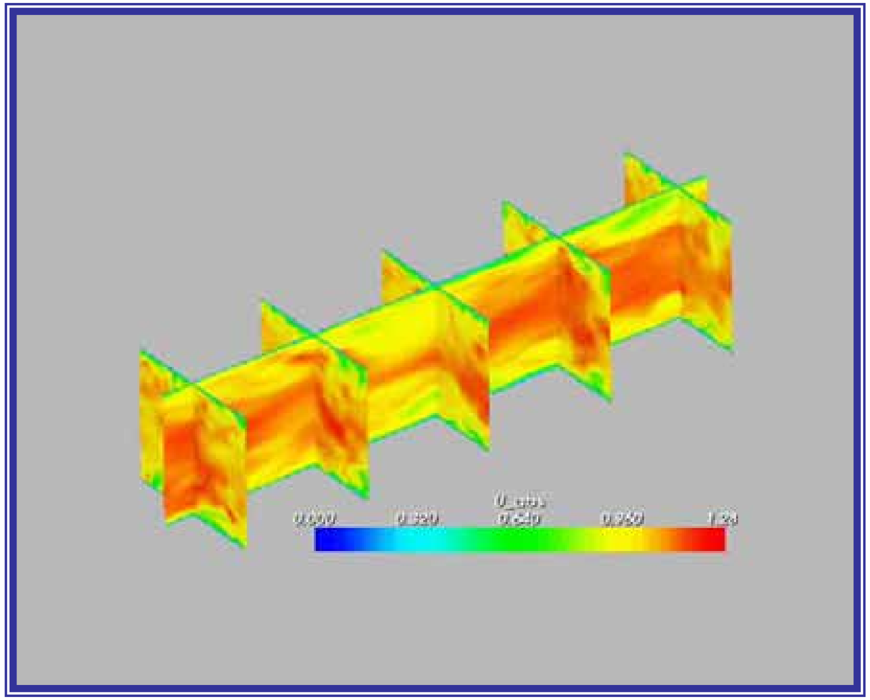
L_t, t_t (boundary.) << L_t, t_t (core)

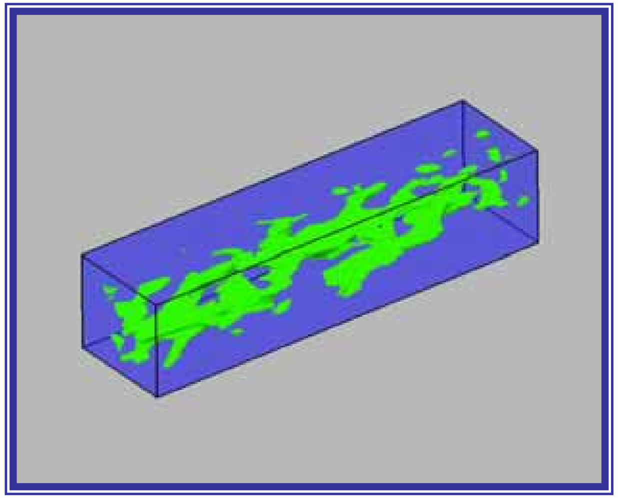
⇒ *Modelling the mean effect of the boundary layer on the core flow.*

