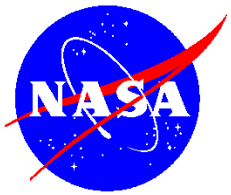

Study of Unsteady Flow in Transonic Compressors at Near Stall Operation With a Large Eddy Simulation

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Objectives

- Current RANS with various Turbulence models does not calculate unsteady flow features in transonic compressor adequately for many applications.
- LES can be applied for better calculation.
- Flow fields in two transonic compressors are used for evaluation.

Order of presentation

- Flow field in the Darmstadt's Rotor 1.
- NASA Rotor 37 Flow field.
- Concluding Remarks.

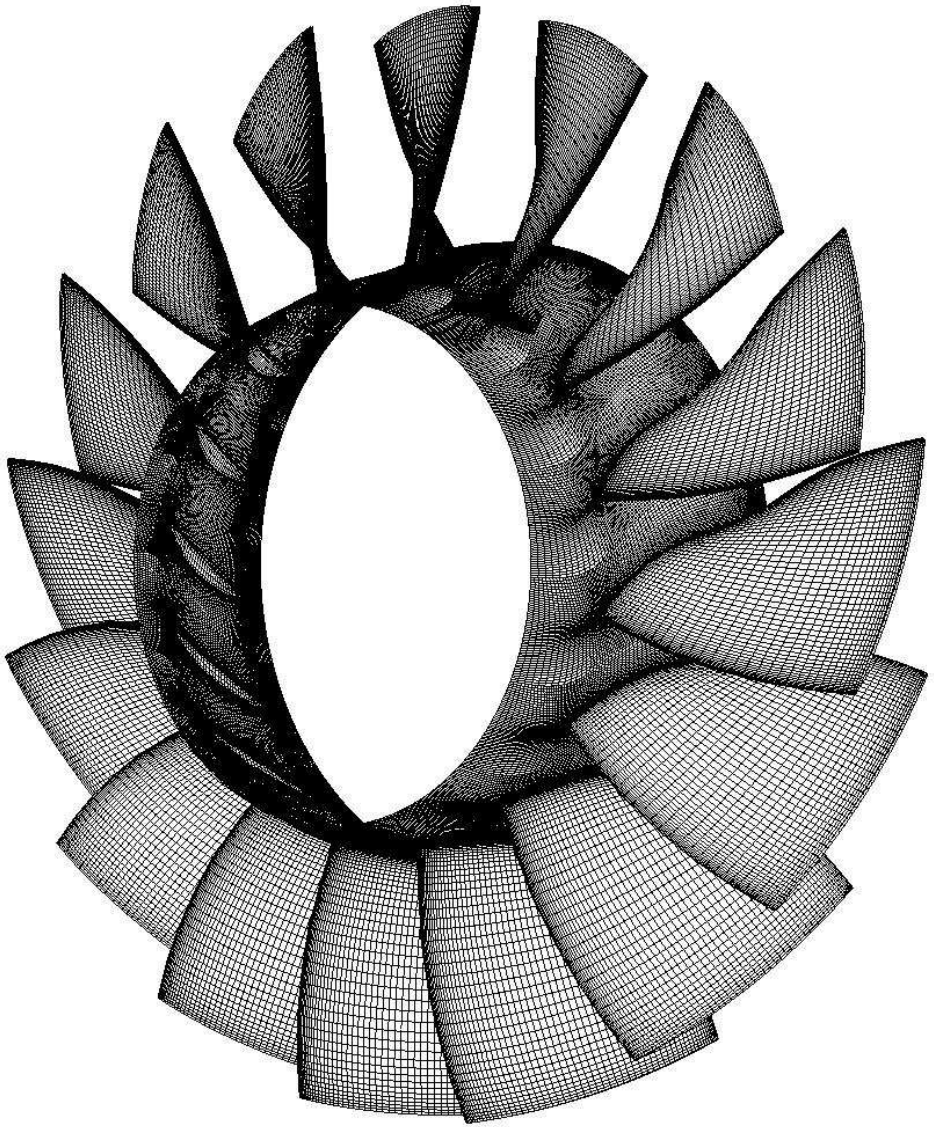
Numerical Procedure

- 3rd-order scheme for convection terms.
- 2nd-order central differencing for diffusion terms.
- Sub-iteration at each time step.
- Dynamic scheme for subgrid-scale model.

Computational grid

Single passage LES. (198x77x200)
Full annulus LES. (16x100x77x200)
NASA Columbia Cluster used.

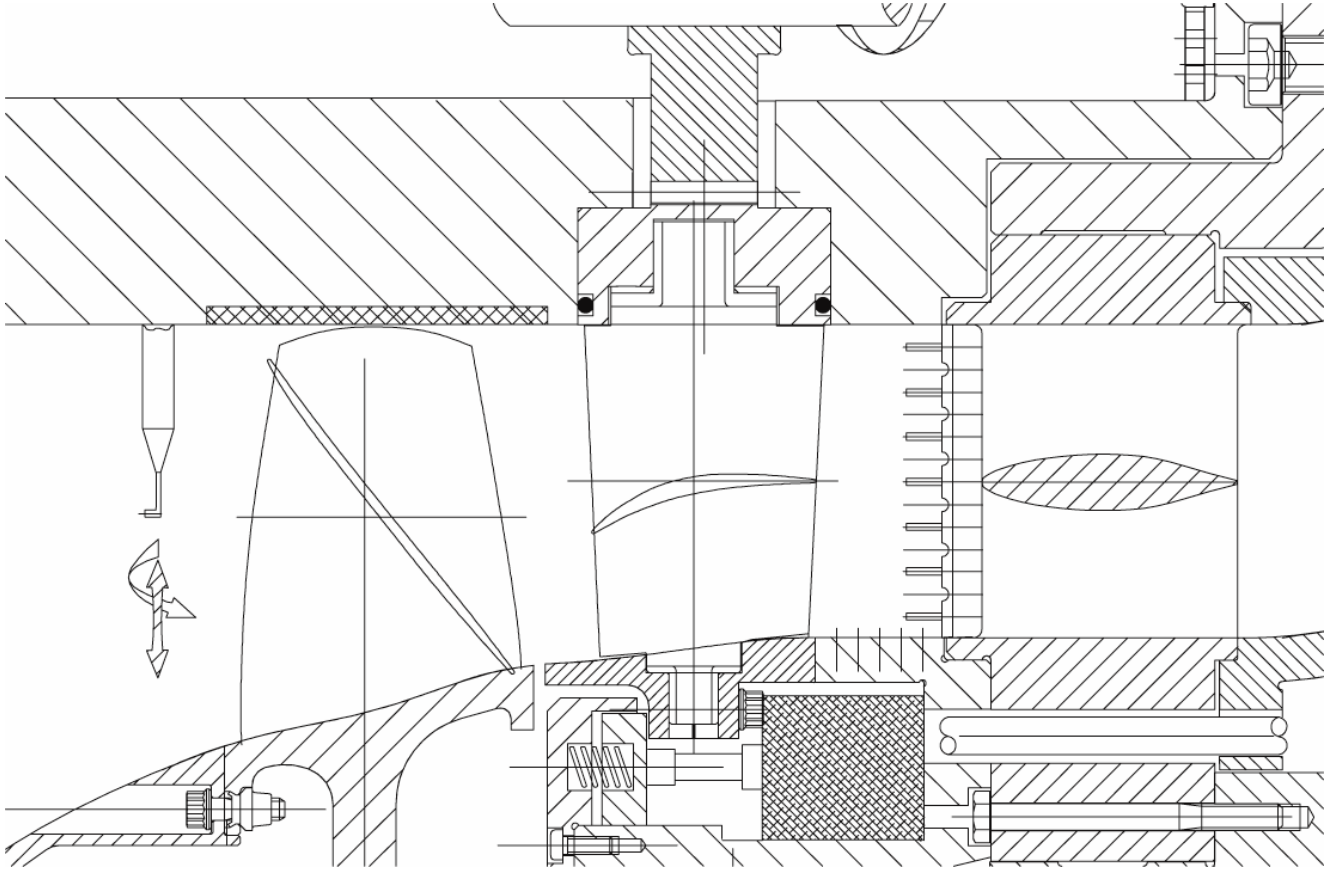
Full annulus grid near the rotor



Flow characteristics in transonic compressors at near stall operation

- Tip leakage vortex, passage shock, vortex shedding.
- Self-induced unsteady flow due to interactions among these.
- Non-synchronous frequencies/vibrations due to unsteadiness and instability observed.

