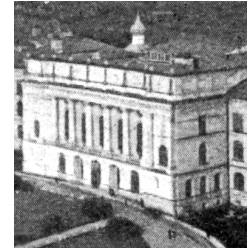


Saint-Petersburg State Polytechnic University



A.M.Levchenya, V.V.Ris, E.M.Smirnov

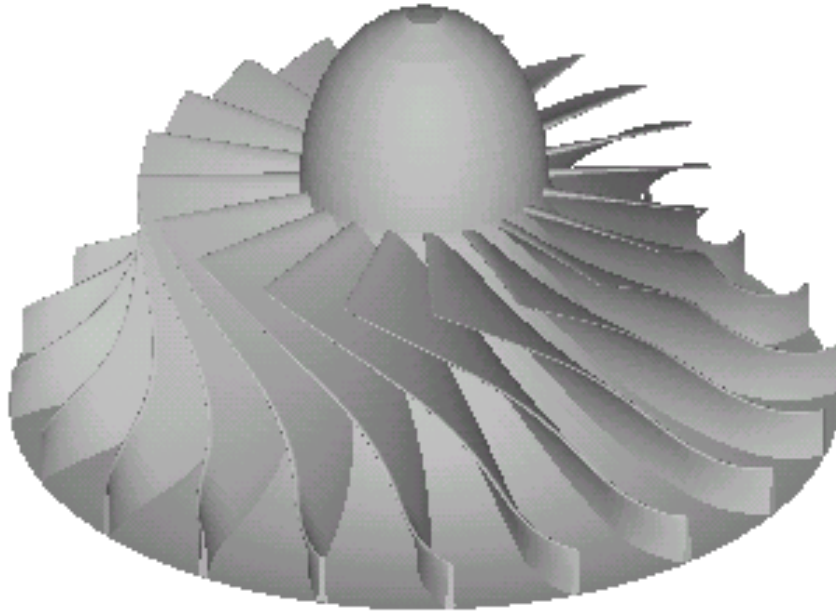
**Test computations of turbulent flow
in an axial-radial centrifugal compressor impeller
using CFX-TASCflow package
and a detailed analysis of tip-clearance effects**

CONTENT

- *Introduction*
- *Experimental model and operating conditions*
- *Numerical model,
computational grid and cases considered*
- *Results and discussion*
- *Conclusions*

Experimental test description

*Centrifugal compressor impeller
(backswept rotor A: experiments
by D.Eckardt et al, 1976-1980)*



- ✓ 20 blades with sweep angle 60°
- ✓ Tip-clearance between shroud and blades:
 $0.5 \div 0.8$??
- ✓ Tip speed: ≈ 300 m/s
- ✓ Pressure ratio: 1.91
- ✓ Efficiency: 88.6%