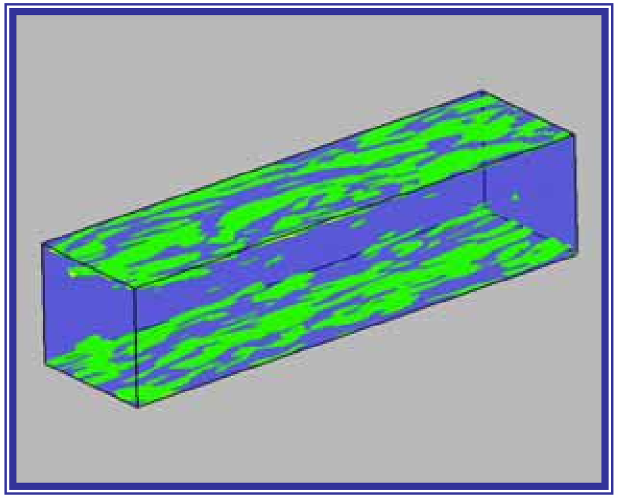
⇒ *Splitting in RANS und LES region.*

4. Validation – channel flow

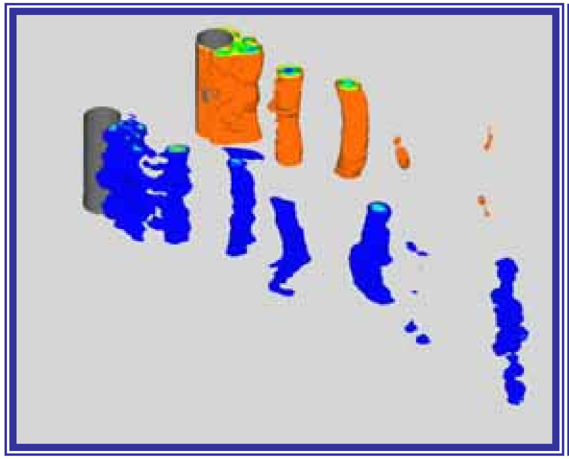
- Results - isosurfaces



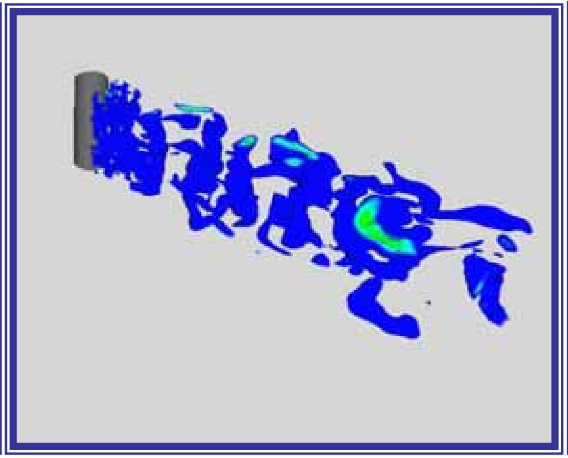




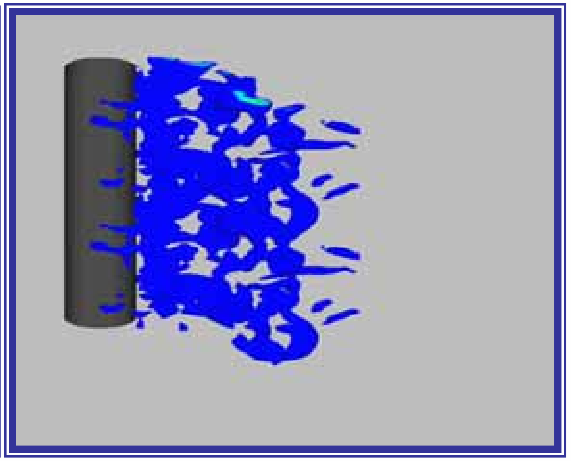
4. Validation – cylinder flow



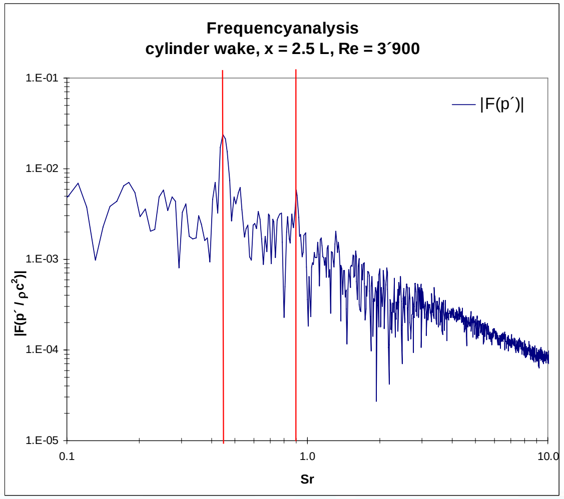
Re: 3´900, ν_{SGS} and p_{stat}

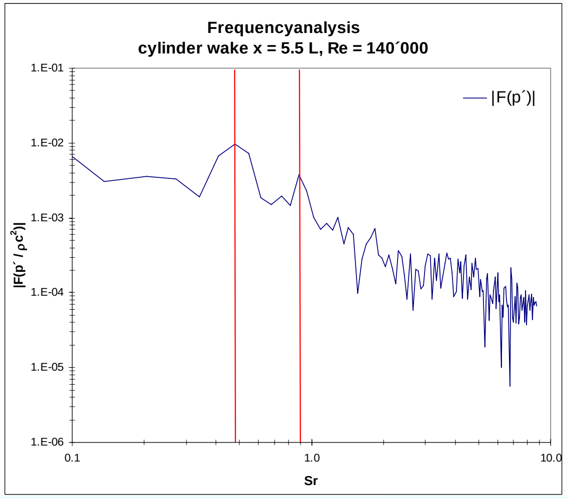


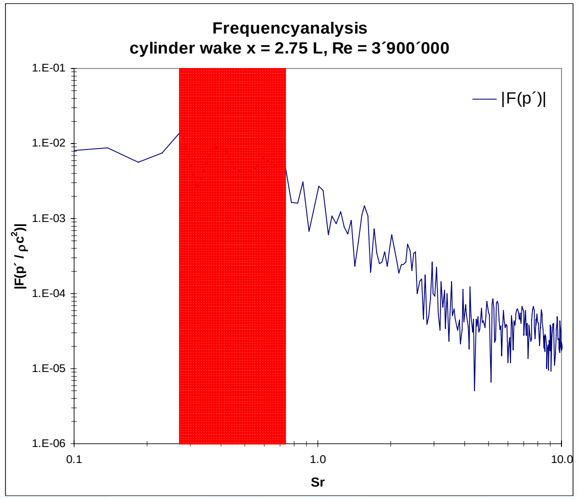
Re: 140´000, ν_{SGS}



Re: 3´600´000, ν_{SGS}

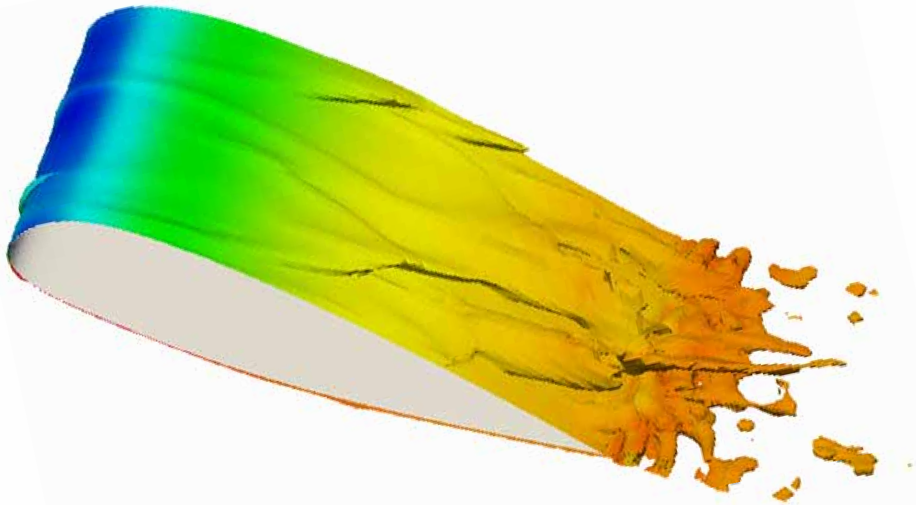






4. Validation – airfoil at maximum lift

- Contourplot of the vorticity

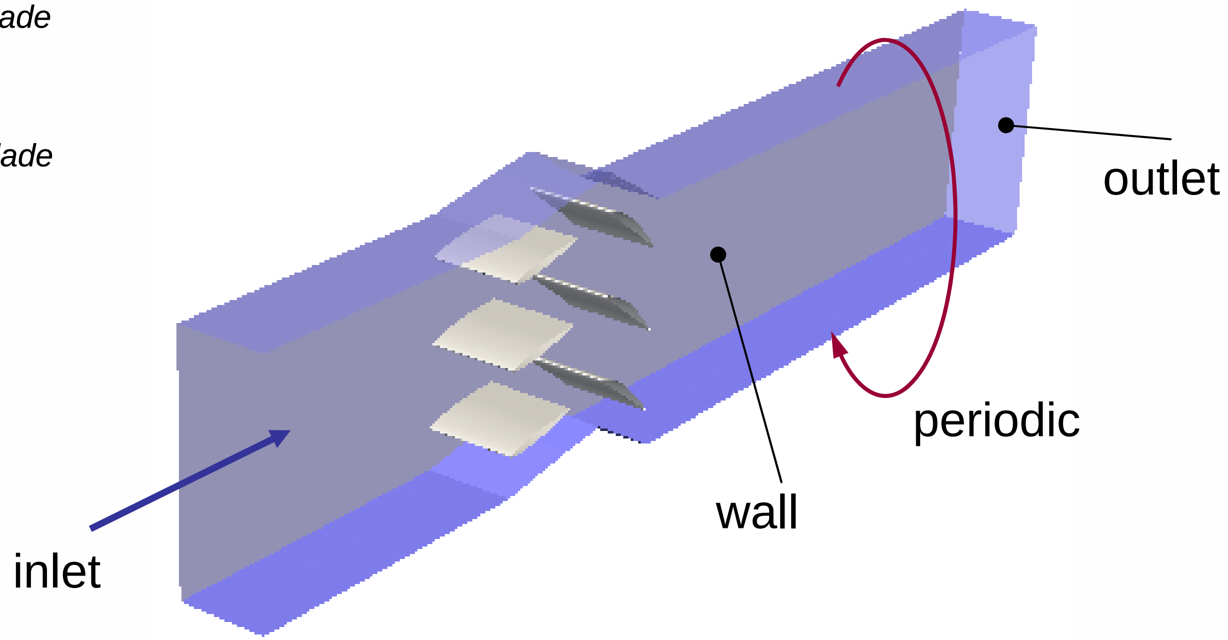


5. Results – 2D tandem cascade

- Geometry

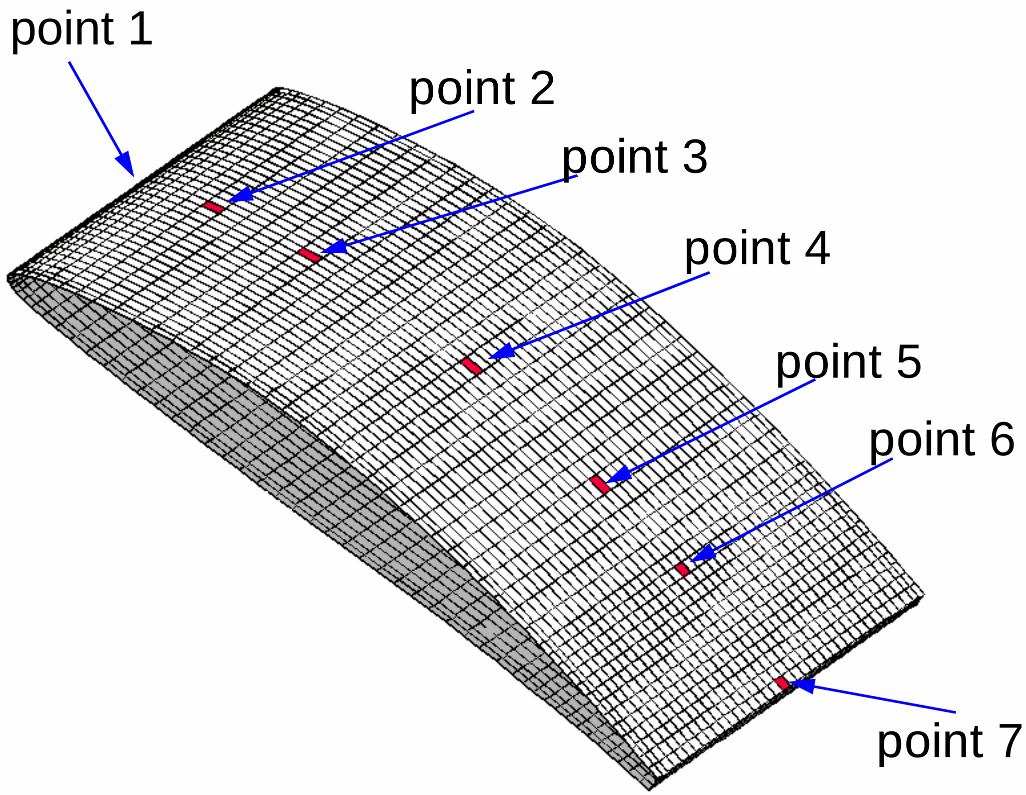
inlet length $= 4 \cdot L_{Blade}$

outlet length $= 8 \cdot L_{Blade}$



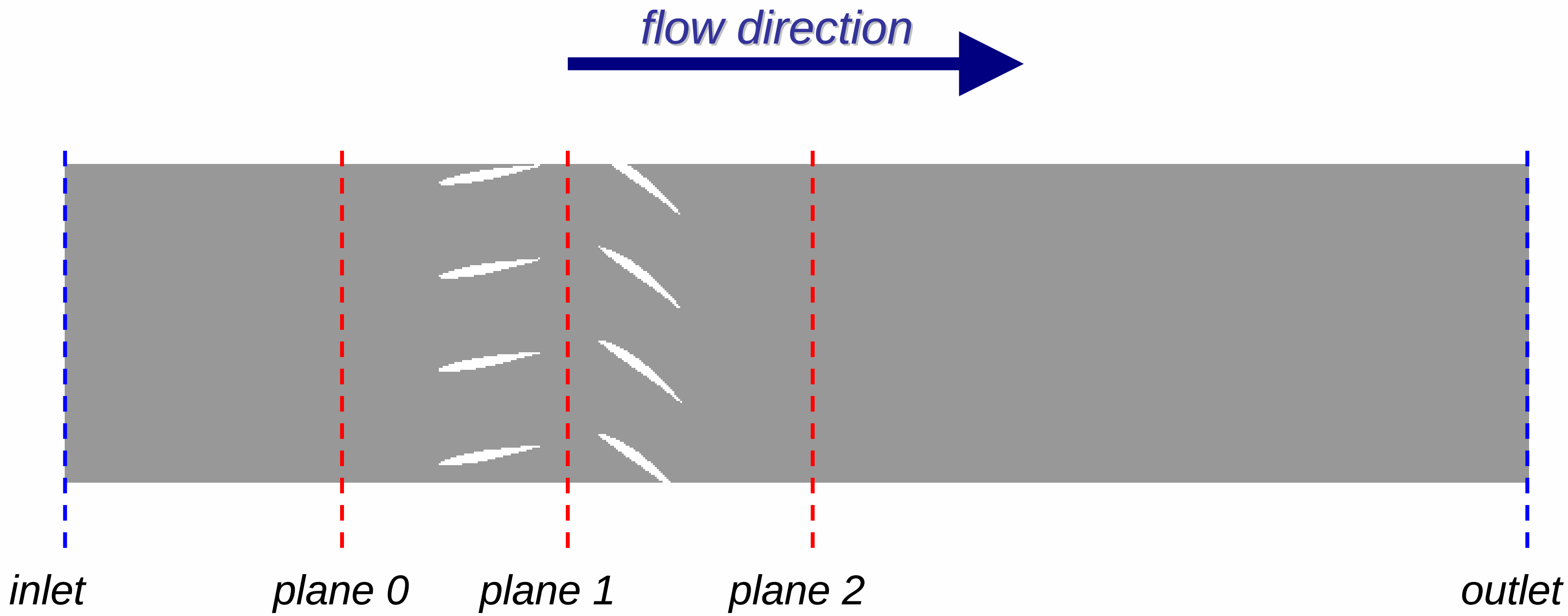
5. Results – 2D tandem cascade

- Measuring points for the static pressure



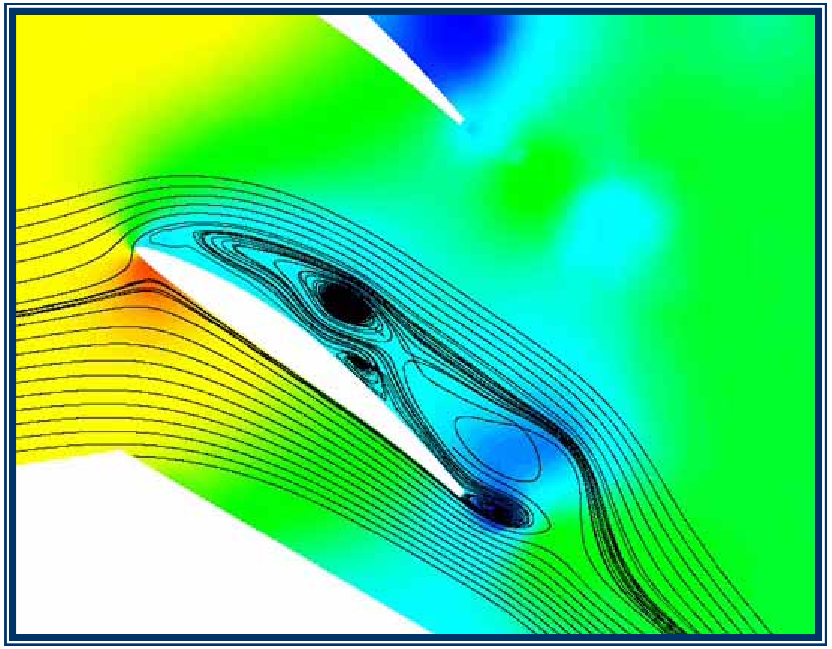
5. Results – 2D tandem cascade

- Measuring planes in the channel

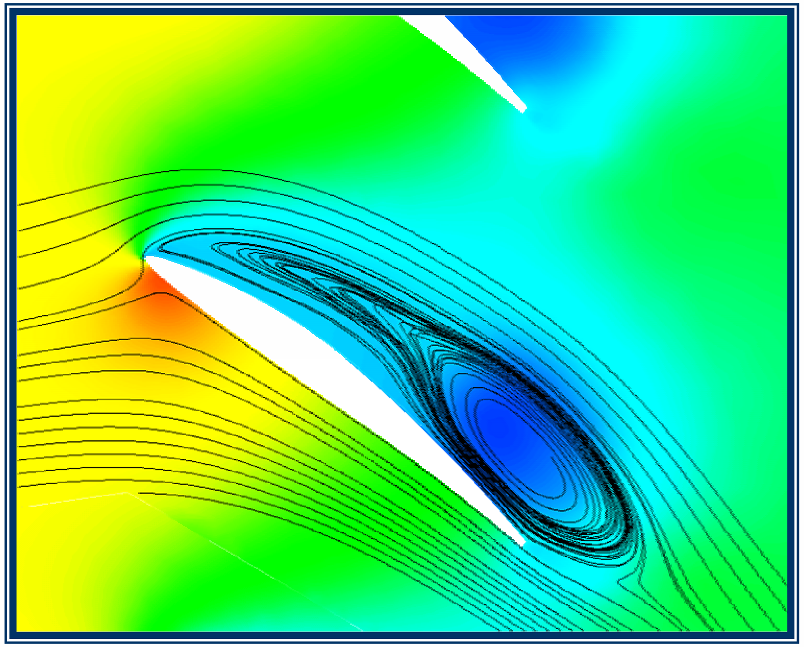


5. Results – 2D tandem cascade

- Fixed front blades: separation - streamlines



Separation, second cascade: realtime



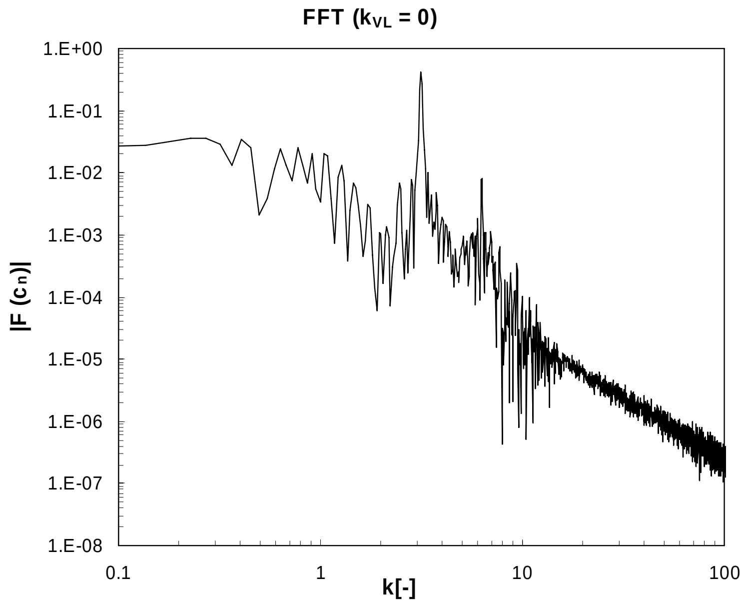
Separation, second cascade: time averaged

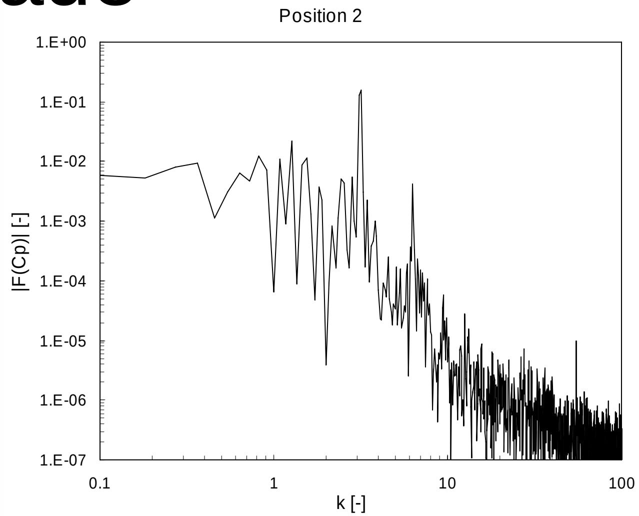
5. Results – 2D tandem cascade

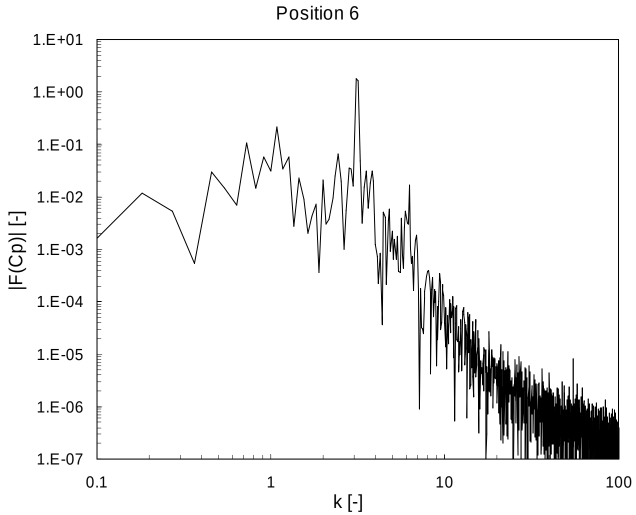
- Fixed front blades: frequency analysis