Cross section of Darmstadt's compressor test rig

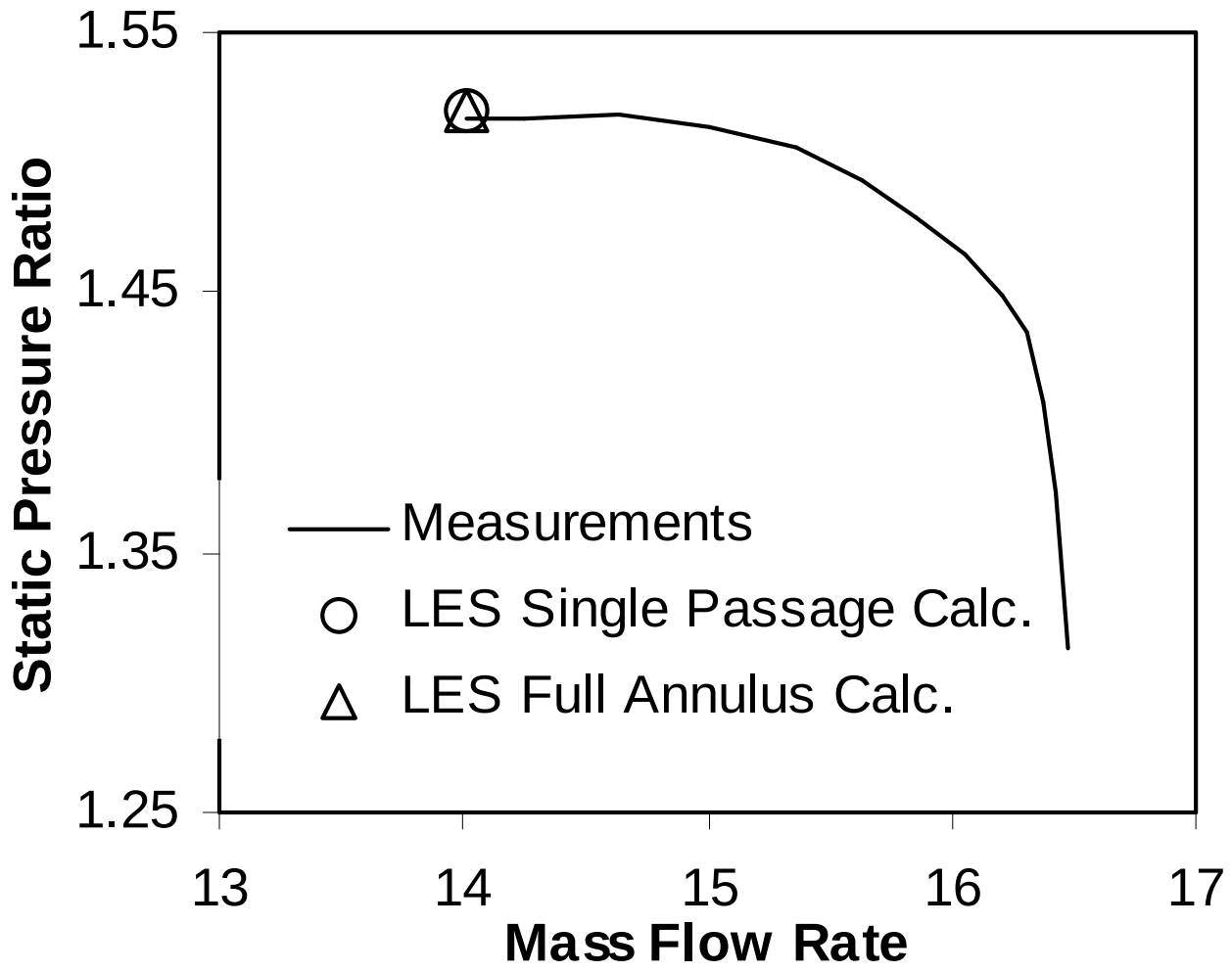


Darmstadt Rotor1

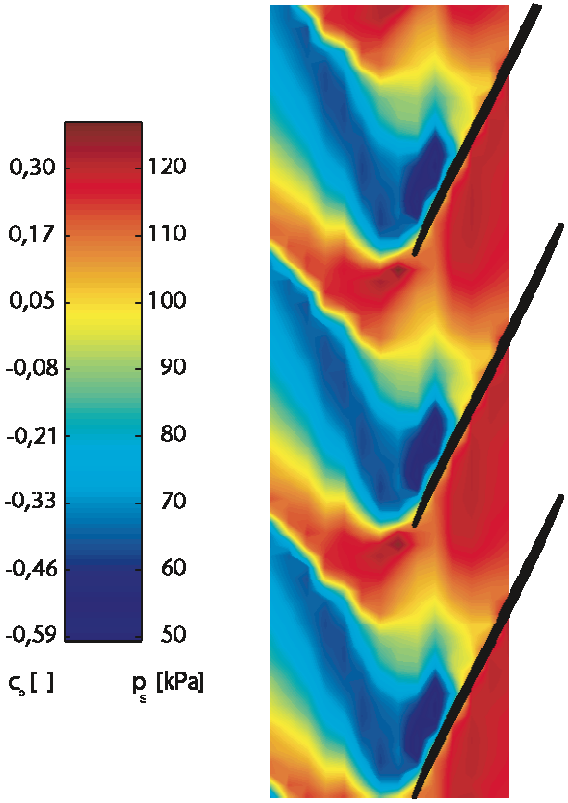
Darmstadt Rotor 1 design parameters

Pressure ratio	1.5
Corrected mass flow rate	16.0 kg/s
Corrected tip speed	398 m/s
Inlet relative Mach number at tip	1.35
Inlet relative Mach number at hub	0.70
Shaft speed	20,000 rpm
Tip diameter	0.38 m
Rotor mean aspect ratio	0.94
Rotor solidity (hub/mid/tip)	1.9/1.5/1.2

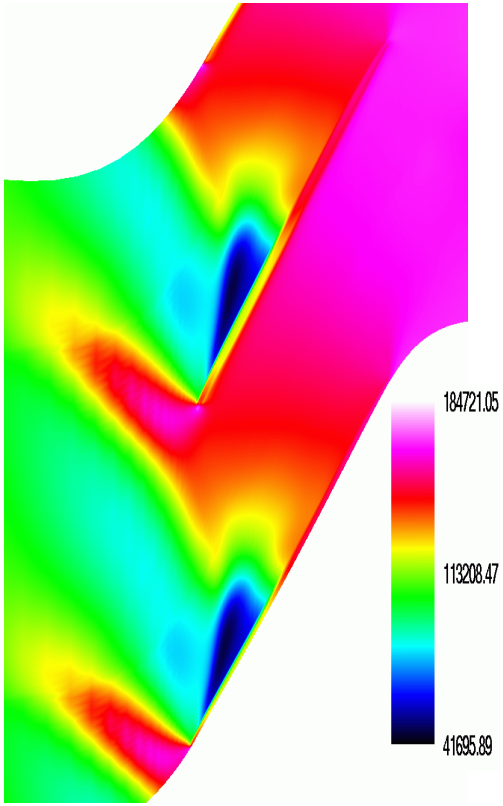
Pressure rise characteristics of the rotor