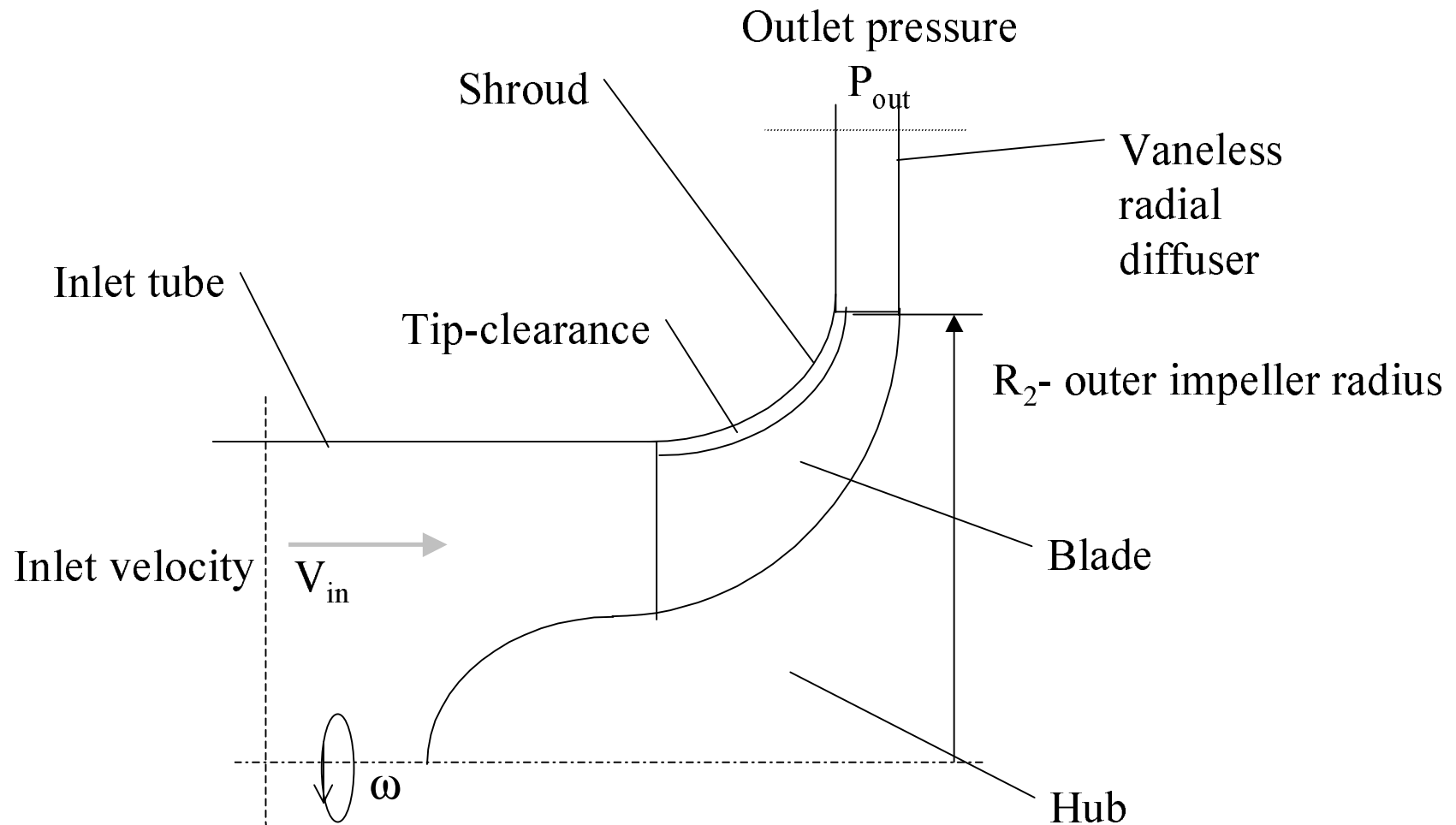
Shaft speed: 14000 r.p.m.
Optimum air mass flow rate: 4.54 kg/s
Inlet total pressure: 101.33 kPa
Inlet total temperature: 15°C

Mathematical model and computational aspects

- Reynolds-averaged Navier-Stokes and energy equation for turbulent compressible flow. Formulation in the reference frame rotating with the impeller
- $k-\omega$ turbulence model (Wilcox, 1993)

- CFX-TASCflow package, version 1.21.1 Beta
- Multiblock structured grid created with software developed at the Department of Aerodynamics of SPSPU was converted to the CFX-TASCflow format
- Second order discretization scheme