$$k = \frac{\pi\, f\, l}{c_0}$$

$$c_n = \frac{F_n}{\frac{1}{2} \cdot \rho \cdot A \cdot c_\infty^2}$$



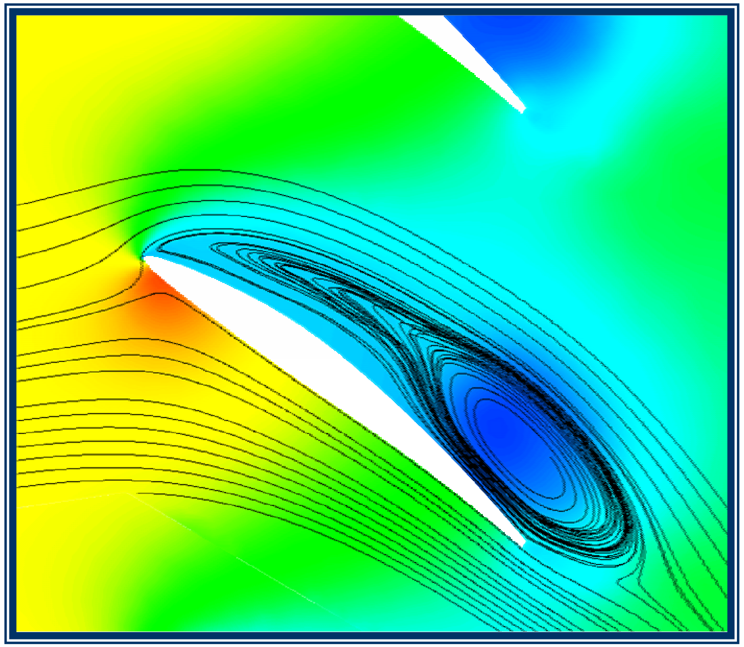




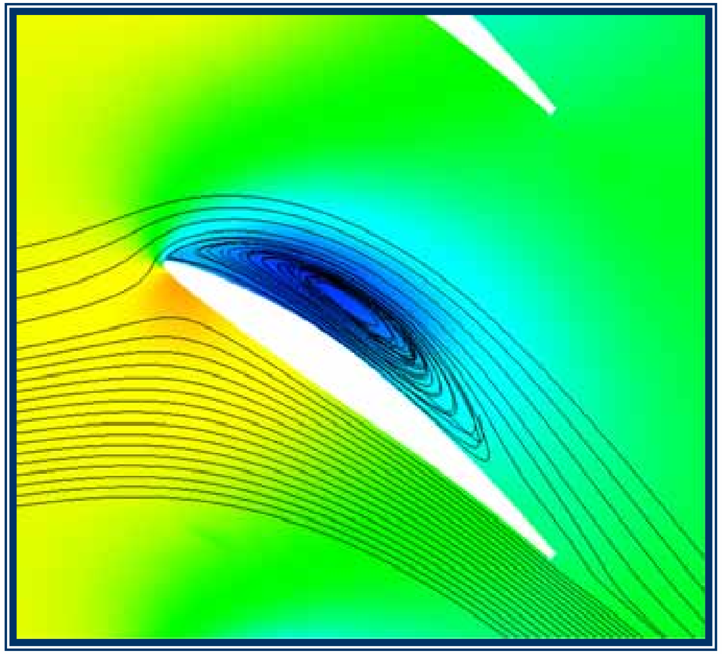
$k_{Eigen} = 3.125$

5. Results – 2D tandem cascade

- Pitching front blades: separation - streamlines



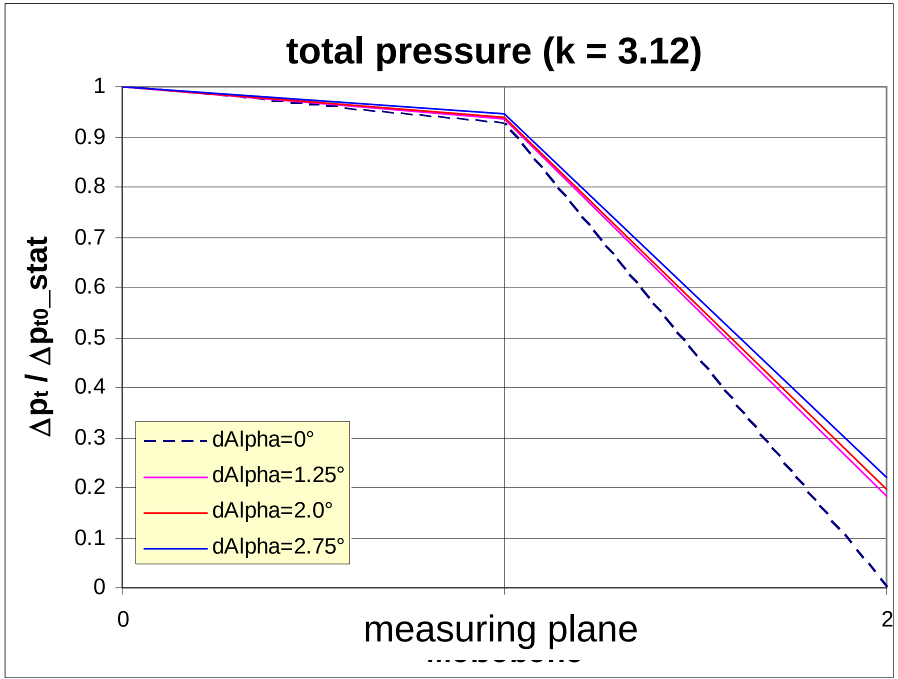
static front blades

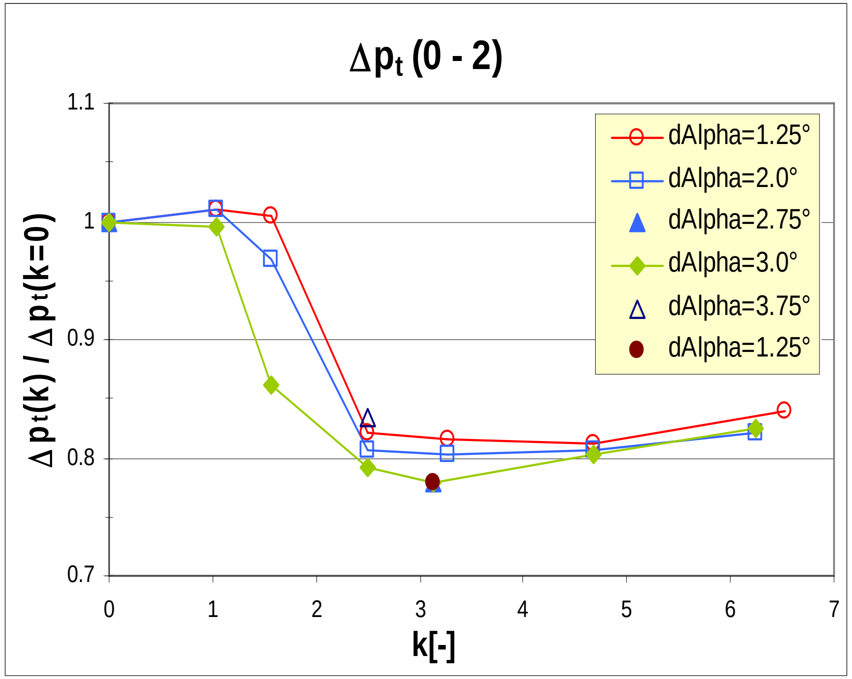


pitching front blades

5. Results – 2D tandem cascade

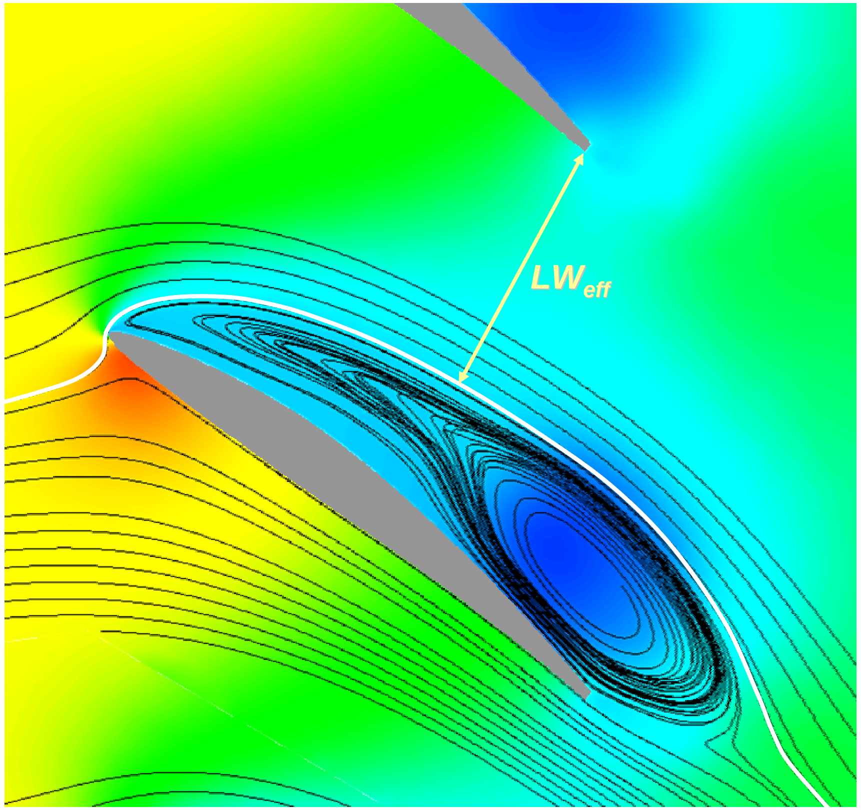
- Pitching front blades: influence on Δp_t





5. Results – 2D tandem cascade

- Pitching front blades: influence on Δp_t – interpretation



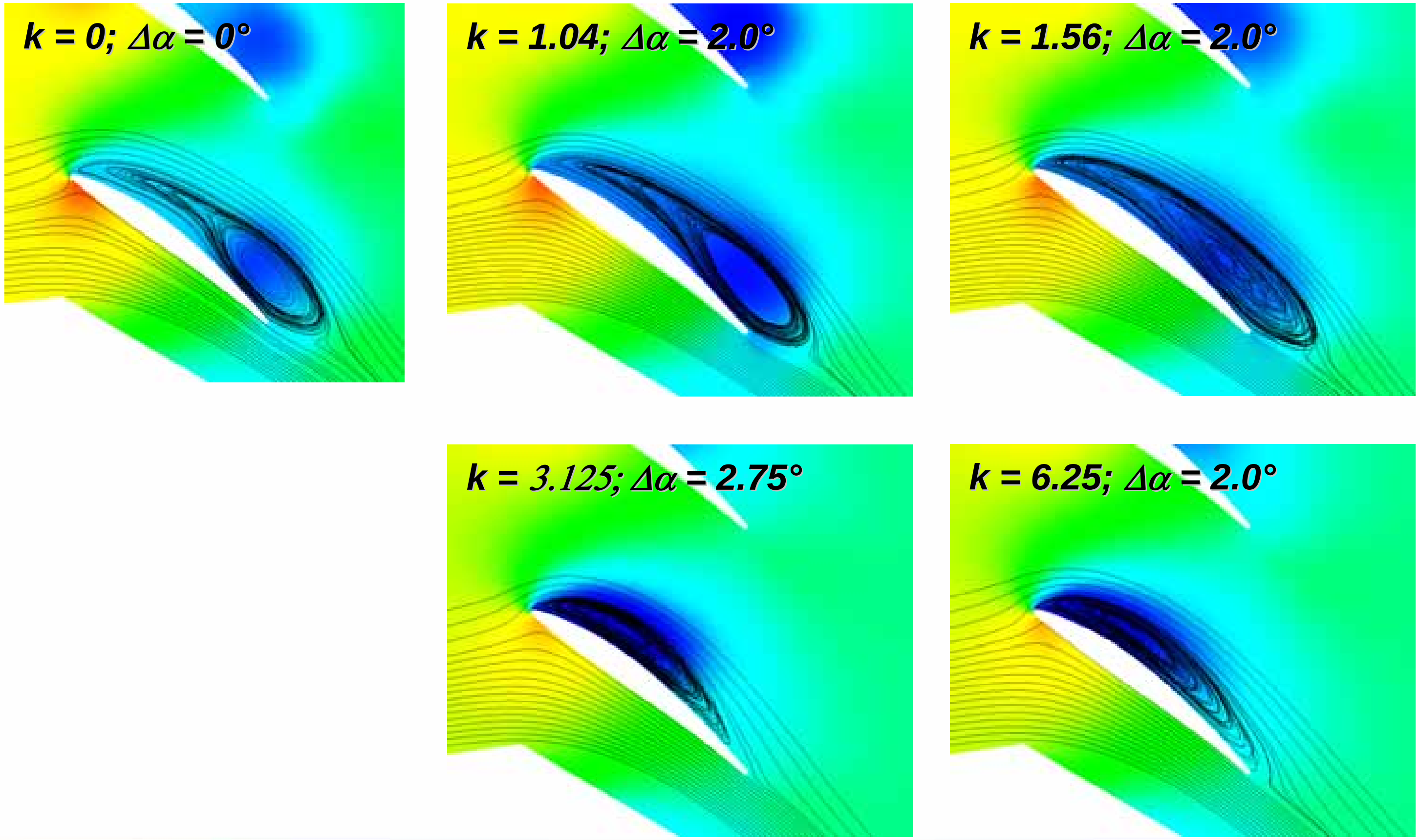
$$\Delta p_t = \frac{1}{2}\rho c^2 \varsigma = \frac{1}{2}\rho \frac{Q^2}{b^2 LW_{eff}^2}\varsigma$$

$$\Rightarrow \frac{\Delta p_{t1}}{\Delta p_{t0}} = \frac{\varsigma_1 \cdot LW_{eff\_0}^2}{\varsigma_0 \cdot LW_{eff\_1}^2} \approx \frac{LW_{eff\_0}^2}{LW_{eff\_1}^2}$$

	LW_0^2 / LW^2	$\Delta p_t / \Delta p_{t0}$
k = 1.04; Δα = 2.0°	1.0	1.0
k = 1.56; Δα = 2.0°	0.96	0.97
k = 3.12; Δα = 2.75°	0.80	0.78
k = 6.25; Δα = 2.0°	0.86	0.83