Casing static pressure near stall

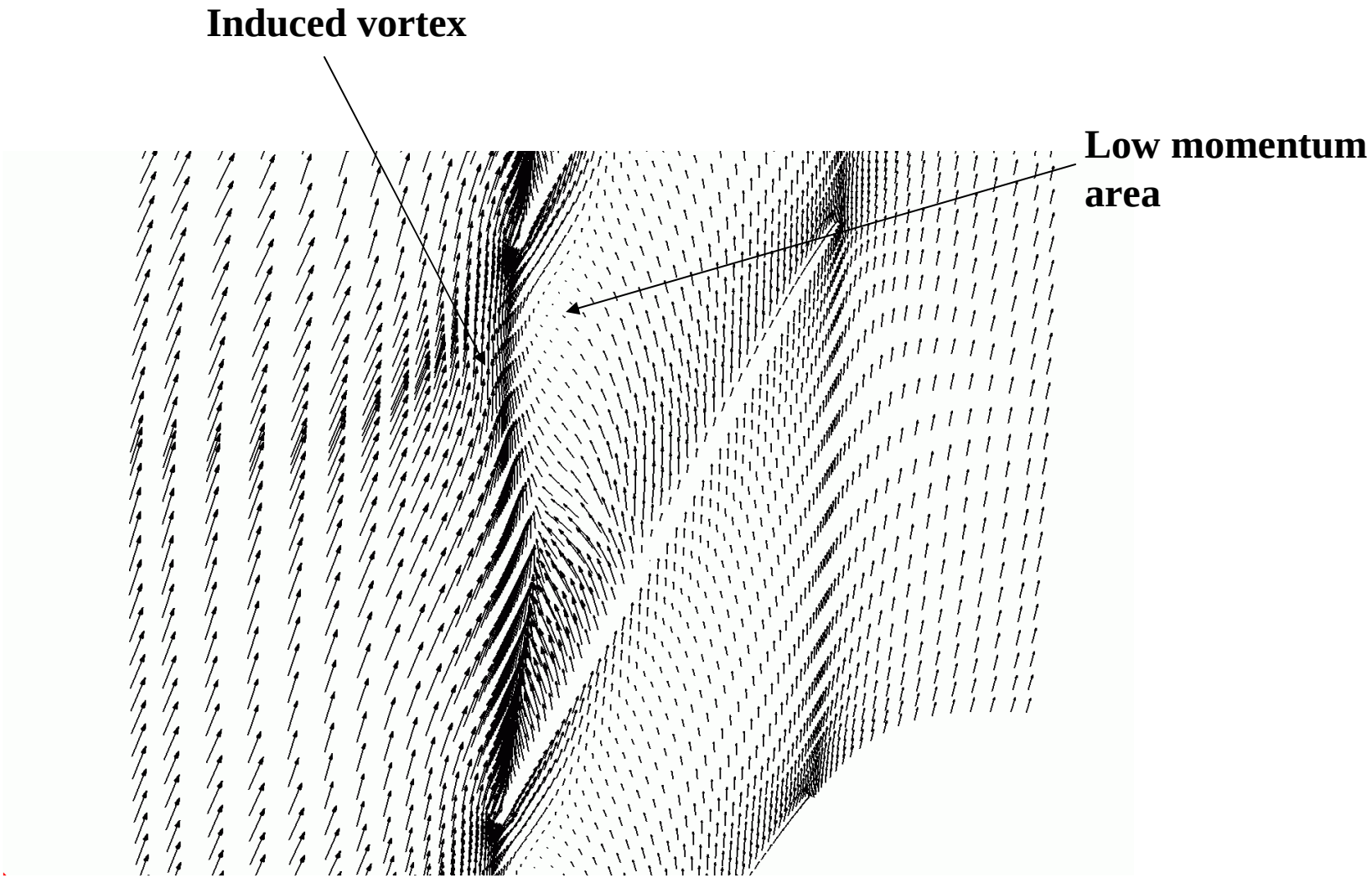


measurement

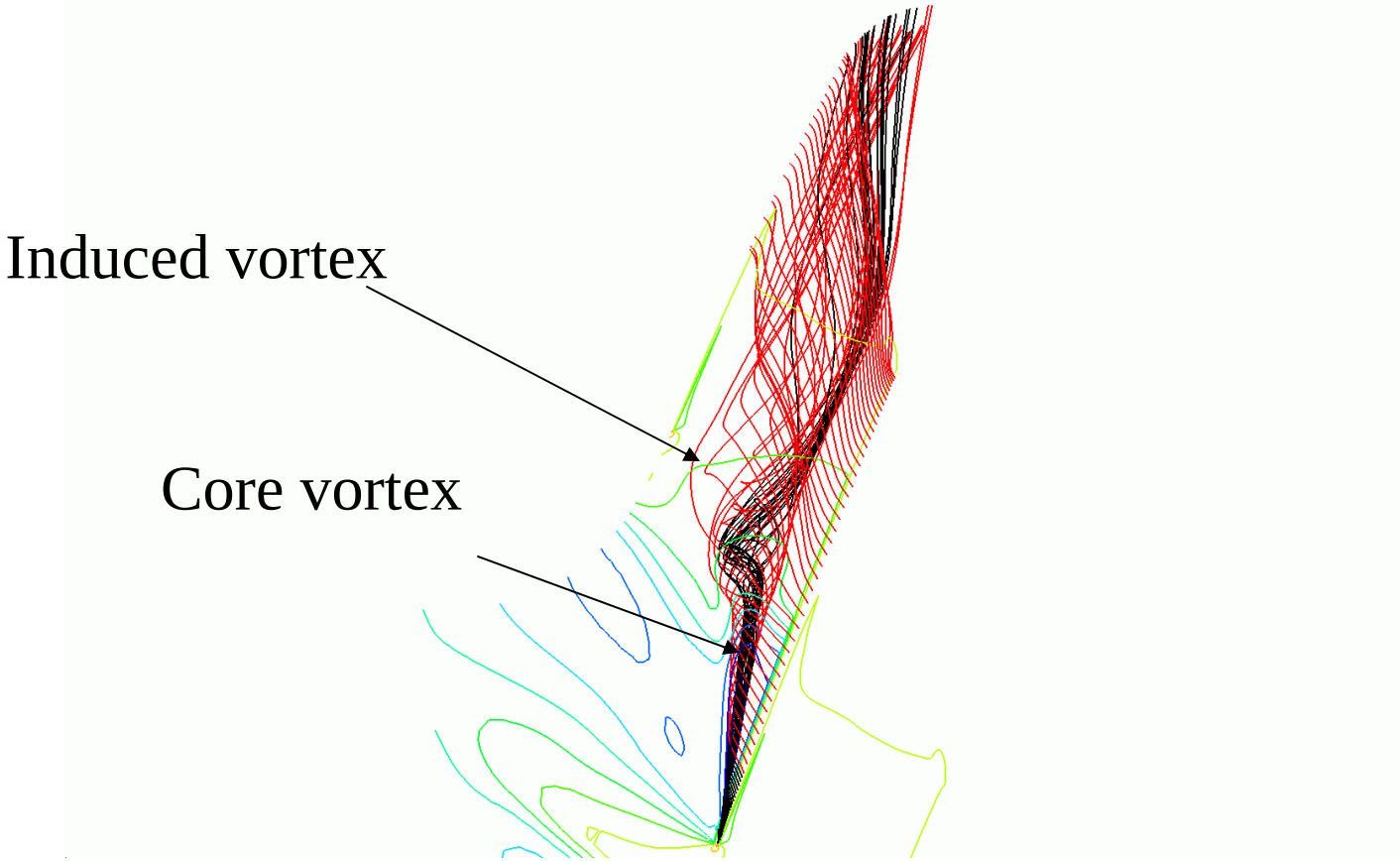


calculation

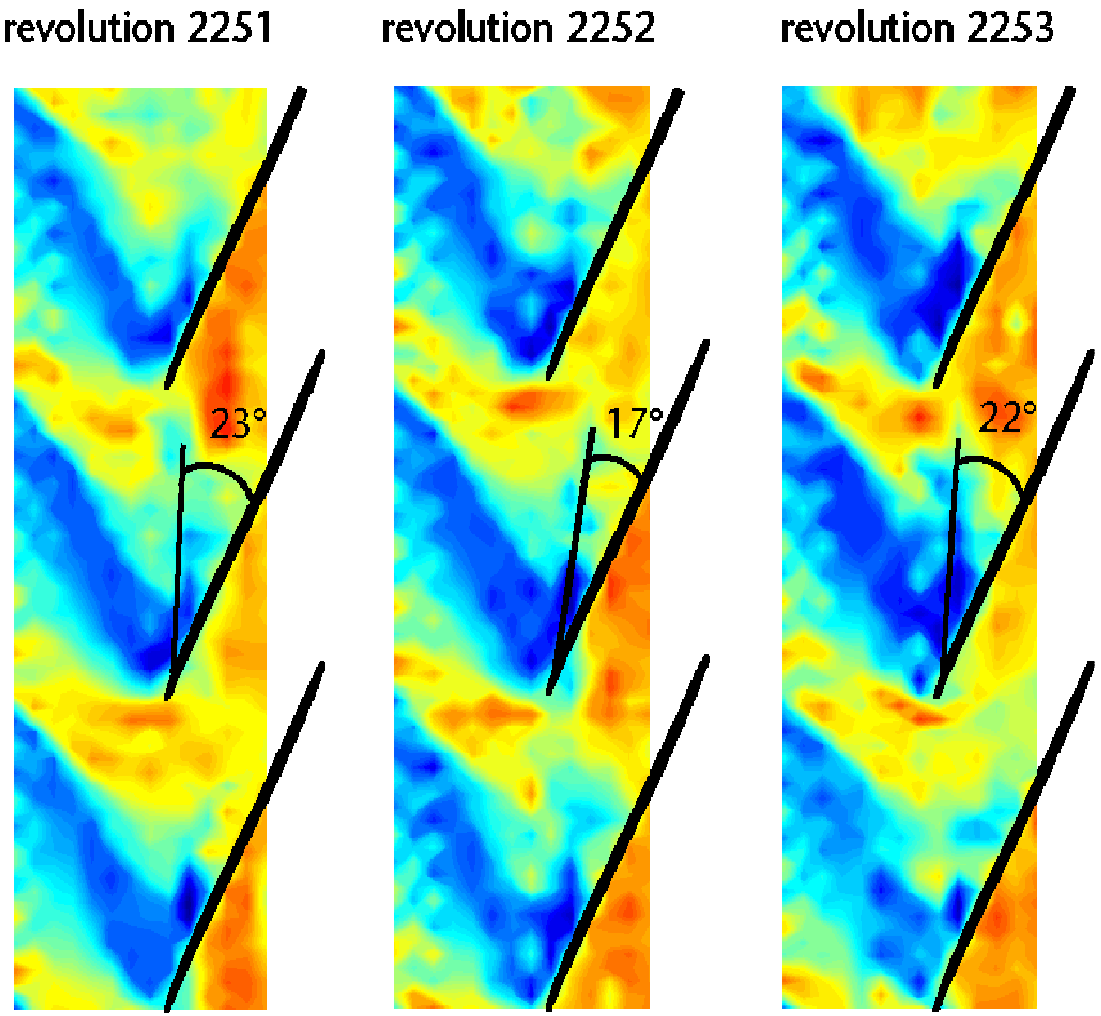
Velocity vectors at rotor tip, near stall, averaged LES