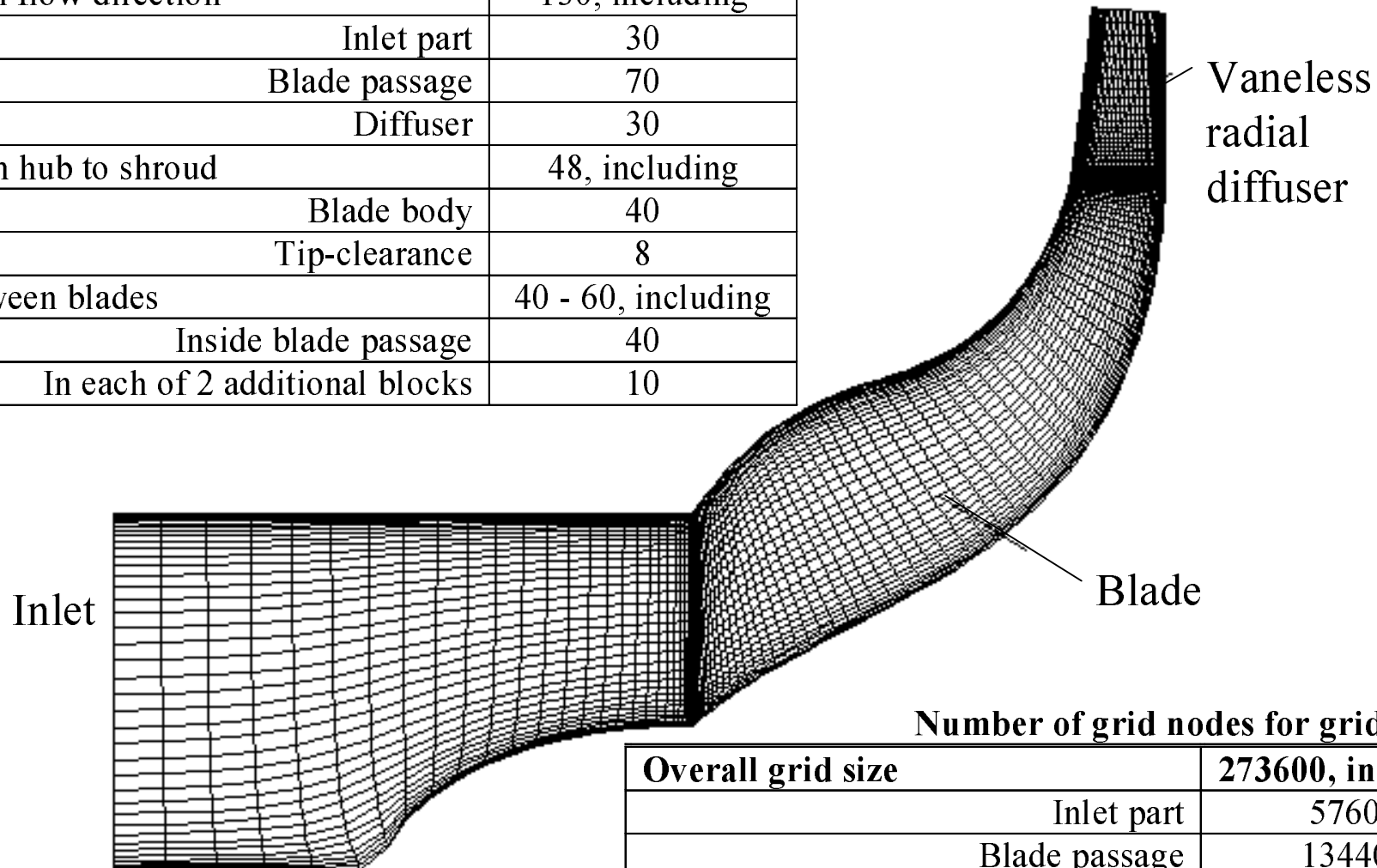
Meridional section of computational domain



Computational grid at a meridional section

Number of grid nodes on main gridlines

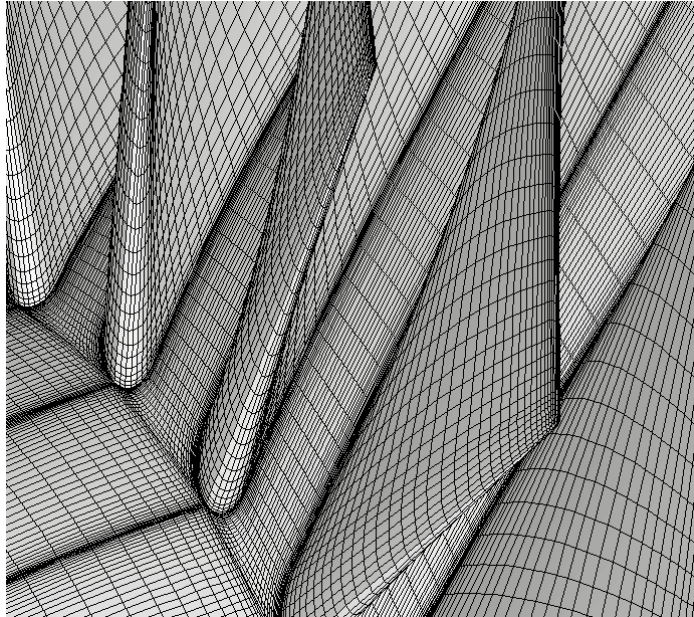
Main flow direction	130, including
Inlet part	30
Blade passage	70
Diffuser	30
From hub to shroud	48, including
Blade body	40
Tip-clearance	8
Between blades	40 - 60, including
Inside blade passage	40
In each of 2 additional blocks	10