5. Results – 2D tandem cascade

- Pitching front blades: influence on Δpt – interpretation

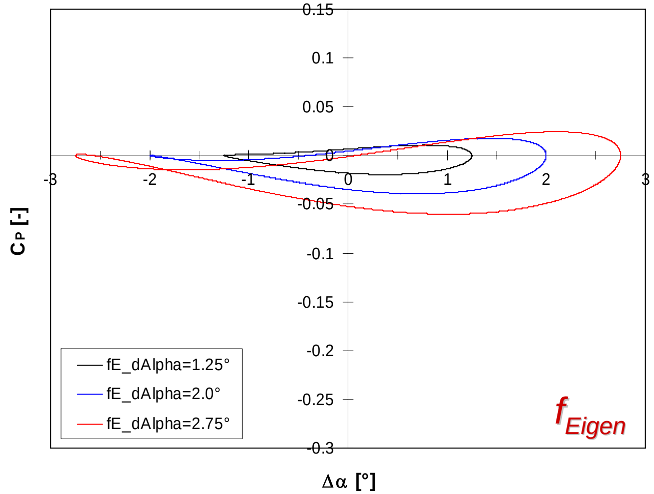


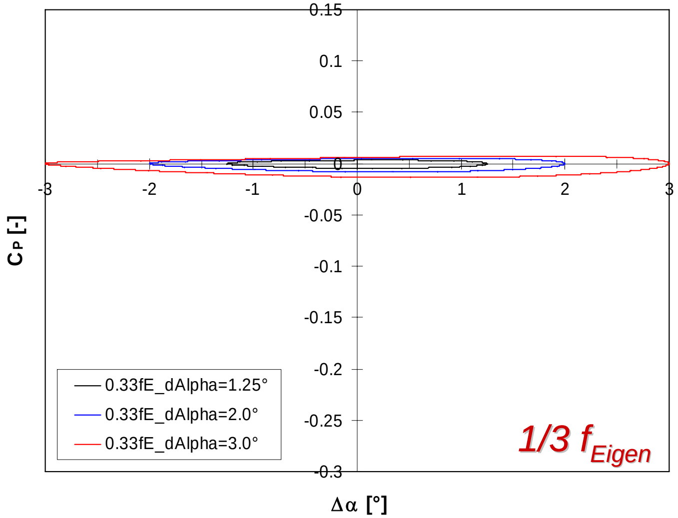
5. Results – 2D tandem cascade

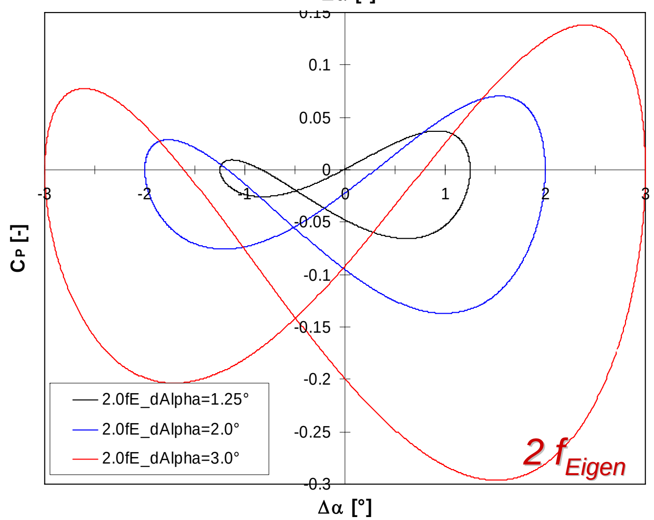
- Pitching front blades: influence on Δpt

  Induced energy – pitching power

$$\frac{E_{pitch1}}{E_{pitch0}} \sim \frac{(A_1\ f_1)^2}{(A_0\ f_0)^2}$$

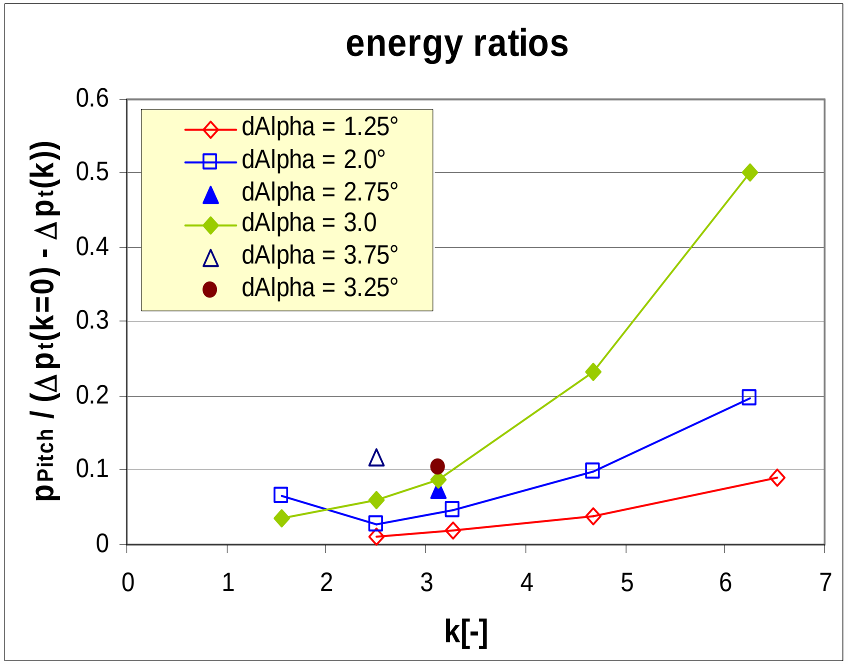


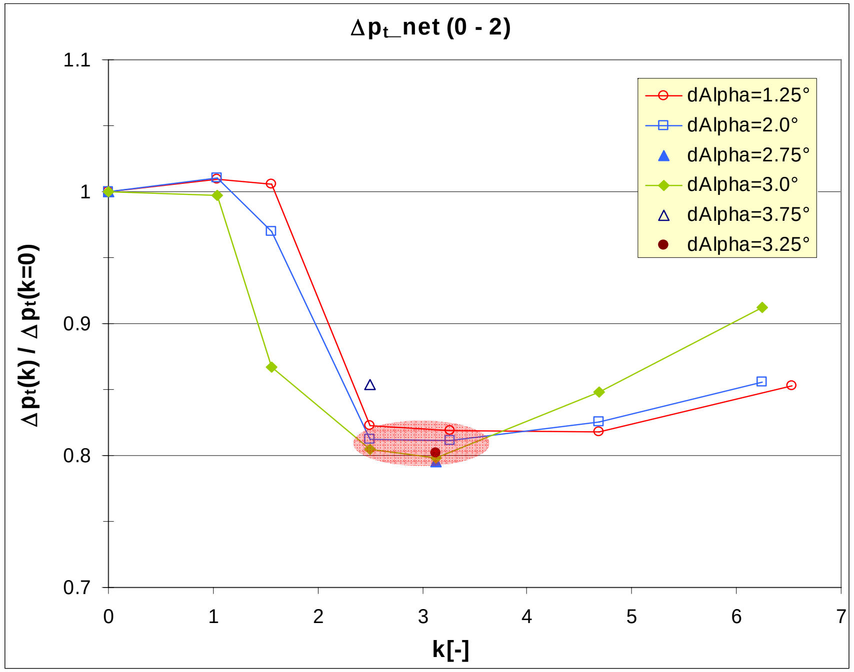




5. Results – 2D tandem cascade

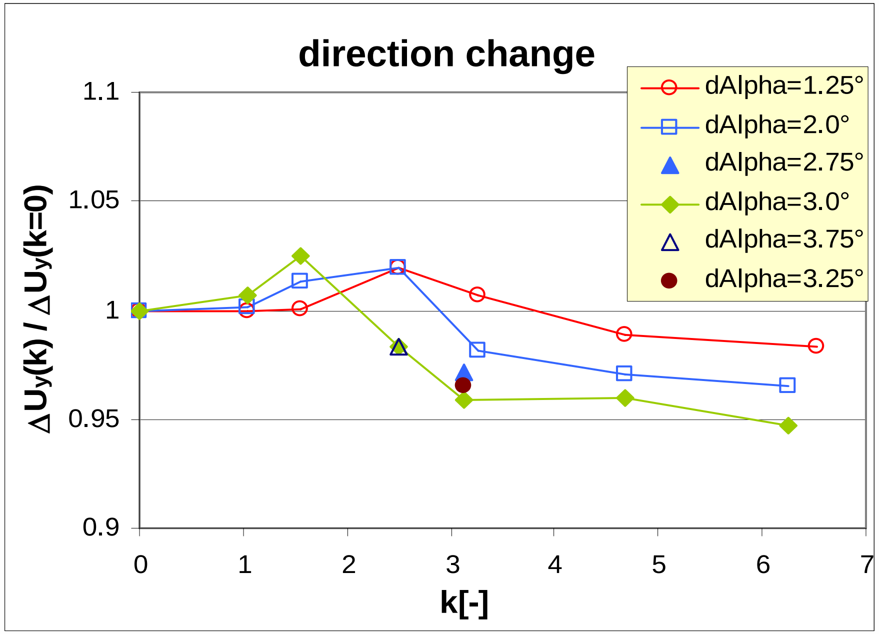
- Pitching front blades: influence on Δpt

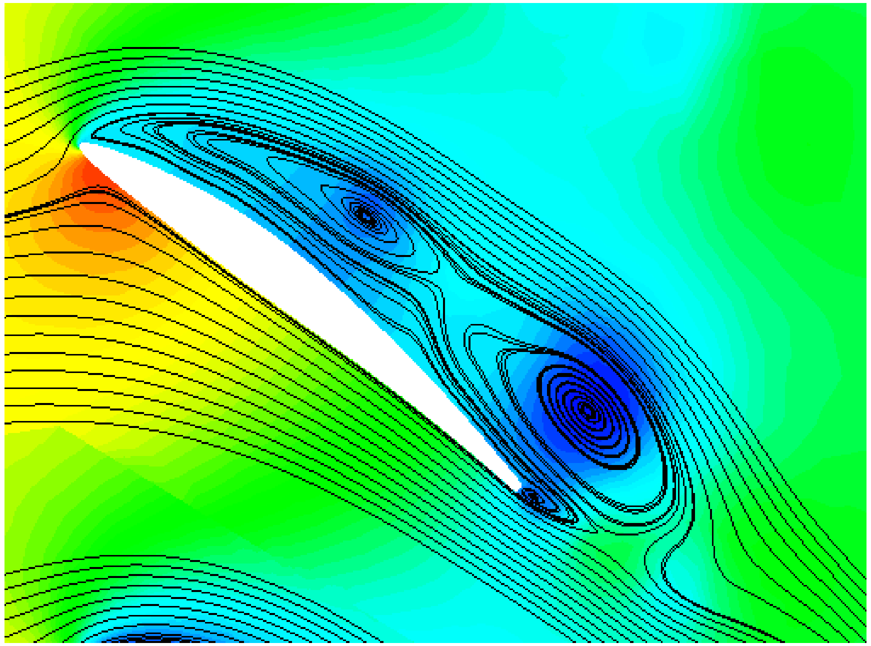




5. Results – 2D tandem cascade

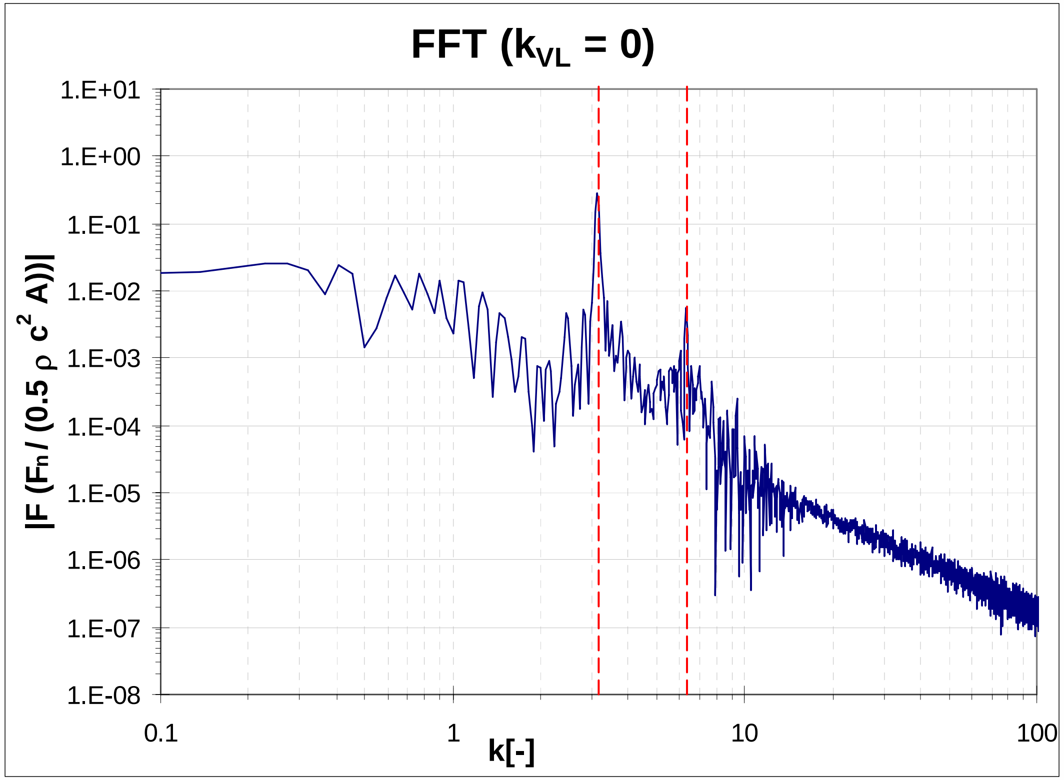
- Pitching front blades: influence on the direction change





5. Results – 2D tandem cascade

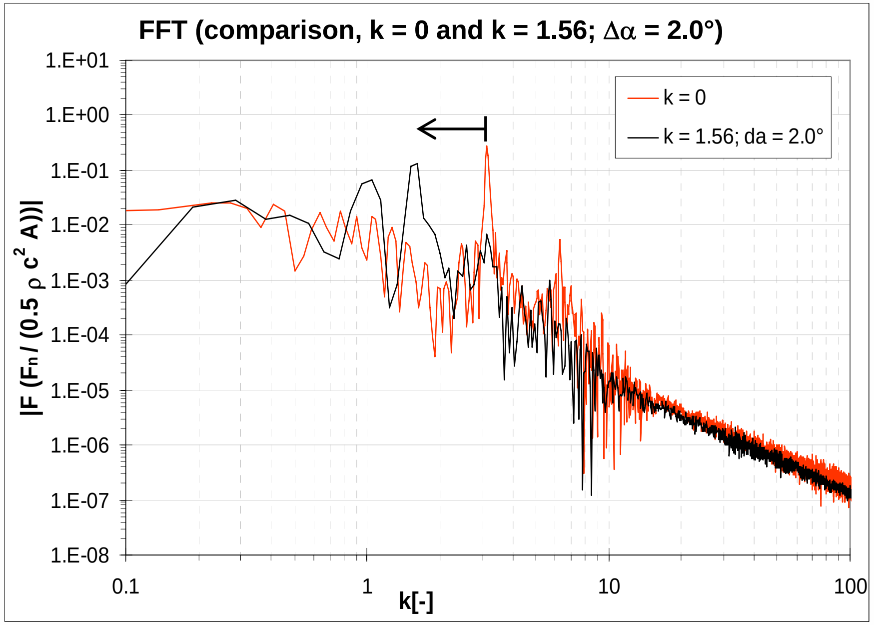
- Pitching front blades: influence on the frequencies