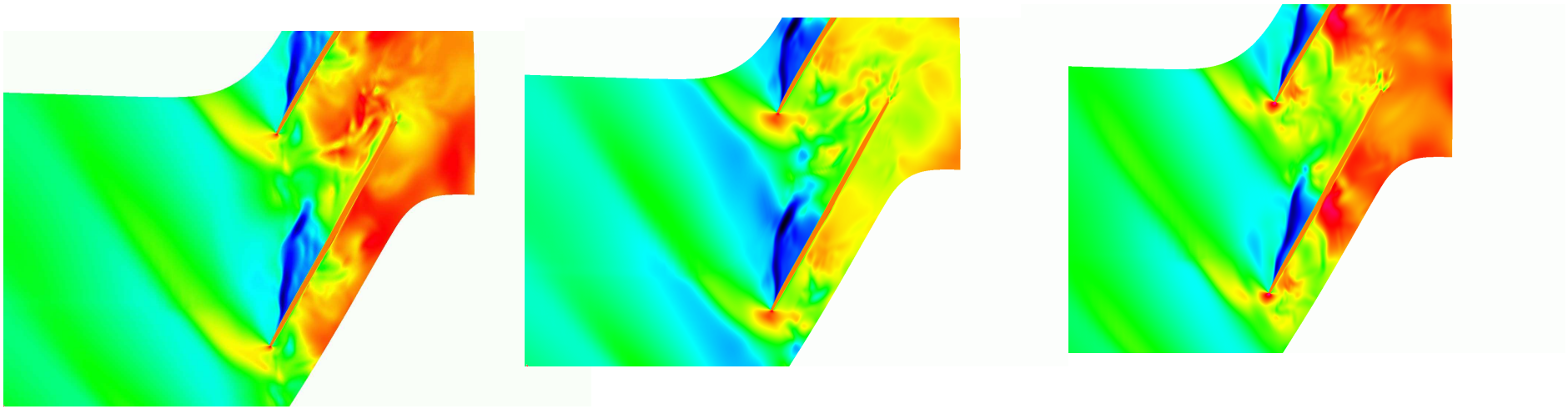
Particle traces at rotor tip



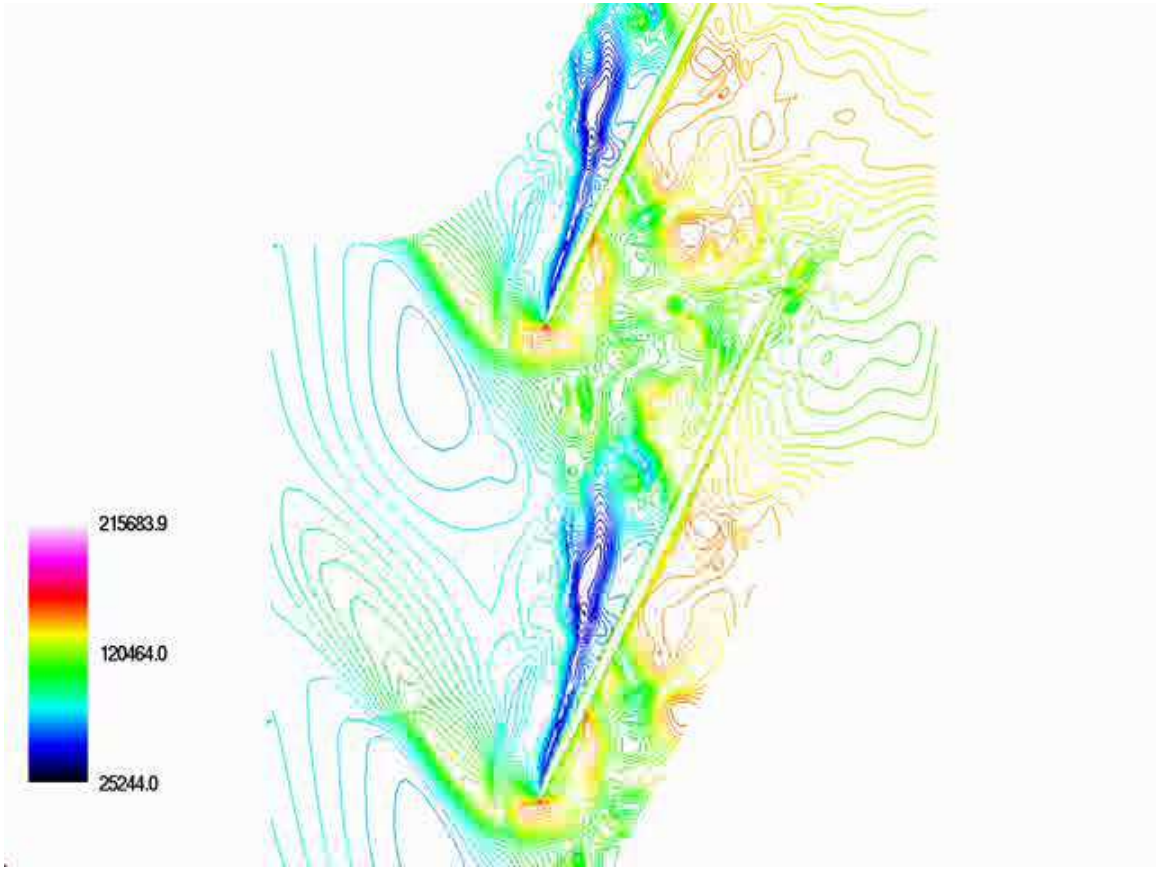
Measured endwall pressure variation



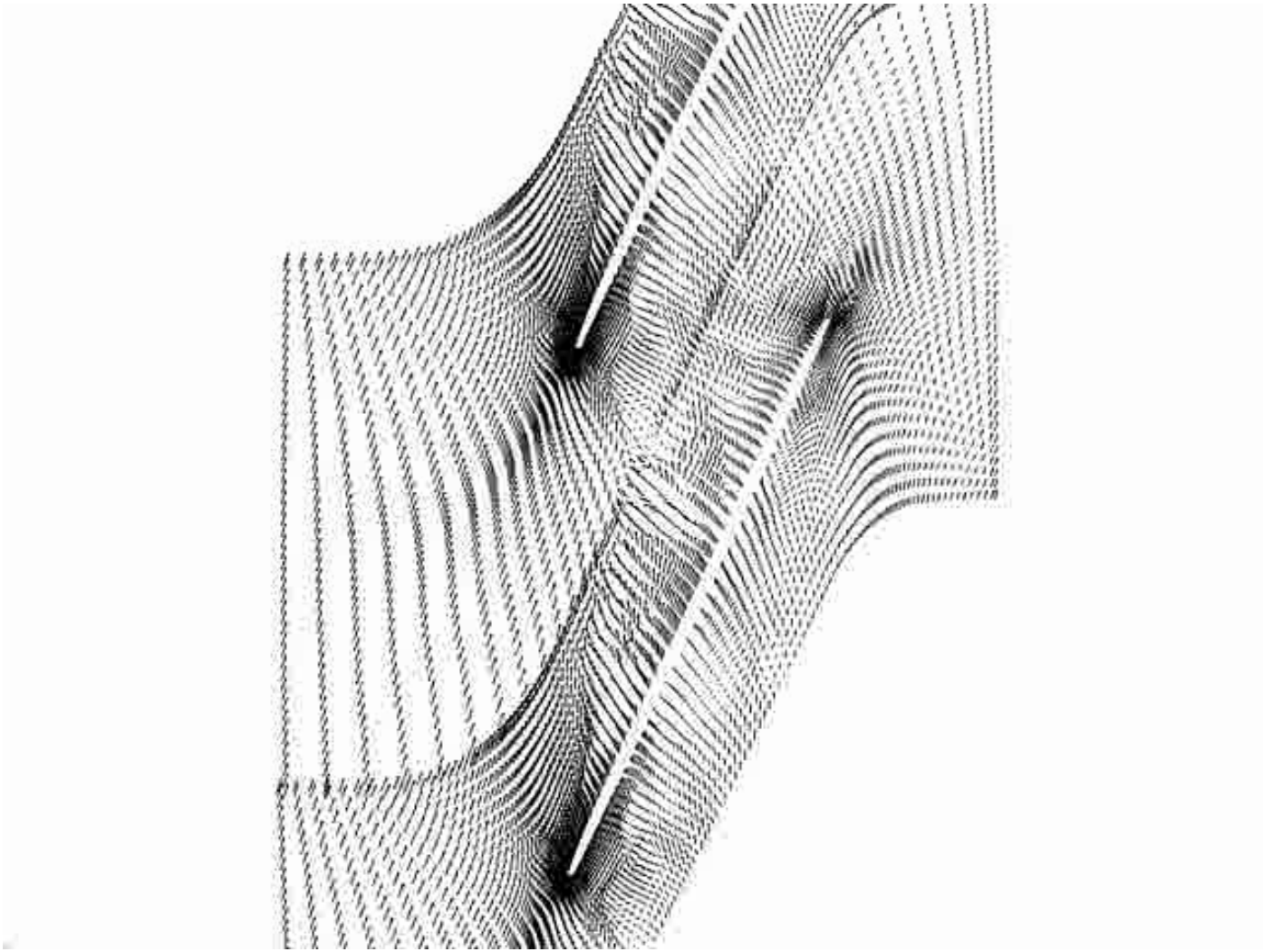
Calculated instantaneous casing pressure