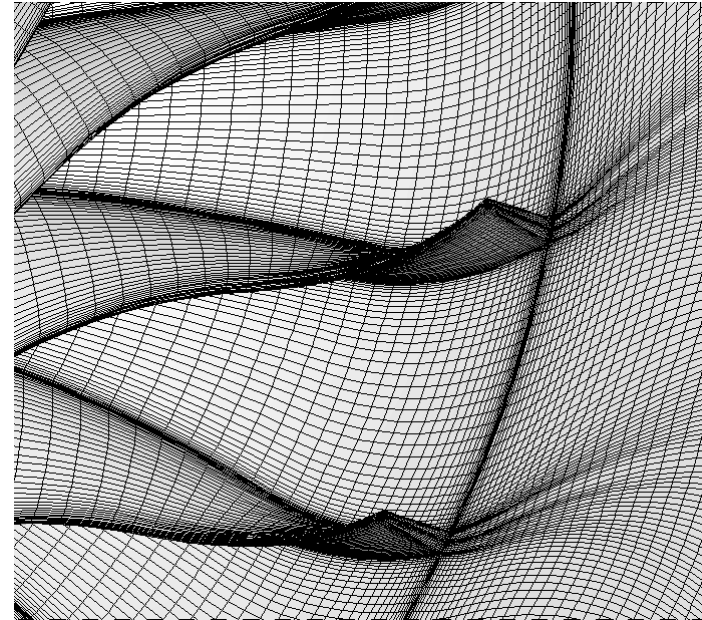
Number of grid nodes for grid blocks

Overall grid size	273600, including
Inlet part	57600
Blade passage	134400
Three-block diffuser	57600 + 2x12000

Computational domain: grid aspects



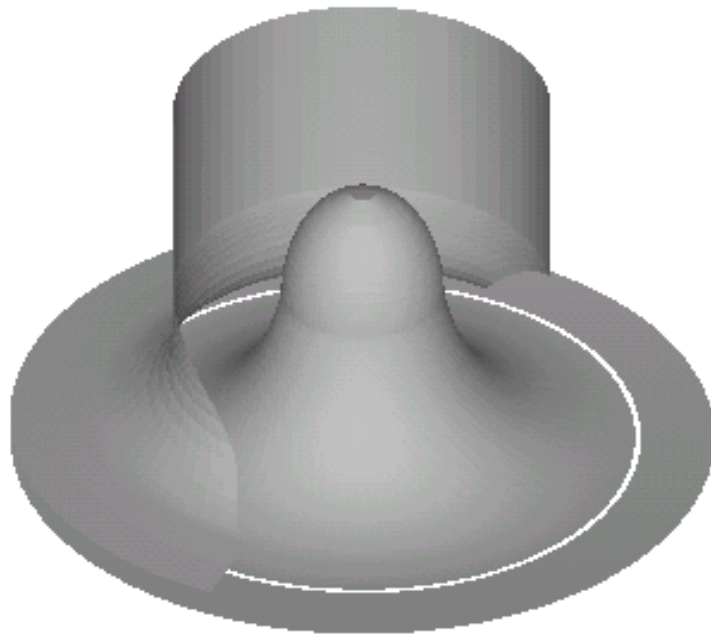
Grid resolution near blade
leading edge



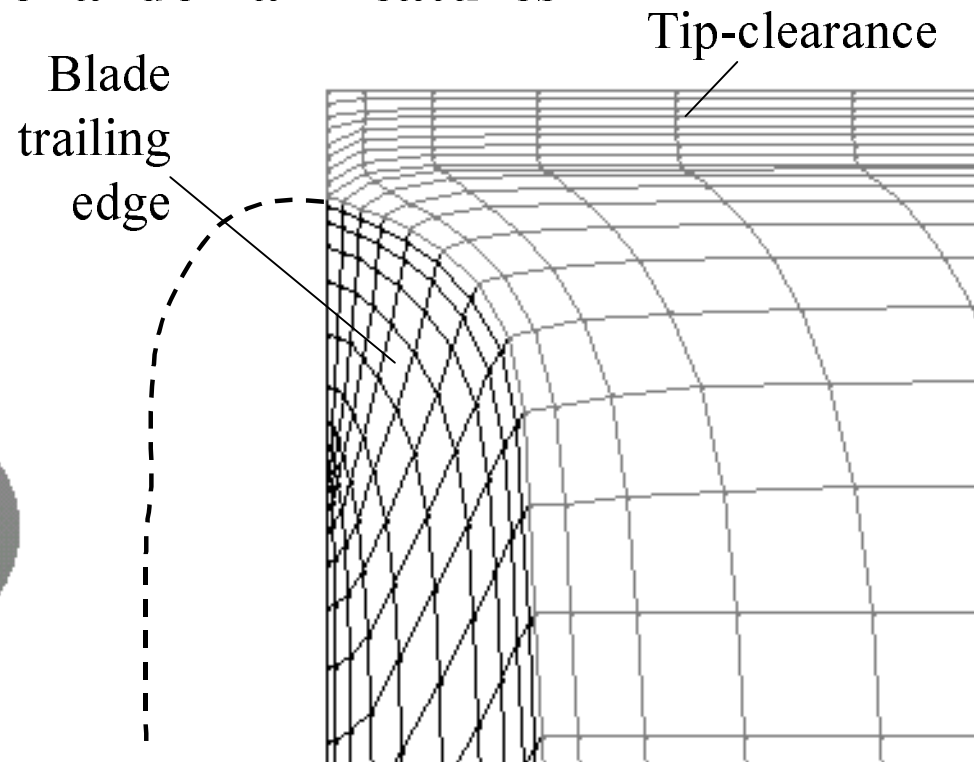
Grid resolution near blade
trailing edge