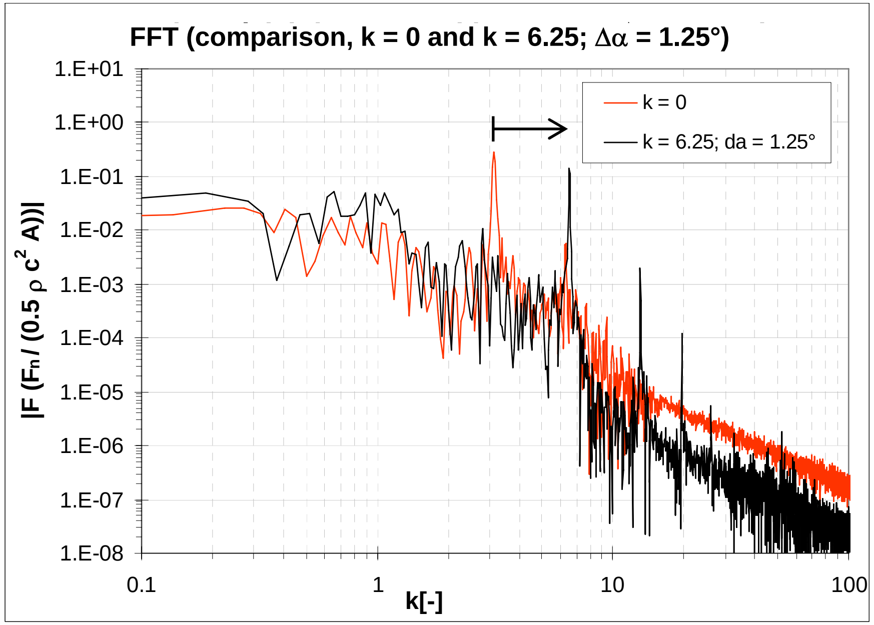


5. Results – 2D tandem cascade

- Pitching front blades: frequency shifting

Normal force

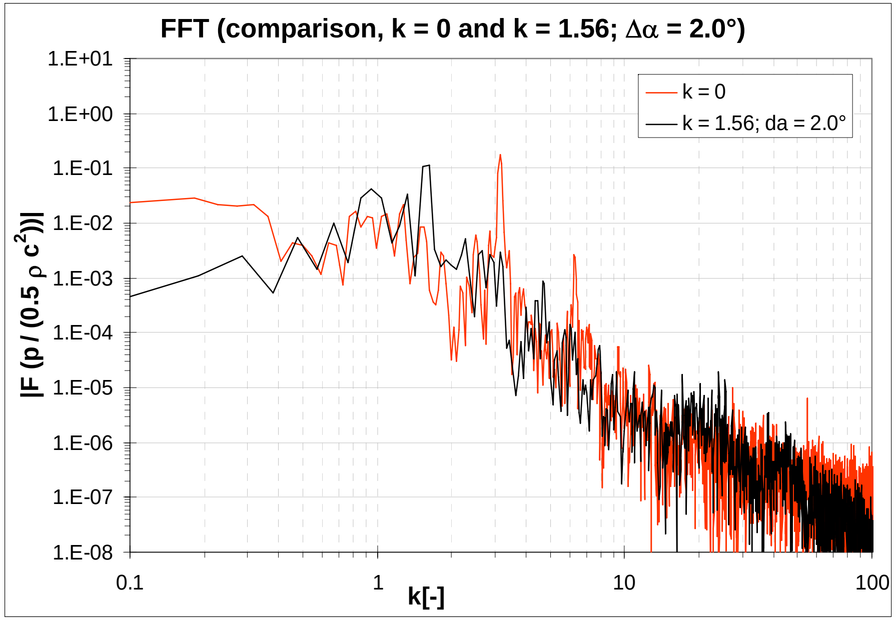


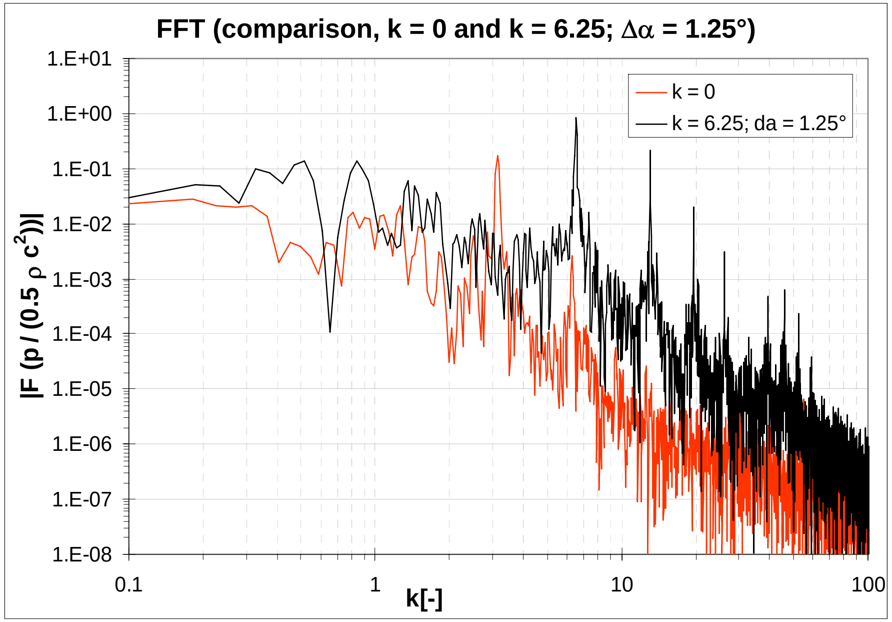


5. Results – 2D tandem cascade

- Pitching front blades: frequency shifting

Static pressure at measuring point 2

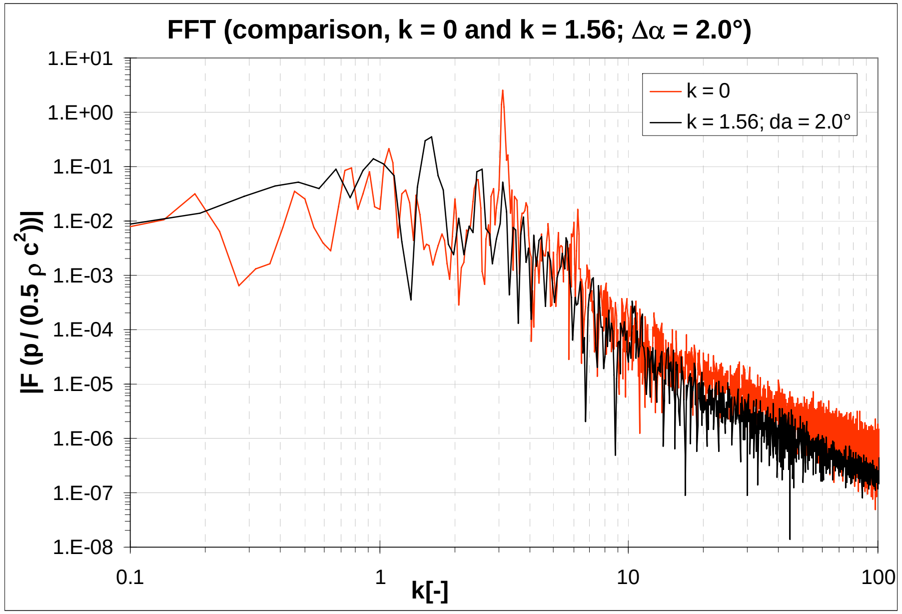


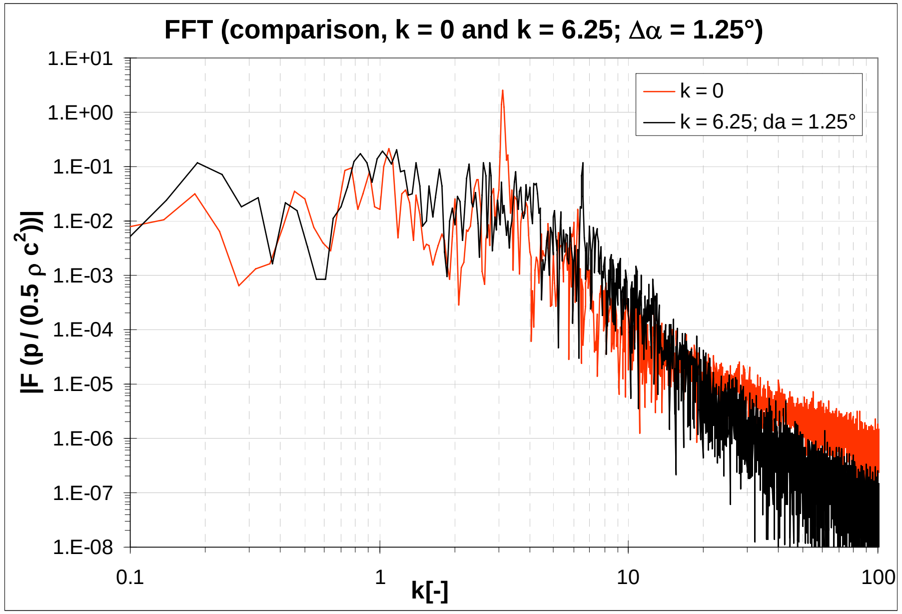


5. Results – 2D tandem cascade

- Pitching front blades: frequency shifting

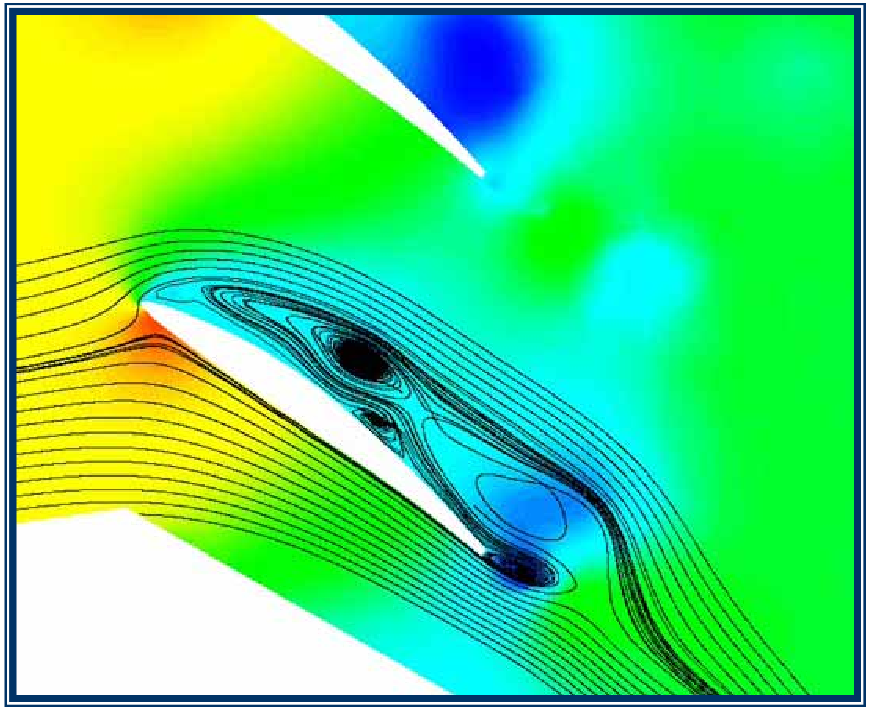
Static pressure at measuring point 6



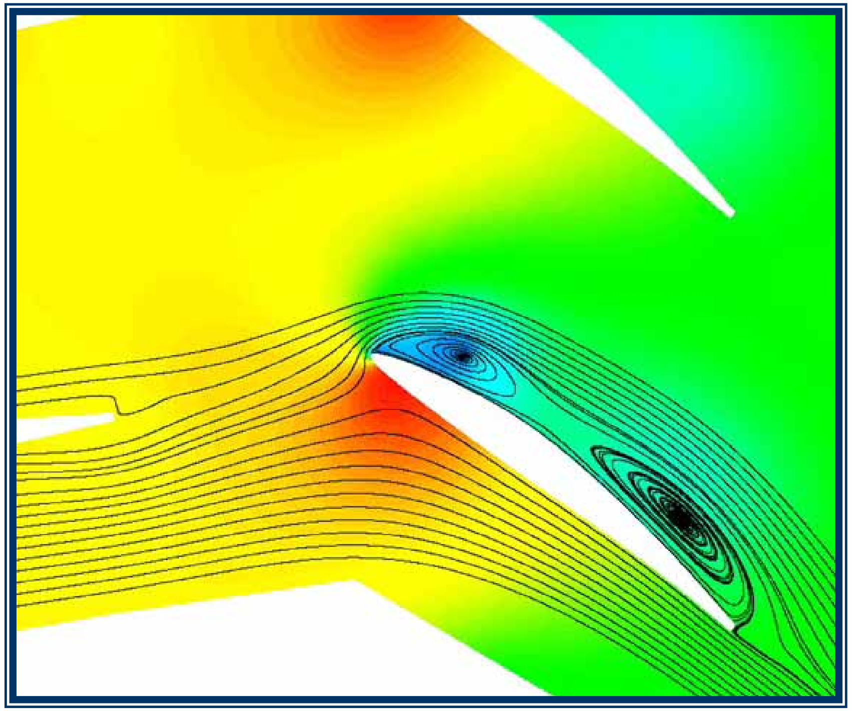


5. Results – 2D tandem cascade

- Animations



Static front blades, realtime.



Pitching front blades, periodic averaged flow.