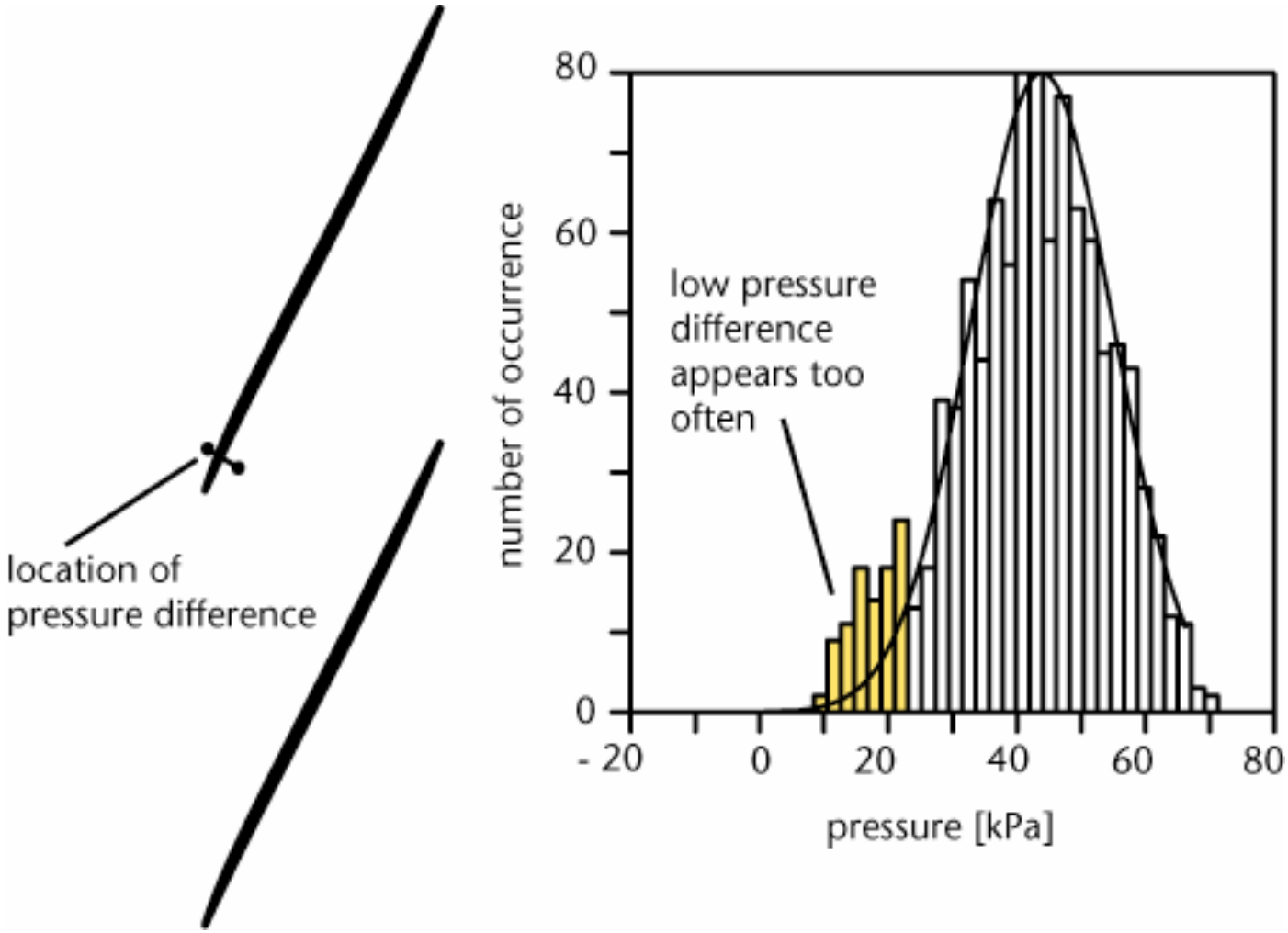


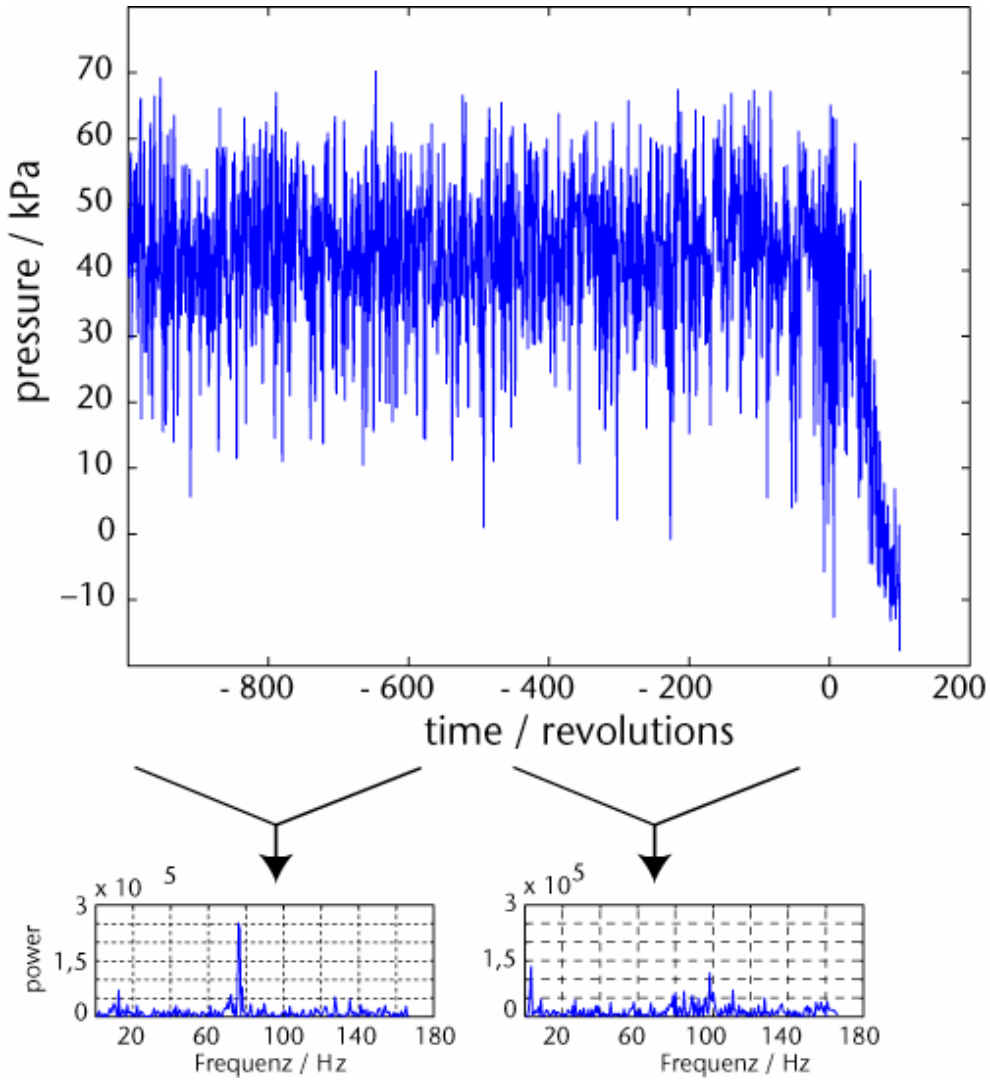
Pressure contours at blade tip (LES)



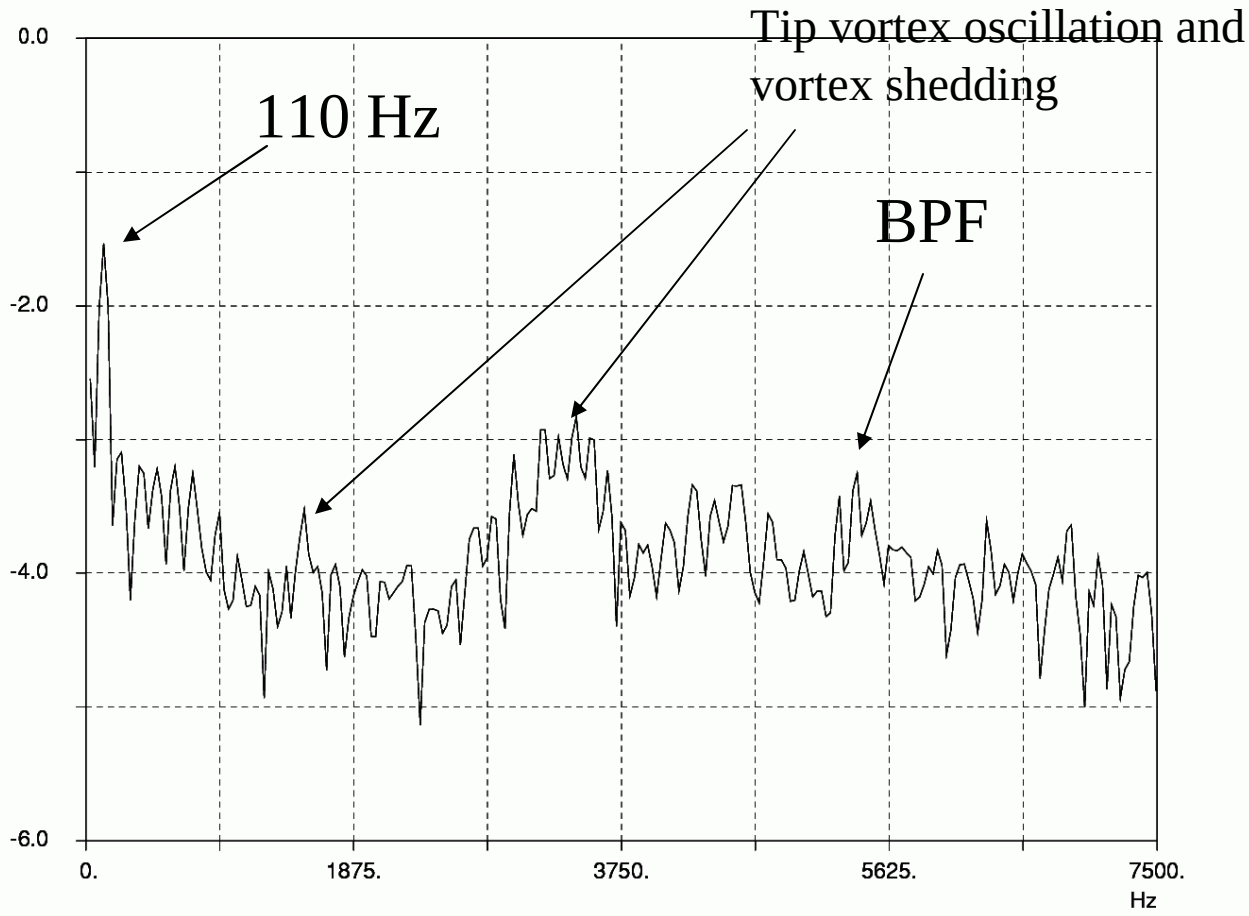
Instantaneous velocity vectors at blade tip (LES)



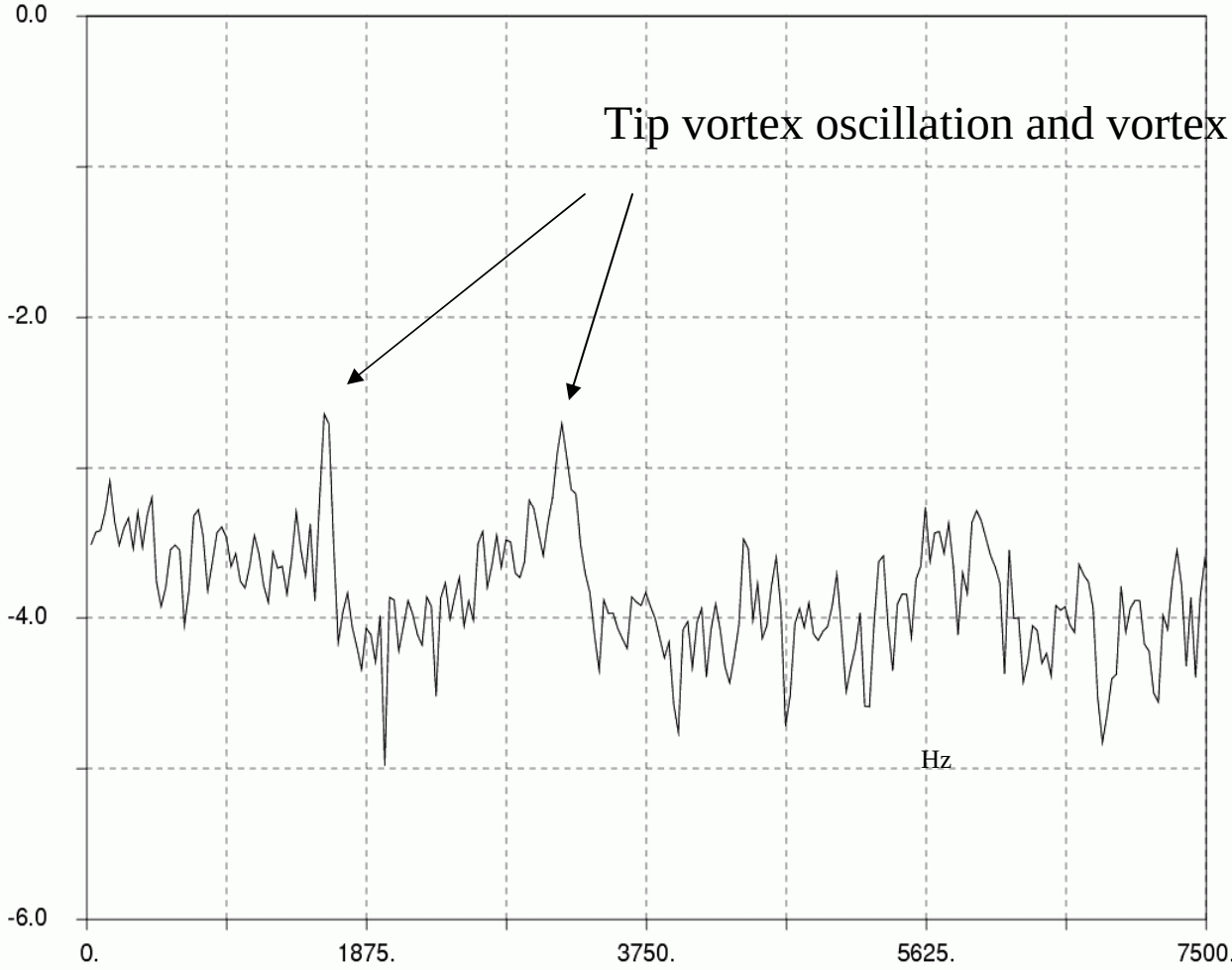

location of
pressure difference
number of occurrence
low pressure
difference
appears too
often
80
60
40
20
0
- 20
0
20
40
60
80
pressure [kPa]