Near-wall grid nodes are situated at distance $Y^+ \approx 10$

Computational domain features

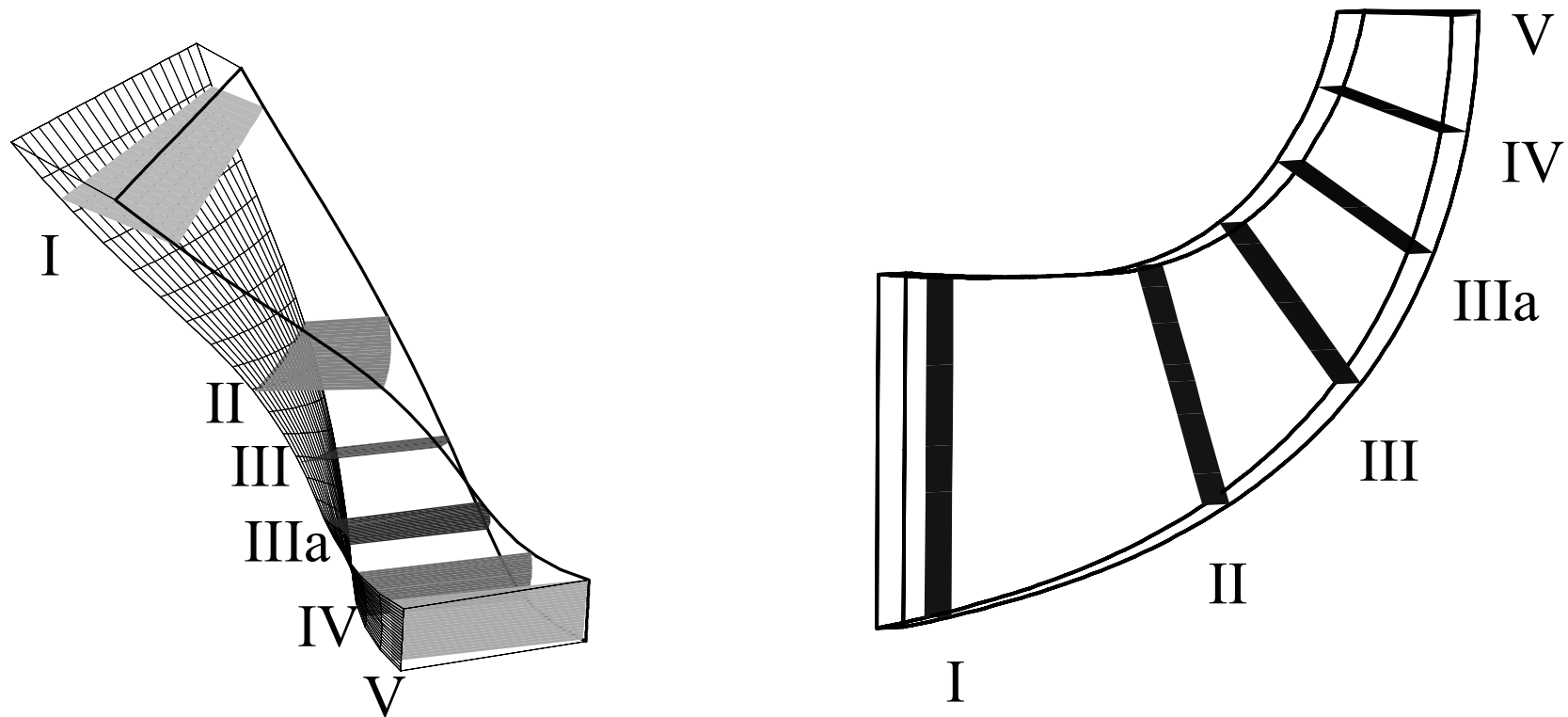


A part of the flow domain, including the circular gap between the stationary diffuser wall and the rotating hub