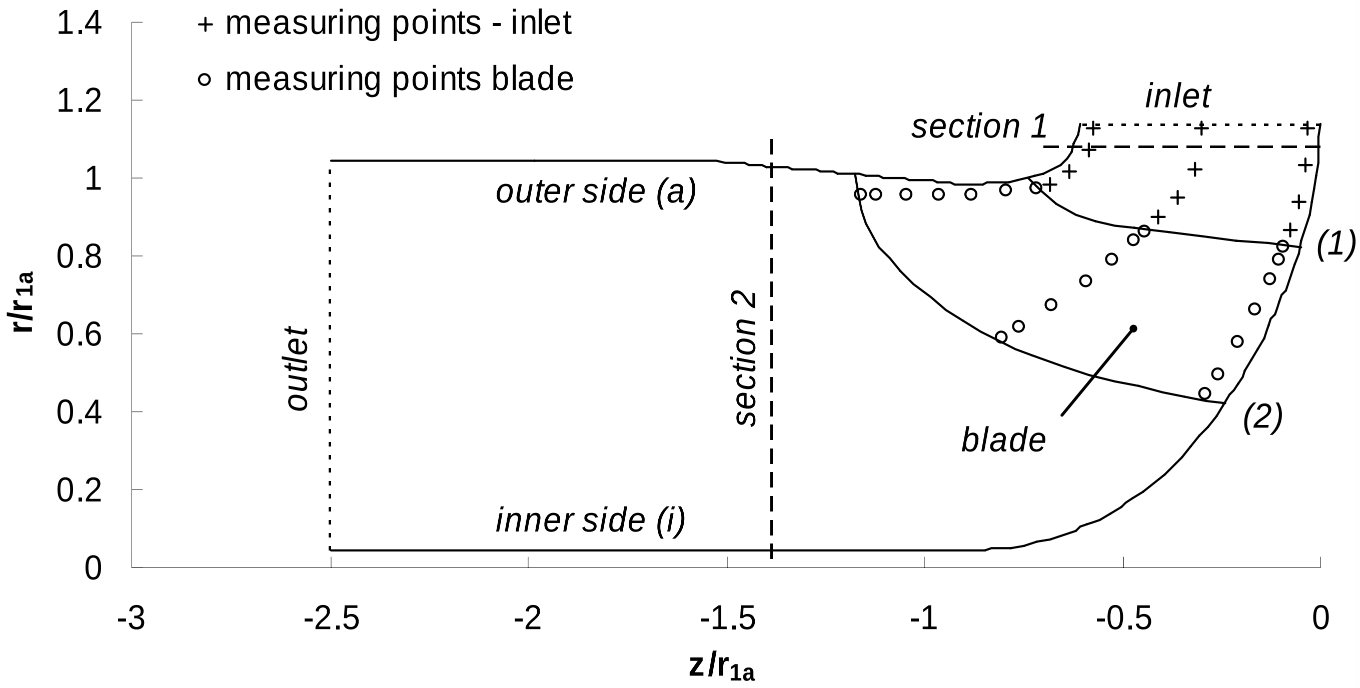
6. Results – 3D Francis turbine runner

- Geometry

$q = Q/Q_{opt} = 0.55$

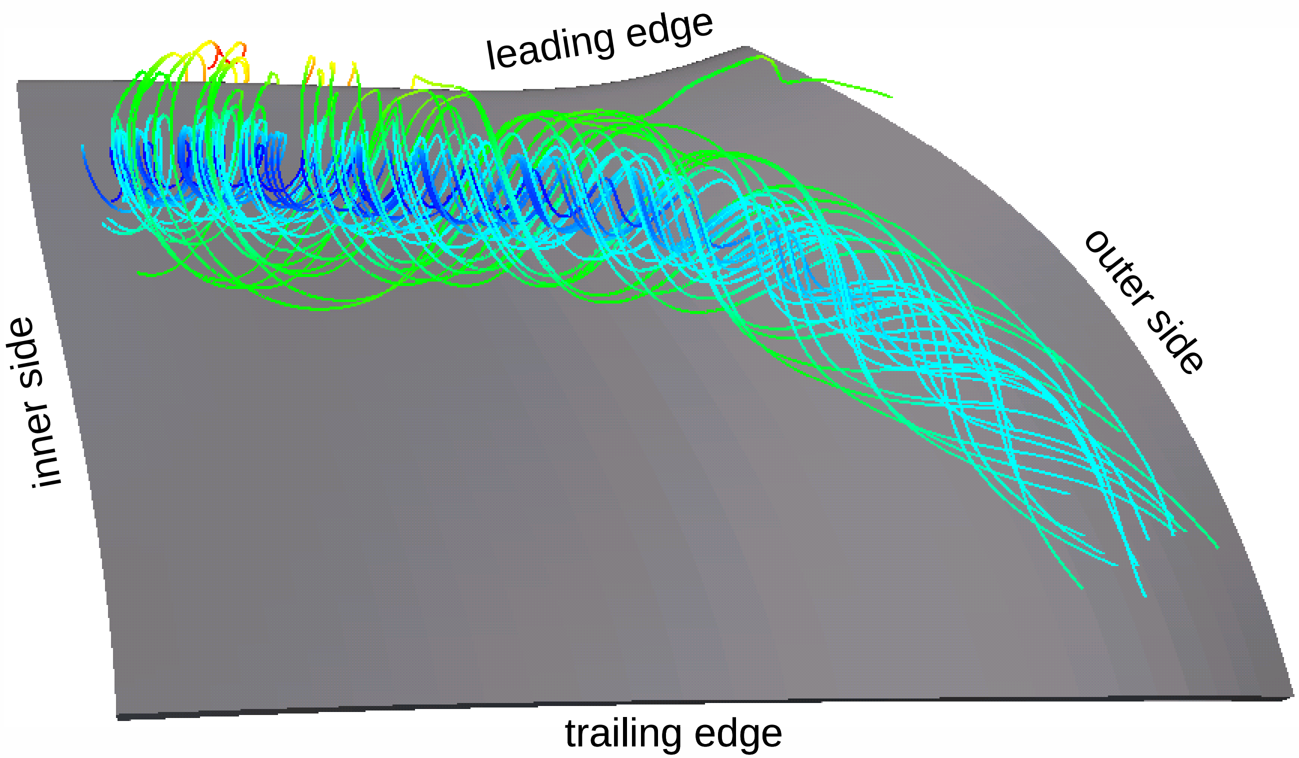
$n_q = 85\ min^{-1}$

$$\frac{l_c \cdot f}{u_c} < 0.1$$



6. Results – 3D Francis turbine runner

- Fixed flow to blades – separation at the leading edge



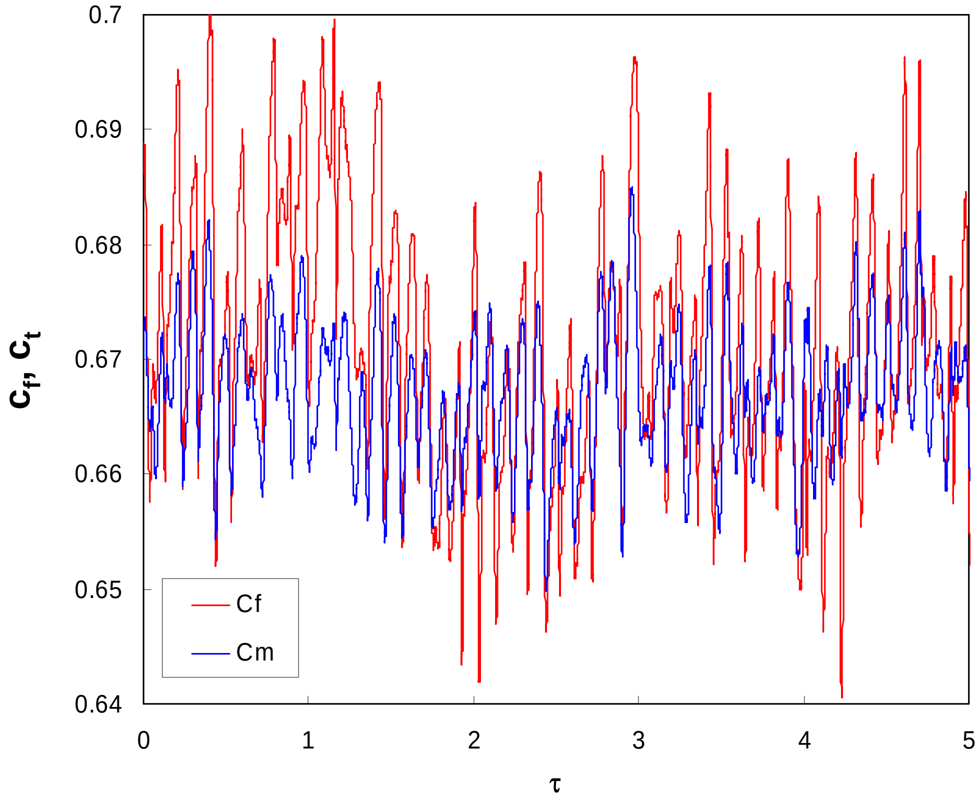
6. Results – 3D Francis turbine runner

- Fixed flow to blades – timeseries of force and torque

$$c_f = \frac{|F|}{\frac{\rho}{2} \cdot \omega^2 \cdot r_{1a}{}^4} \cdot N_{La}$$

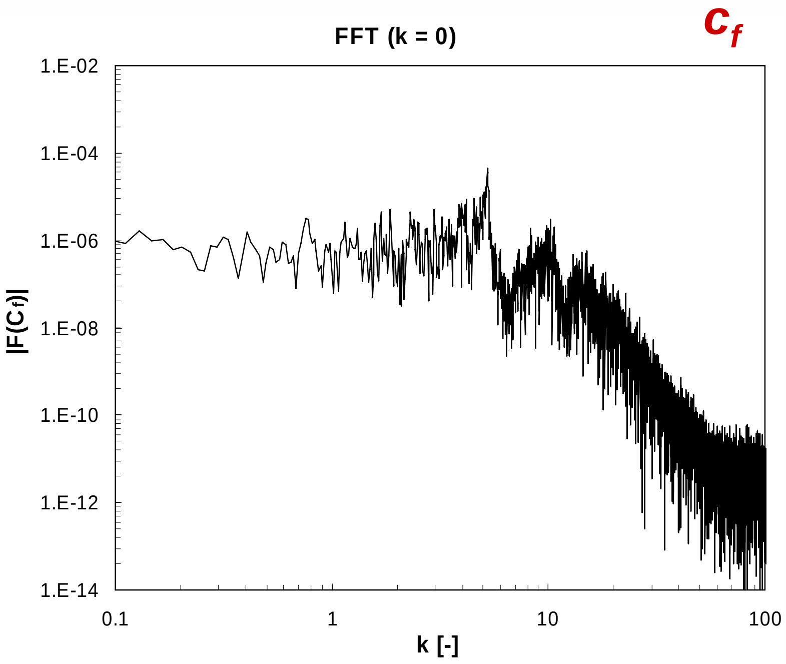
$$c_t = \frac{|T|}{\frac{\rho}{2} \cdot \omega^2 \cdot r_{1a}{}^5} \cdot N_{La}$$