pressure / kPa
70
60
50
40
30
20
10
0
–10
- 800
- 600
- 400
- 200
0
200
time / revolutions
power
x 10 5
3
1,5
0
20
60
100
140
180
Frequenz / Hz
x 10^5
3
1,5
0
20
60
100
140
180
Frequenz / Hz

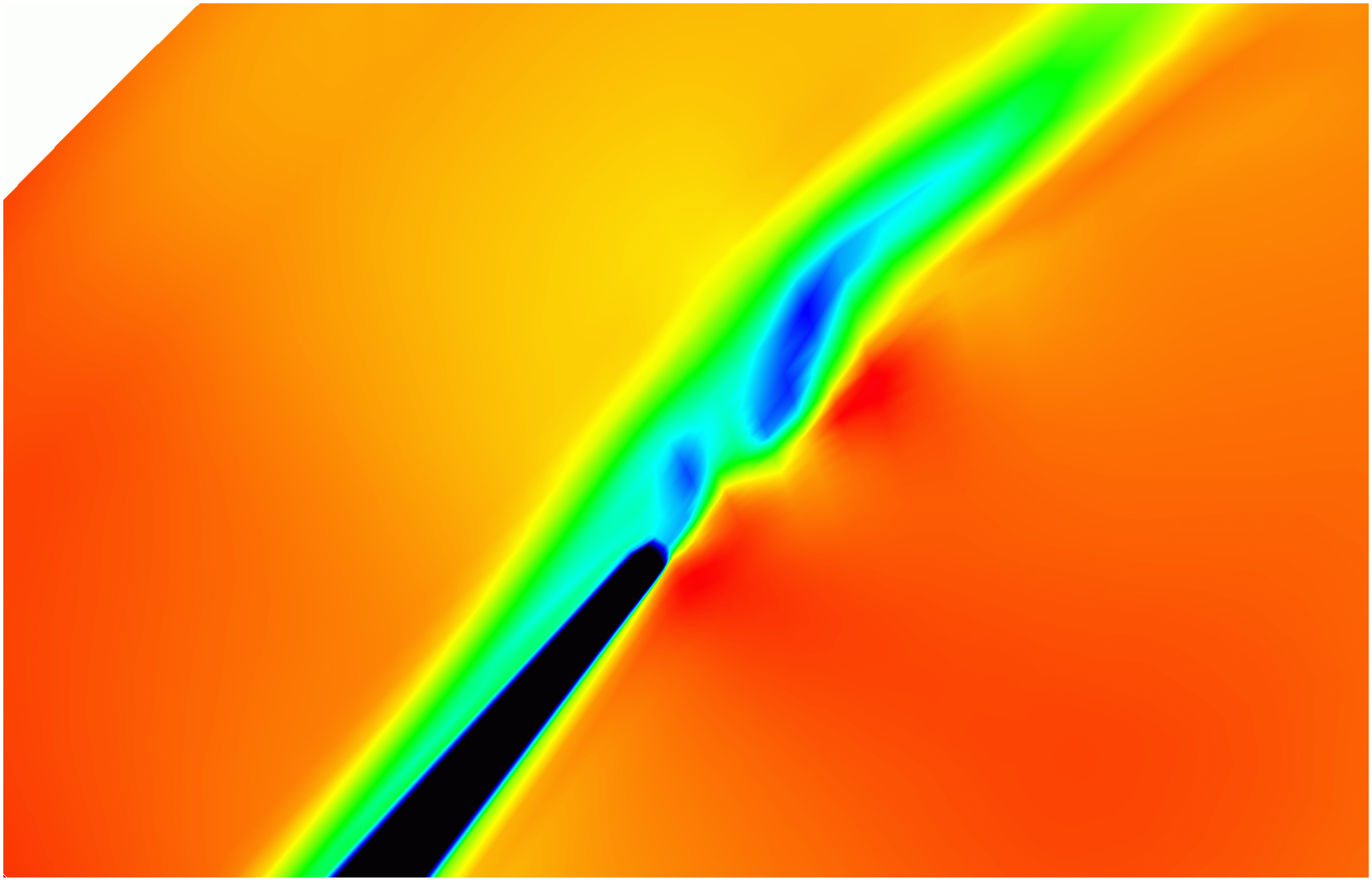
Wall pressure spectrum from full annulus LES



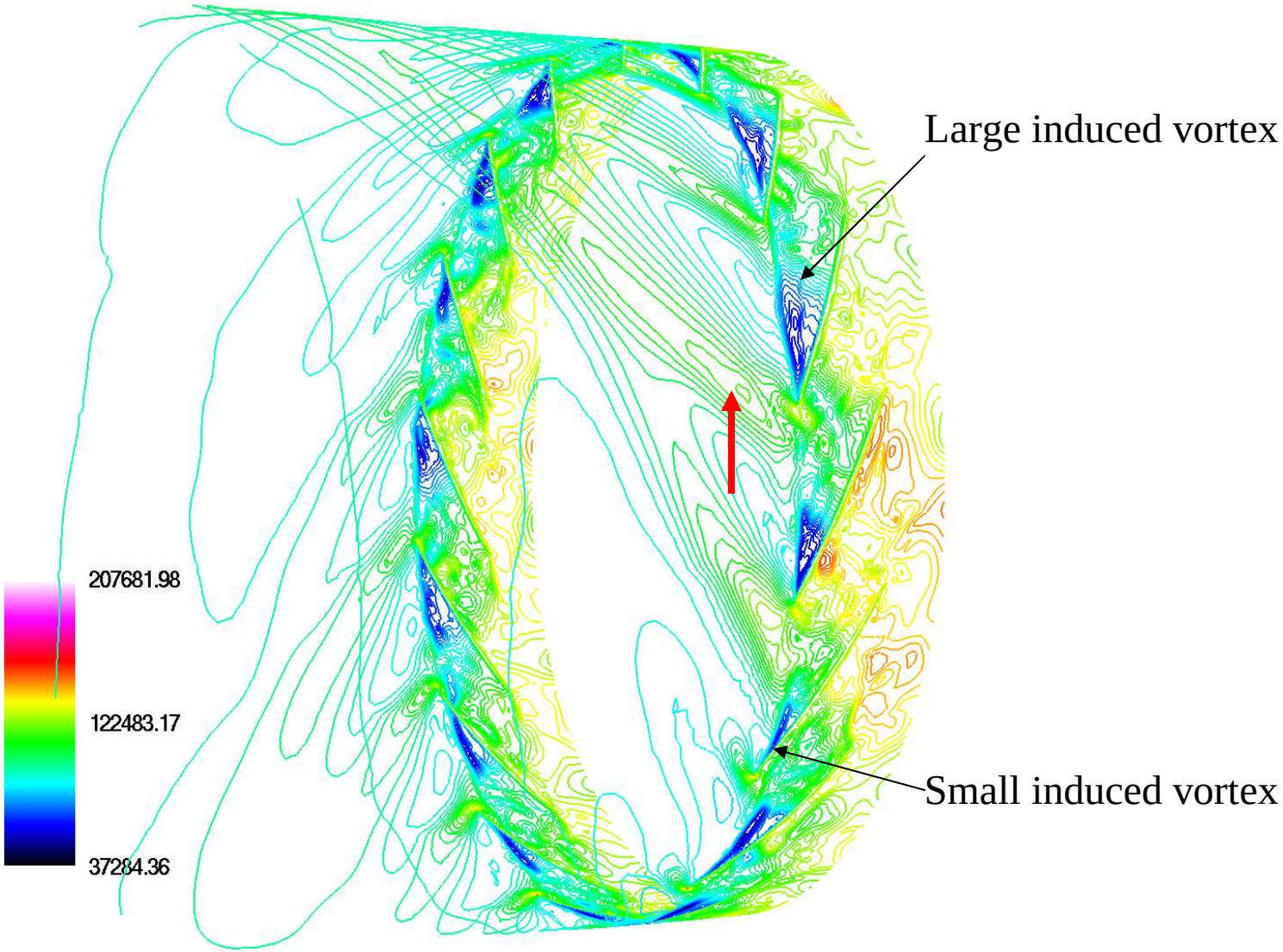
Wall pressure spectrum from single passage LES