Grid resolution near the tip-clearance at impeller discharge

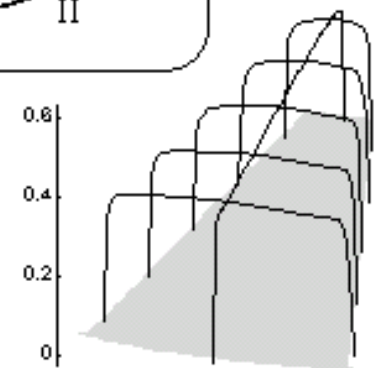
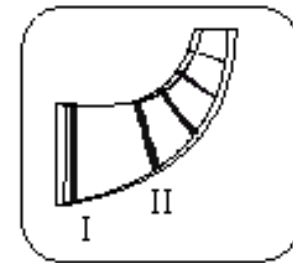
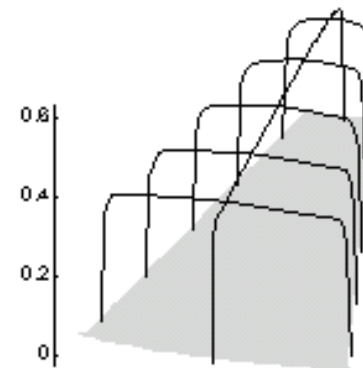
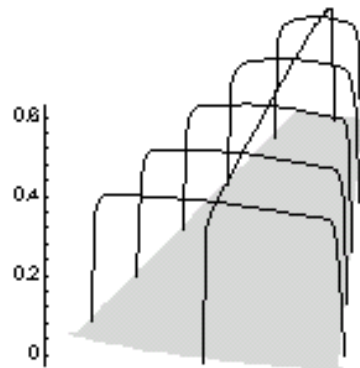
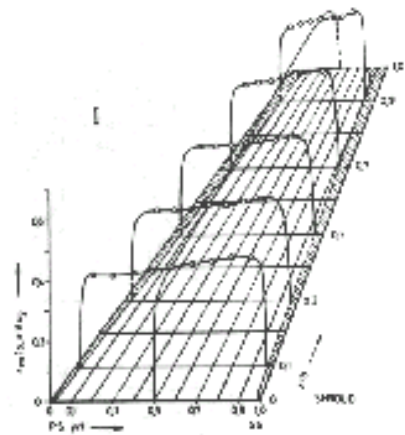
Flow analysis inside the blade passage



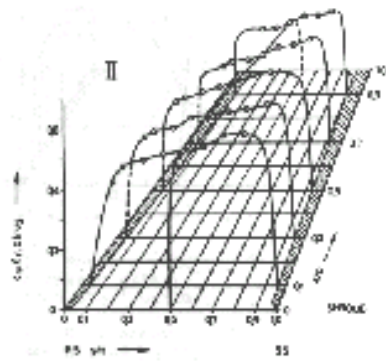
Two schemes defining passage cross-sections for velocity measurements*)

*) *Relative velocity on next slides is referred to impeller tip speed*

Section I



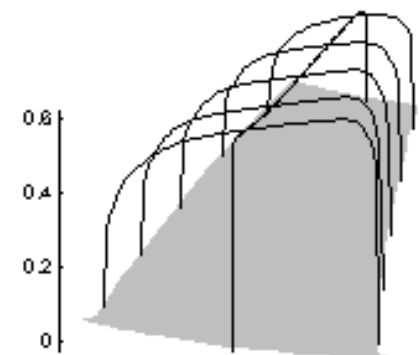
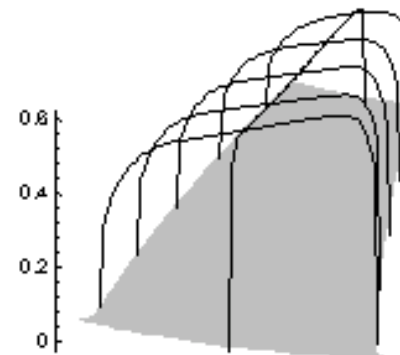
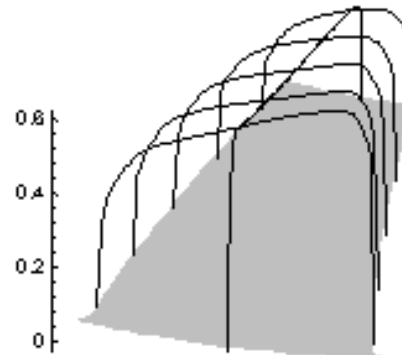
Section II