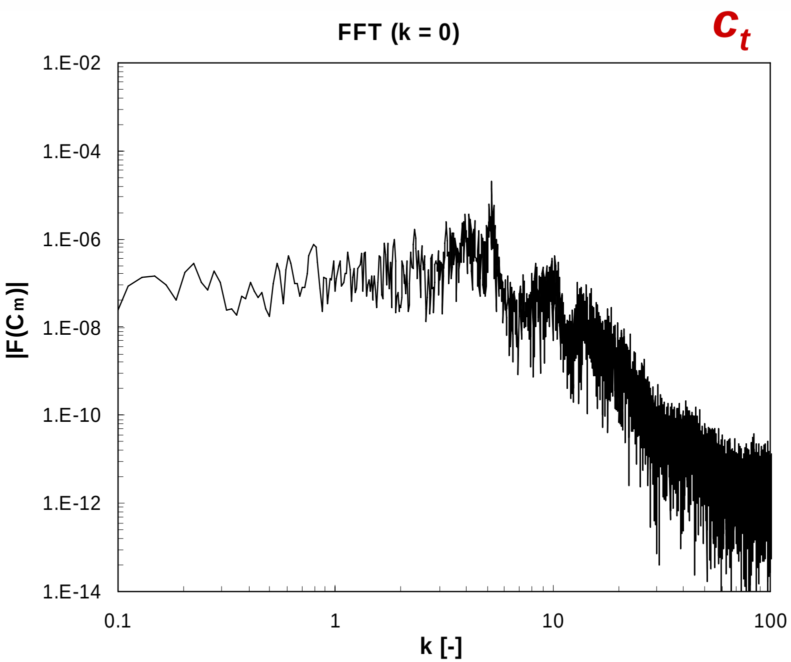
$$\tau = t \cdot \frac{\omega}{2\pi}$$



6. Results – 3D Francis turbine runner

- Fixed flow to blades – frequency analysis
  Axial force and torque

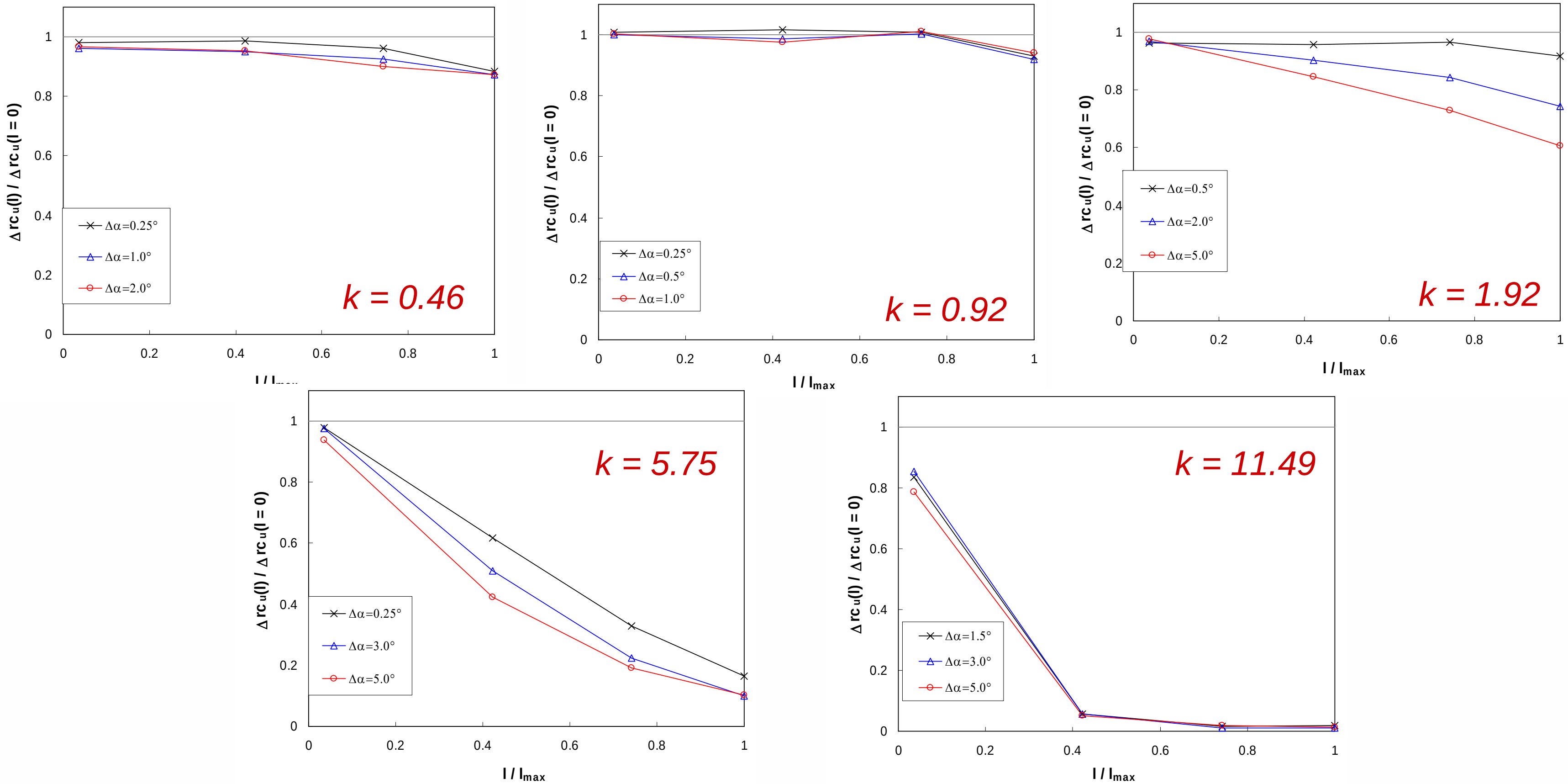




$k_{Eigen} = 5.4$

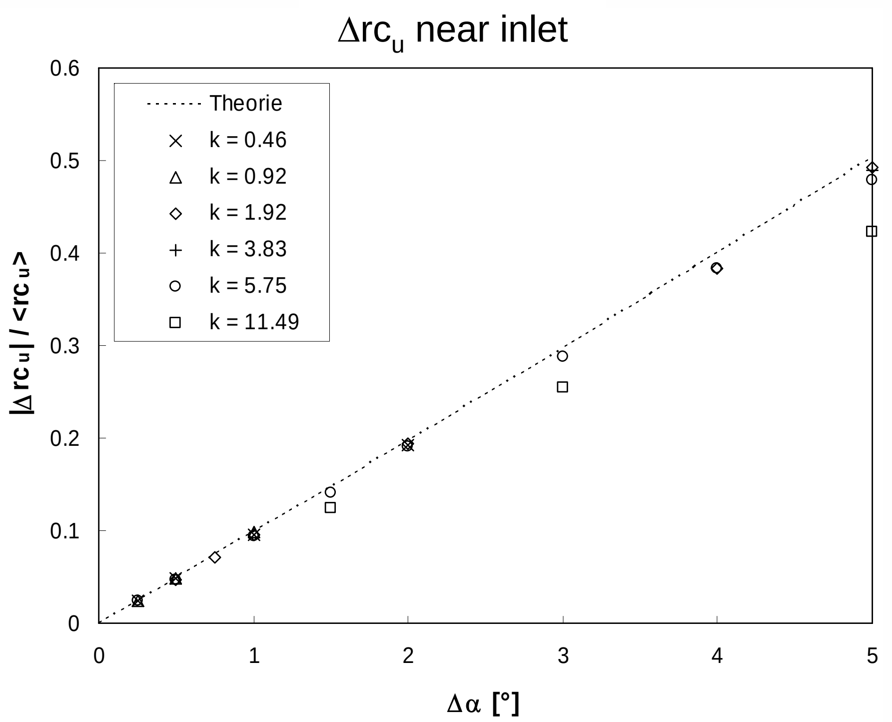
6. Results – 3D Francis turbine runner

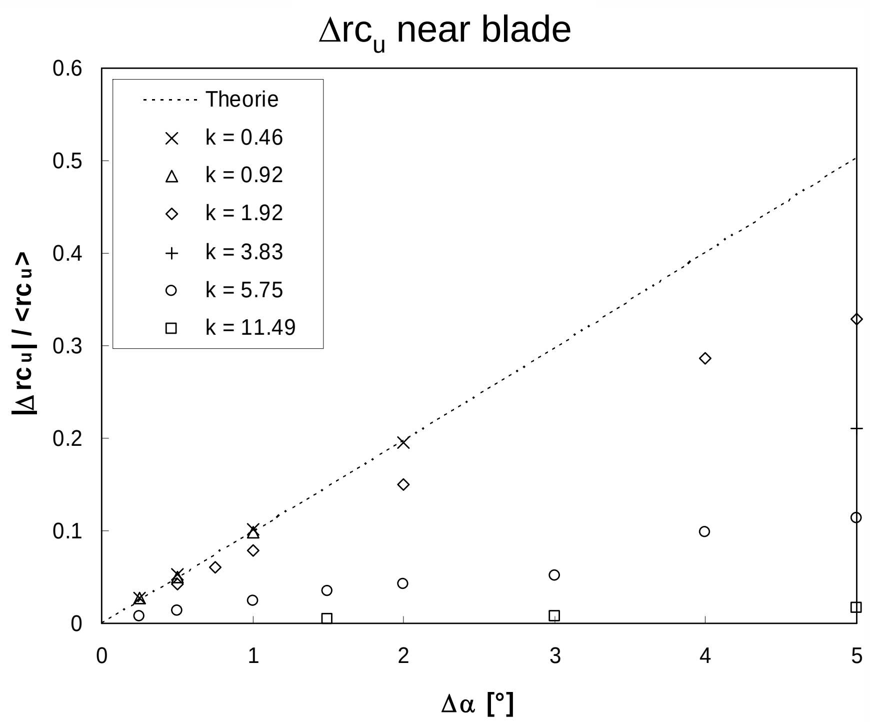
- Pitching flow to blades – inlet damping – averaged values