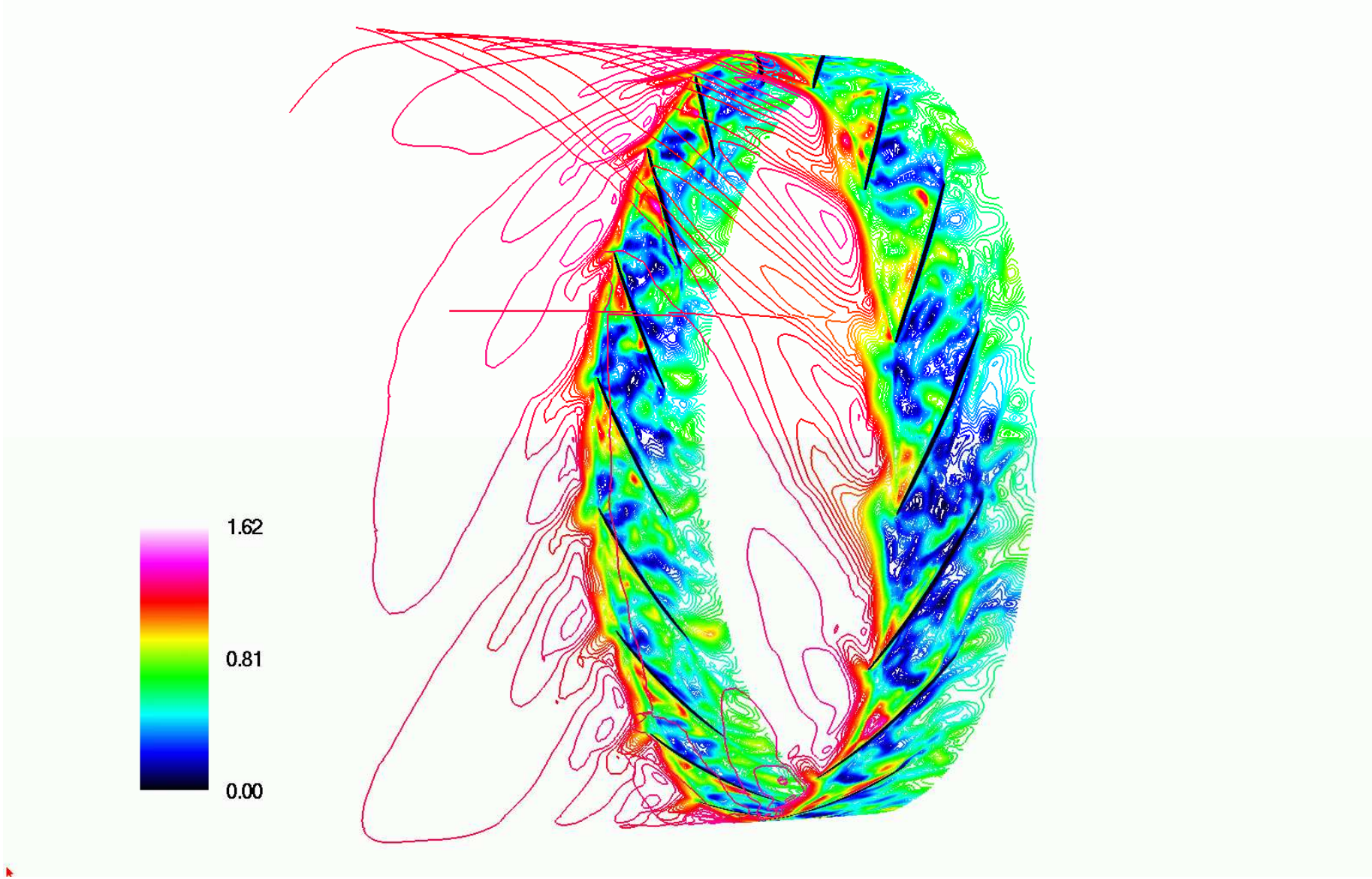
Instantaneous Mach number distribution at mid-span



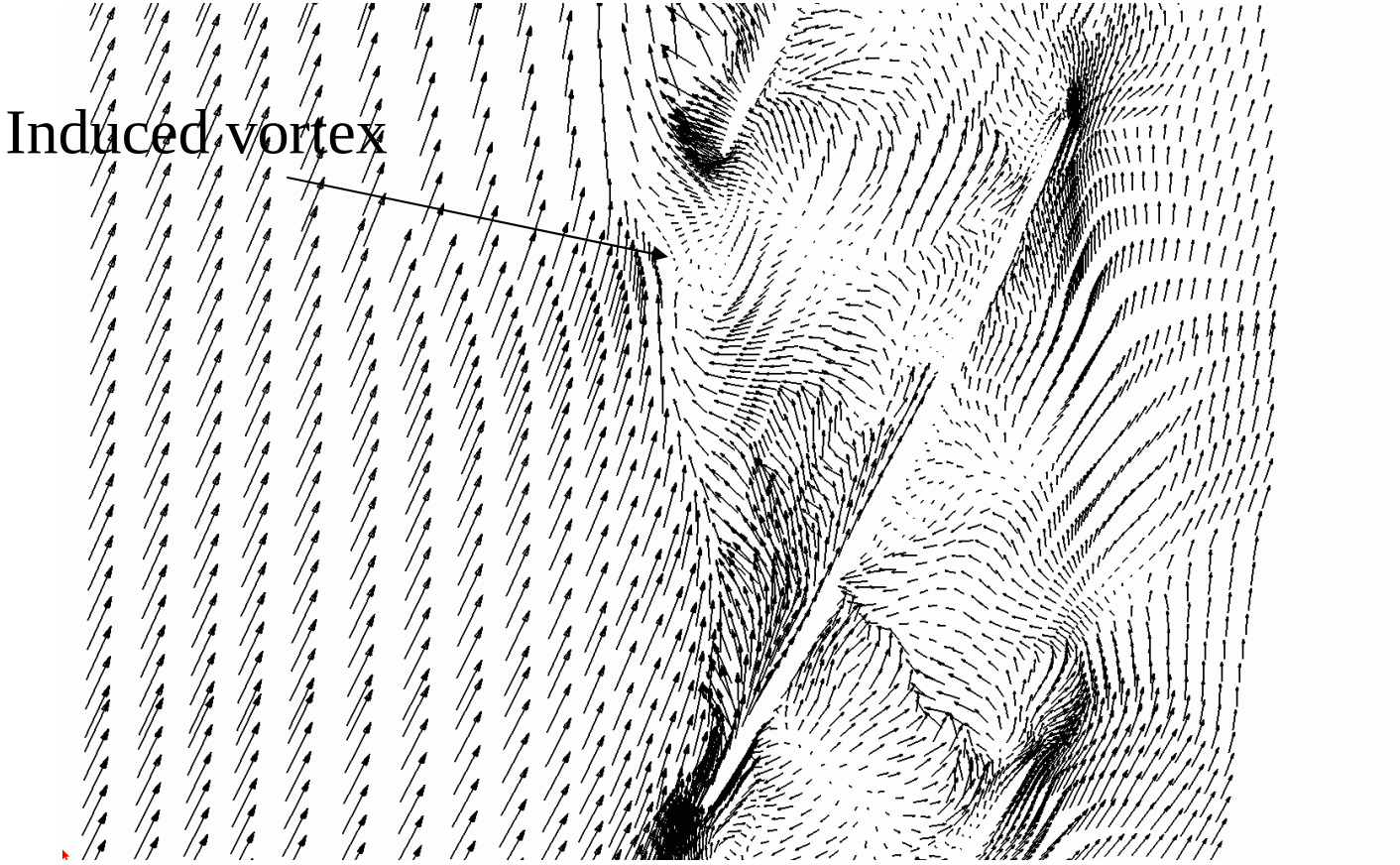
Instantaneous pressure distribution, blade tip, time 1