Full tip-clearance

50% tip-clearance

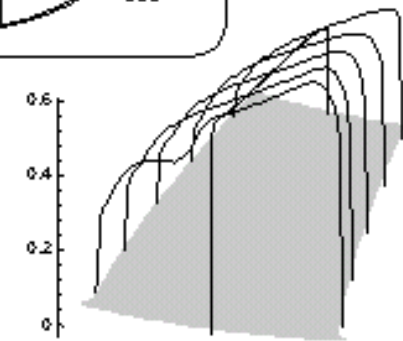
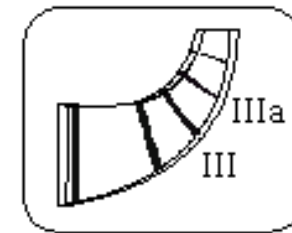
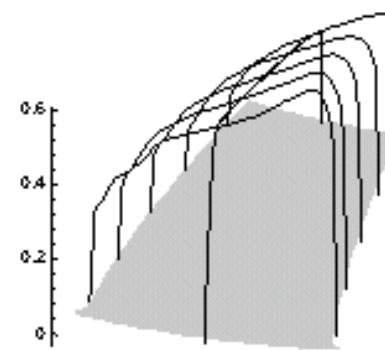
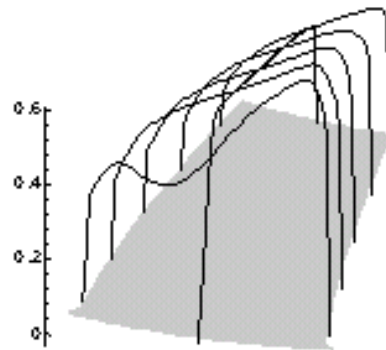
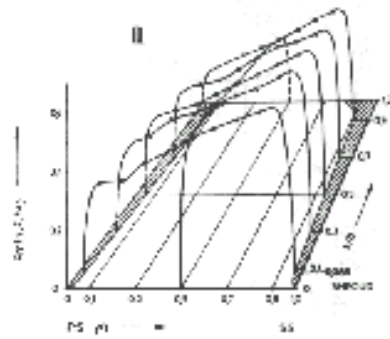
No tip-clearance



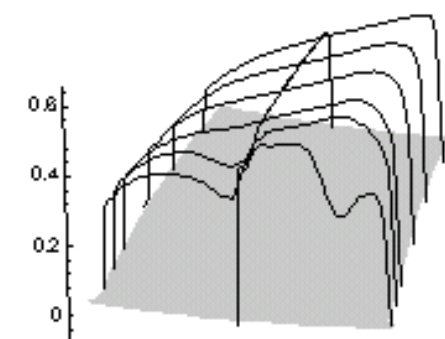
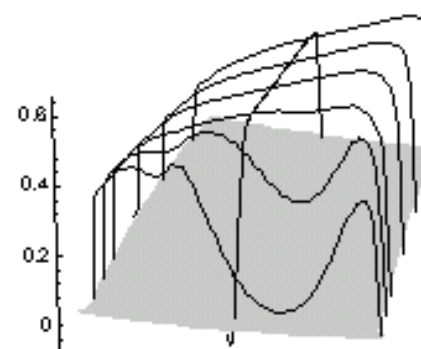
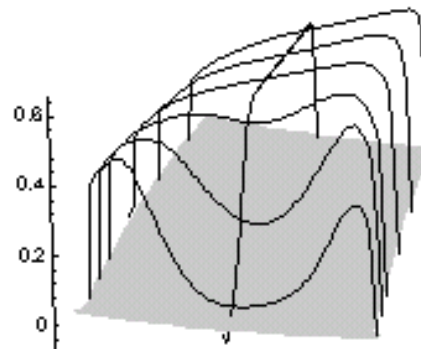
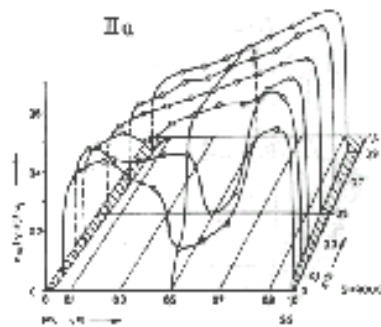
Experiment