6. Results – 3D Francis turbine runner

- Pitching flow to blades – inlet damping – averaged values





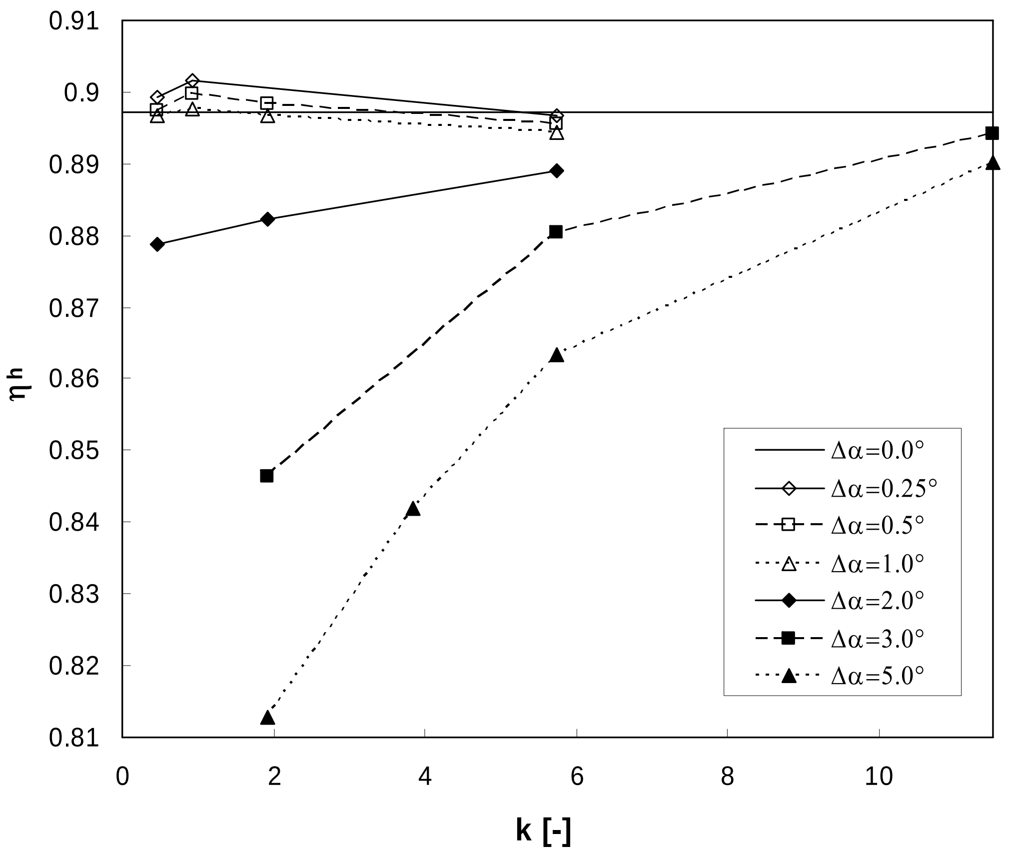
6. Results – 3D Francis turbine runner

- Pitching flow to blades – hydraulic efficiency

η_{pitch} = 90.2%

⇧

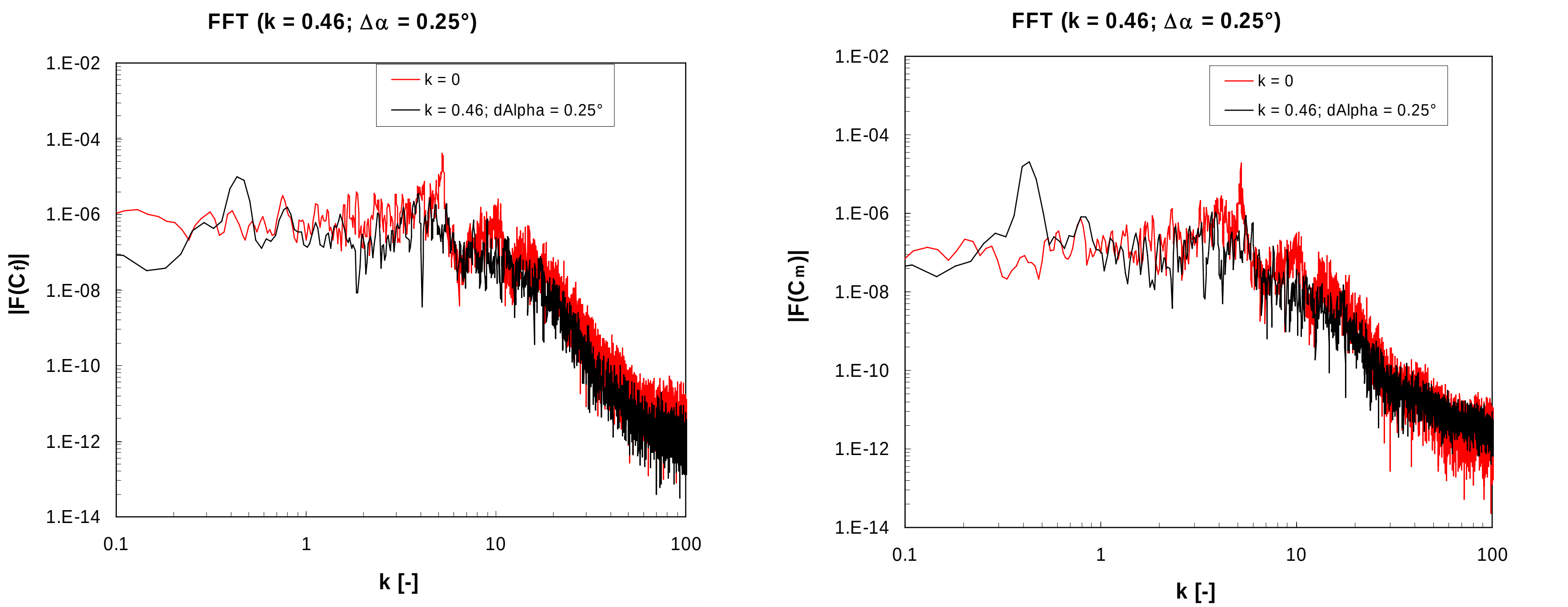
η_{fixed} = 89.7%



6. Results – 3D Francis turbine runner

- Pitching flow to blades – frequency shifting

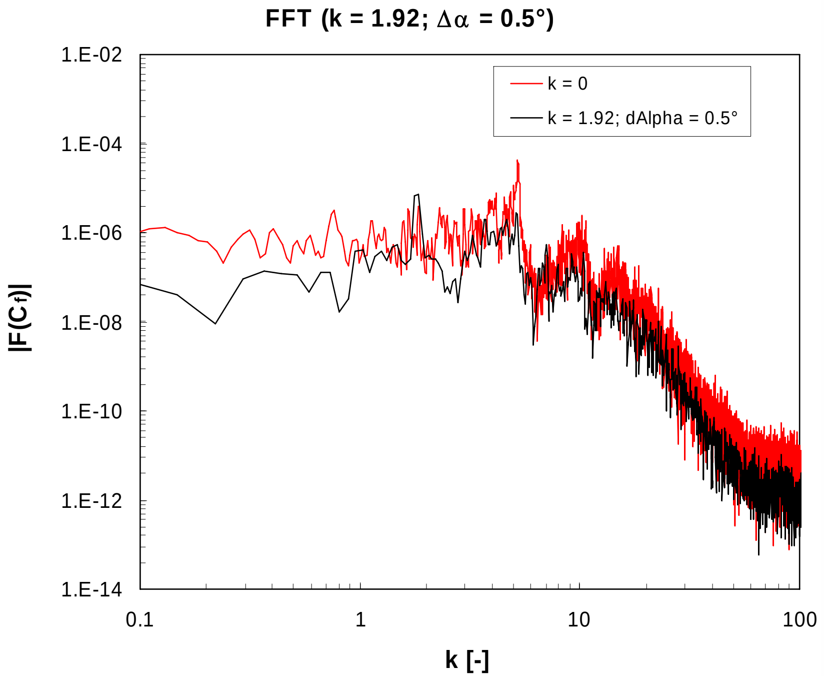
  Axial force and torque

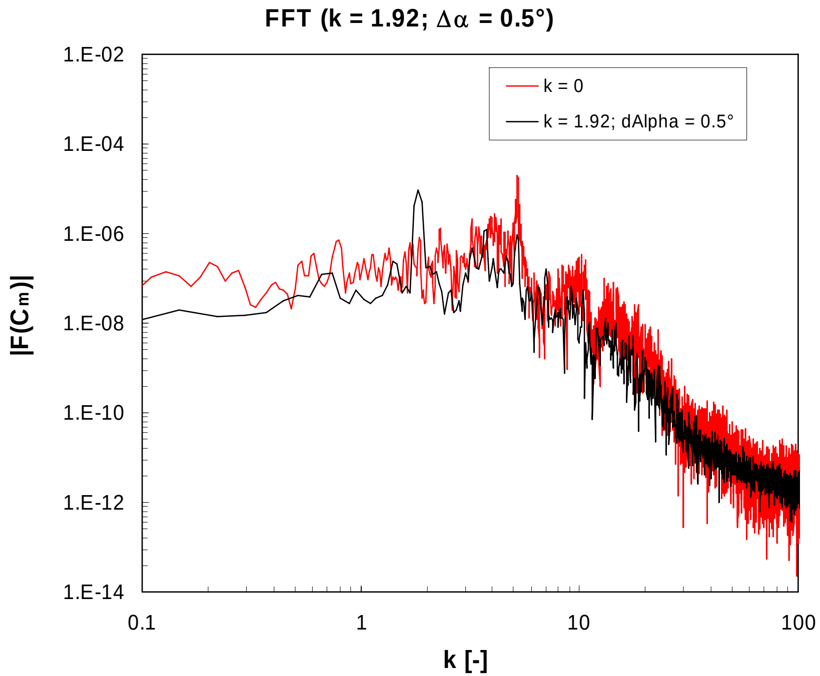


6. Results – 3D Francis turbine runner

- Pitching flow to blades – frequency shifting

  Axial force and torque

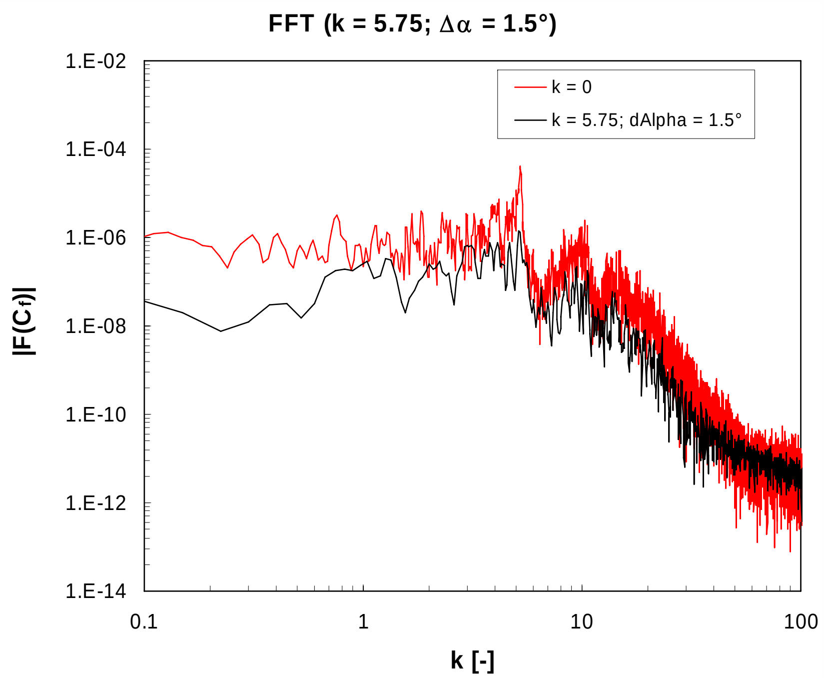


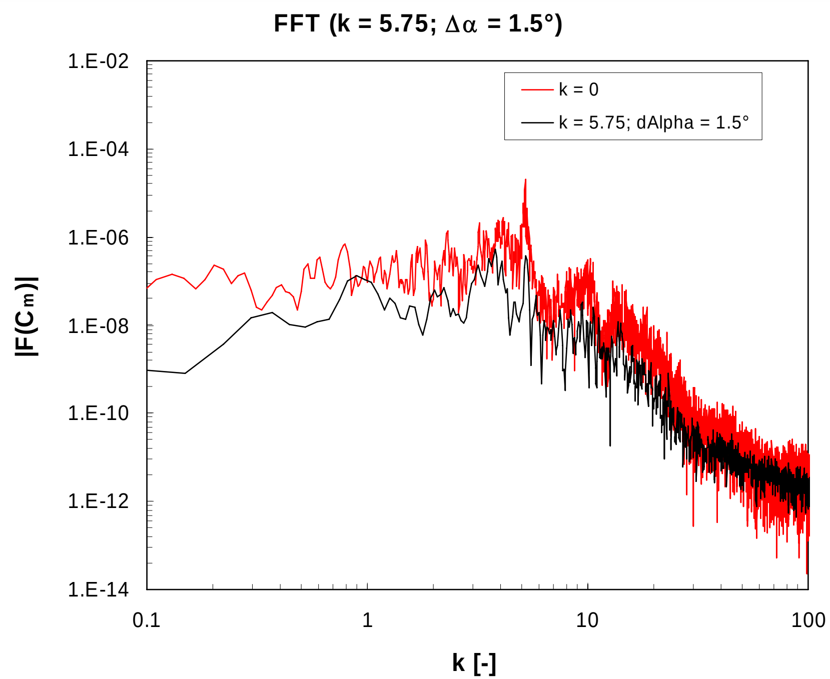


6. Results – 3D Francis turbine runner

- Pitching flow to blades – frequency shifting

Axial force and torque



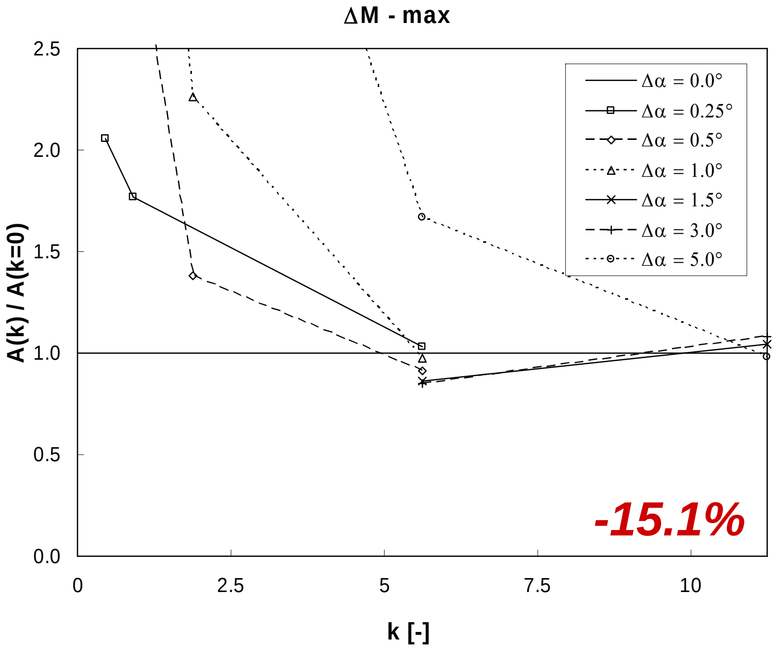


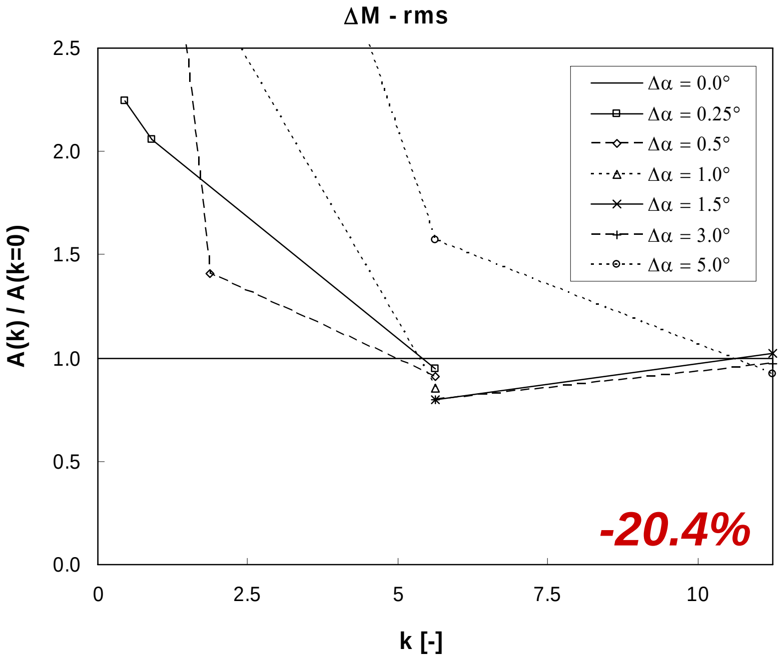
6. Results – 3D Francis turbine runner

- Pitching flow to blades – amplitude reduction

  Max and rms amplitudes of the torque

$$A_{rms} = \sqrt{\frac{1}{N}\sum_{n=1}^{N}(A_n)^2}$$



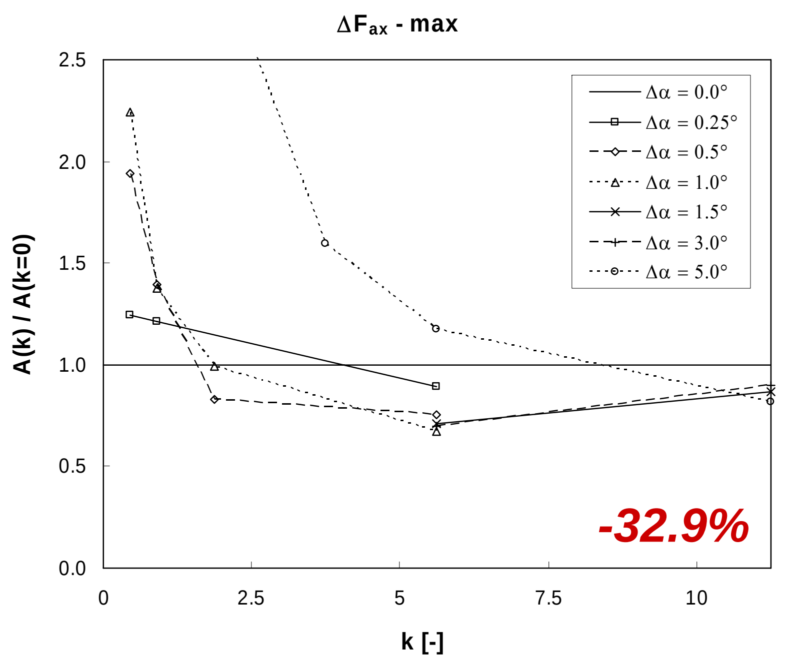


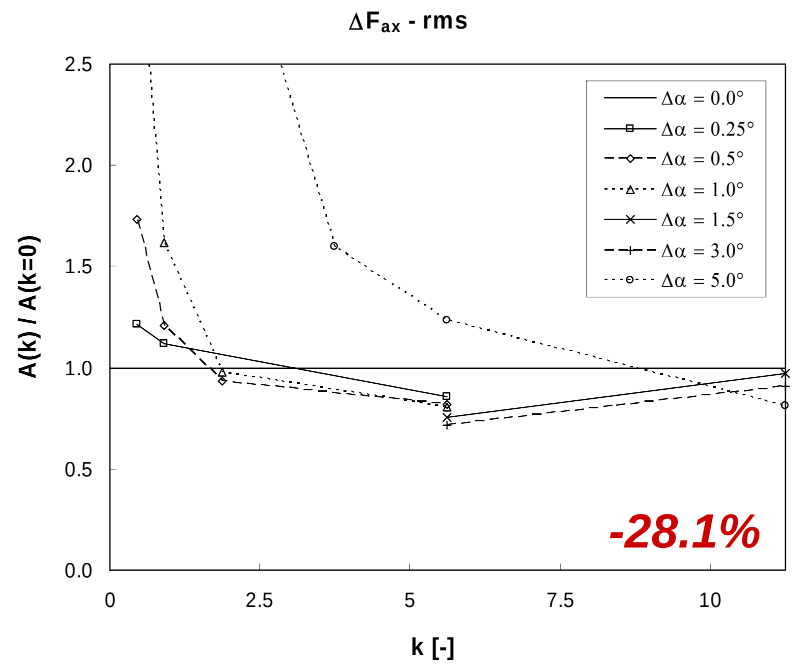
6. Results – 3D Francis turbine runner

- Pitching flow to blades – amplitude reduction

Max and rms amplitudes of the axial force

$$A_{rms} = \sqrt{\frac{1}{N}\sum_{n=1}^{N}(A_n)^2}$$





7. Conclusions

- Reducing the losses due to pitching guide vanes.
- Shifting the frequency maximum due to pitching guide vanes.
- Reducing the pressure fluctuations on the blade surface due to pitching guide vanes.
- Only LES / DES is appropriate to simulate the transient effects with adequate accuracy.

--- Thank you ---