Instantaneous Mach Number from LES



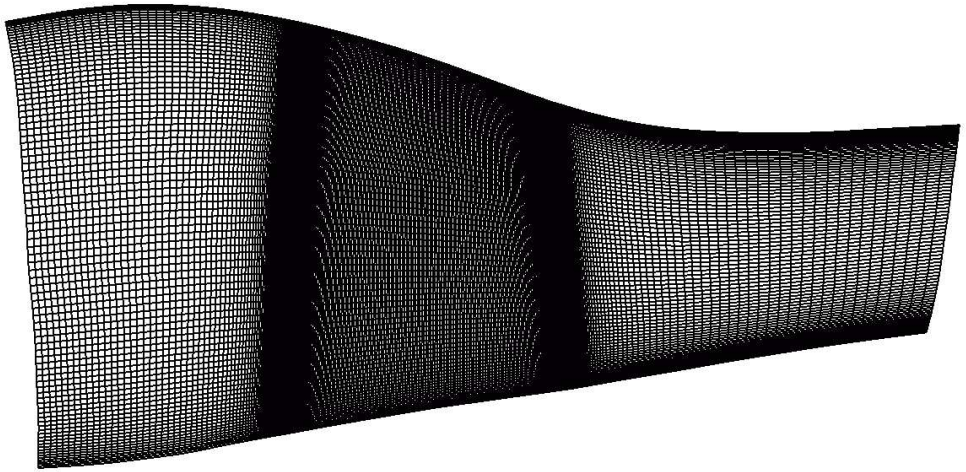
Instantaneous velocity vectors



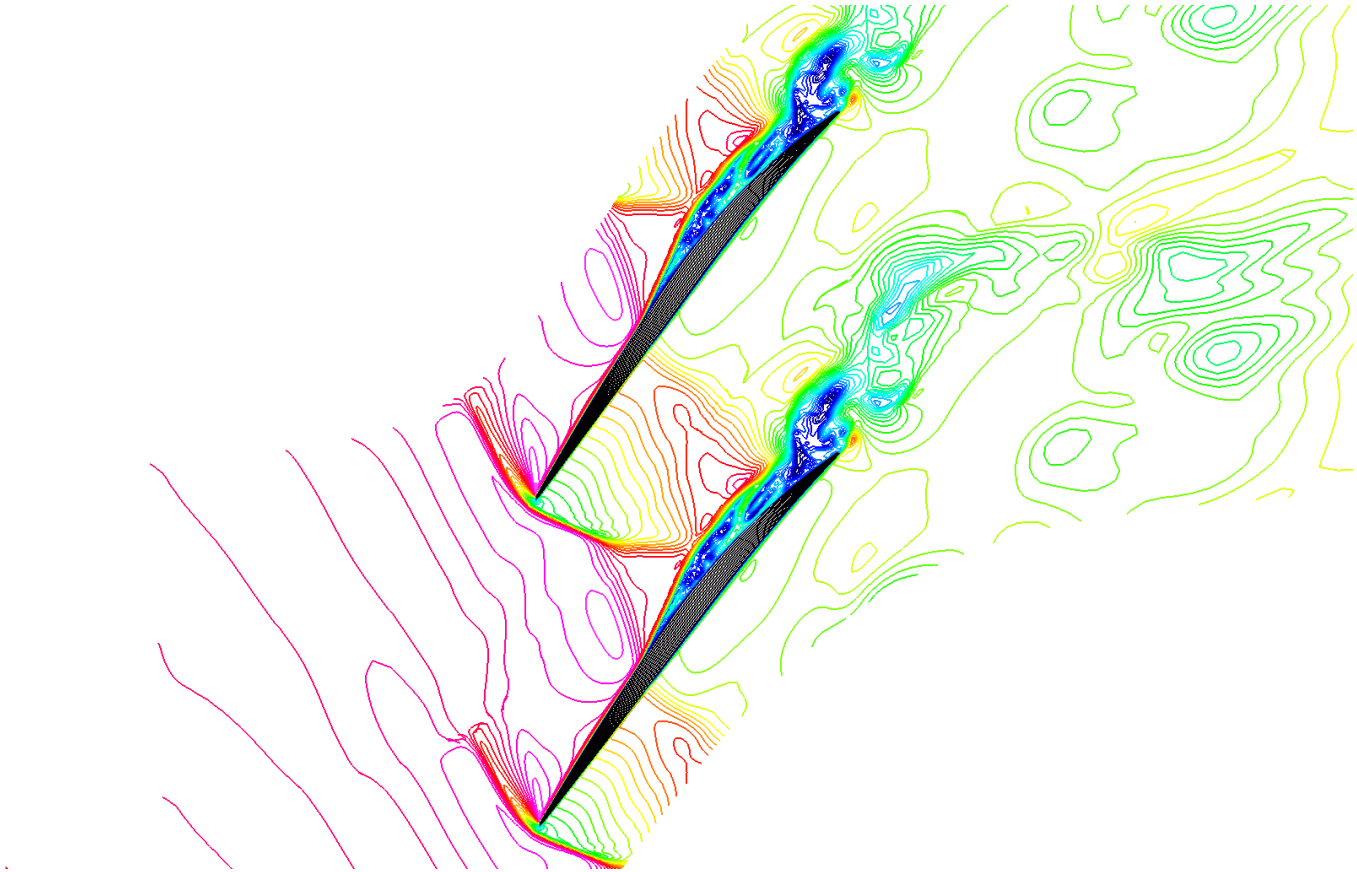
NASA Rotor 37

- Transonic flow field with passage shock over the full span.
- Used as a a blind test case by ASME in 1992.
- Many flow features are not fully understood yet.

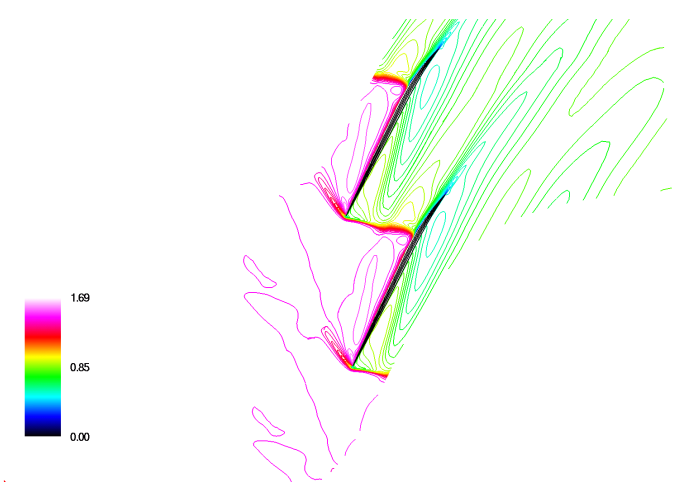
Computational grid



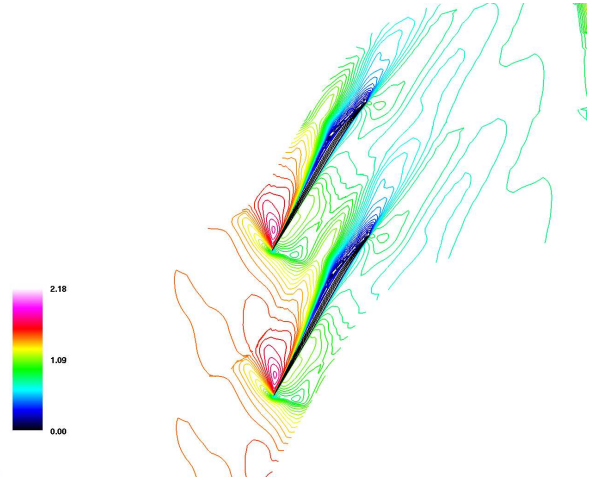
Instantaneous Mach number



Comparison of average Mach Number, near Peak effi.

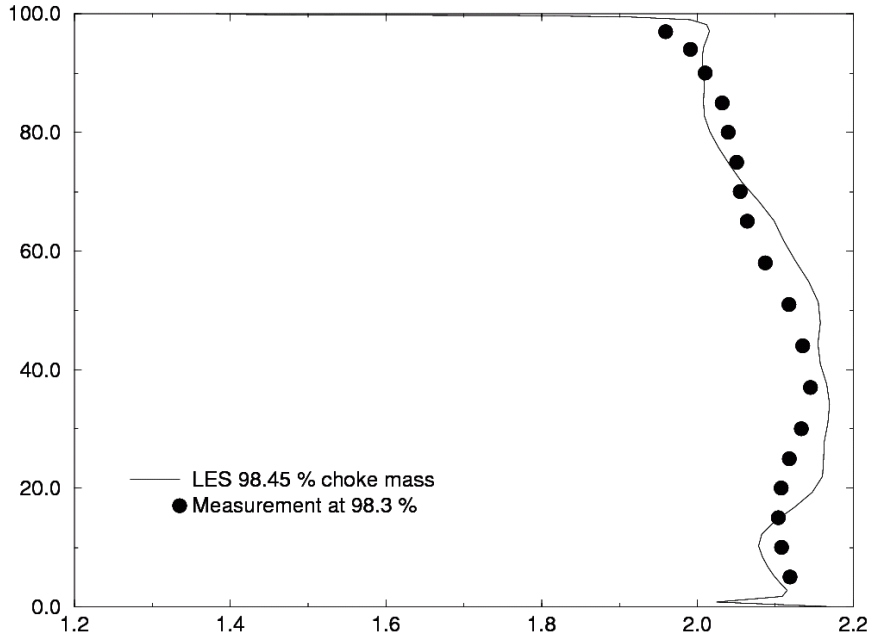


RANS

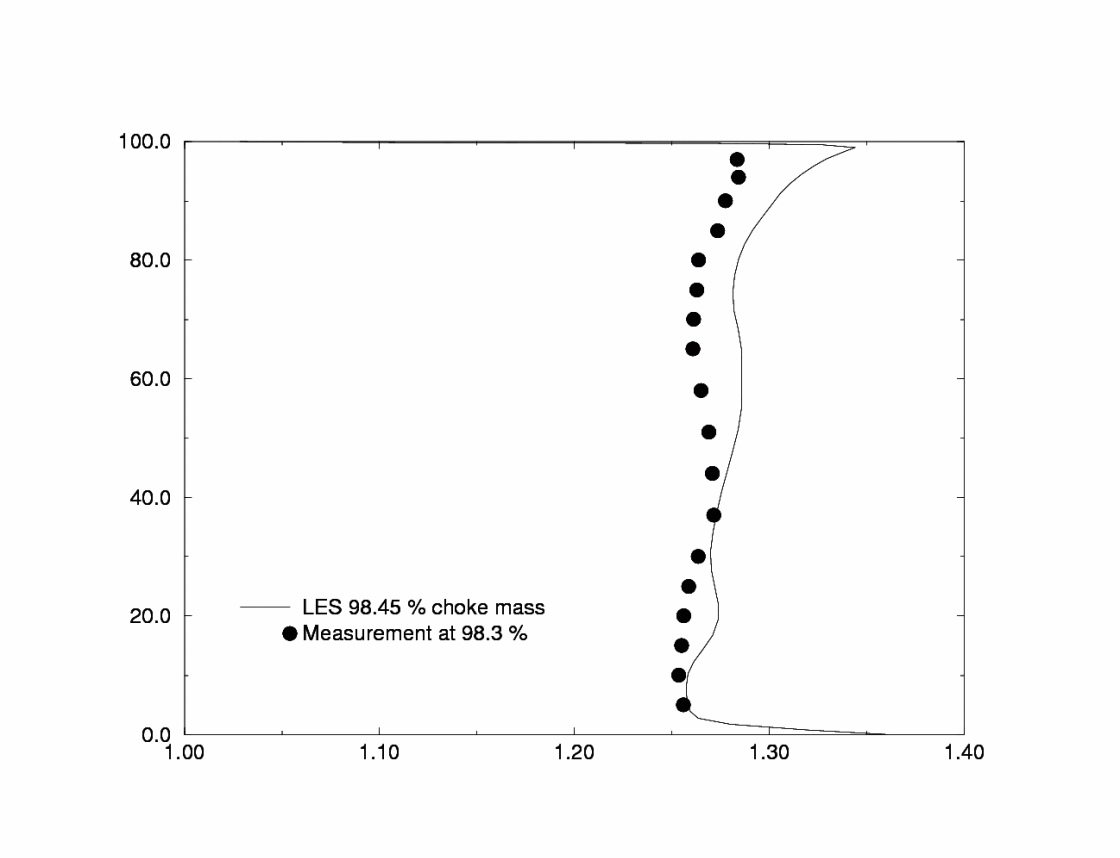


LES

Comparison of Pt distribution



Comparison of Tt distribution



Observations and future research

- Promising results for simulation of transonic compressor flow field with LES.
- Further validations planned.