Results of computations

Section III

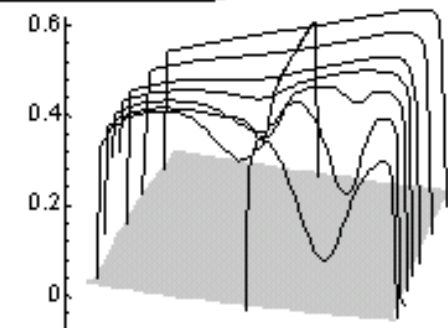
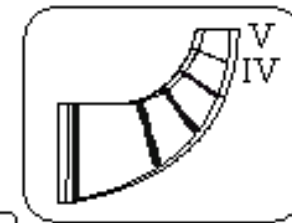
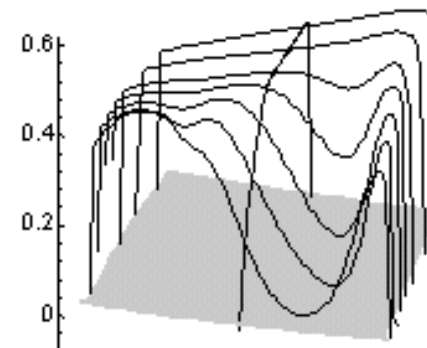
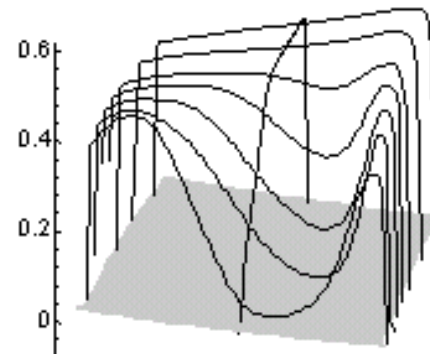
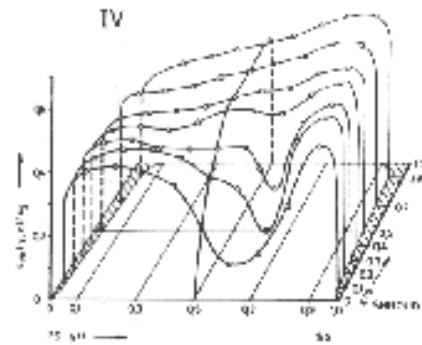
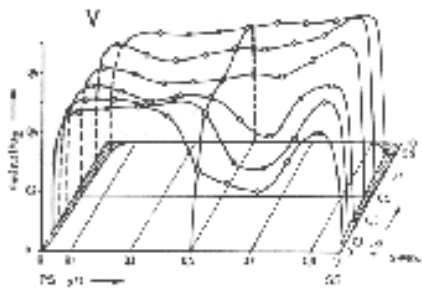


Section IIIa

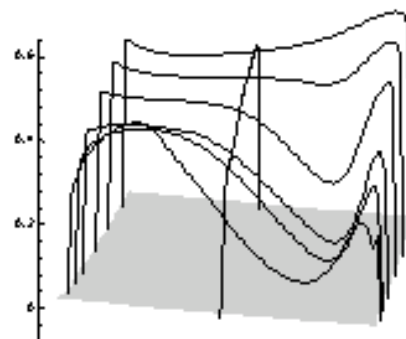


Experiment

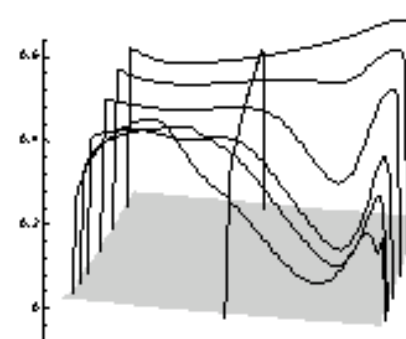
Results of computations

Section IV**Section V**

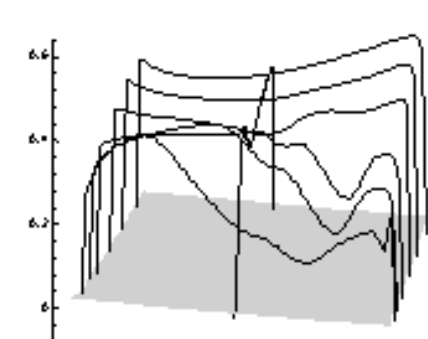
Full tip-clearance



50% tip-clearance

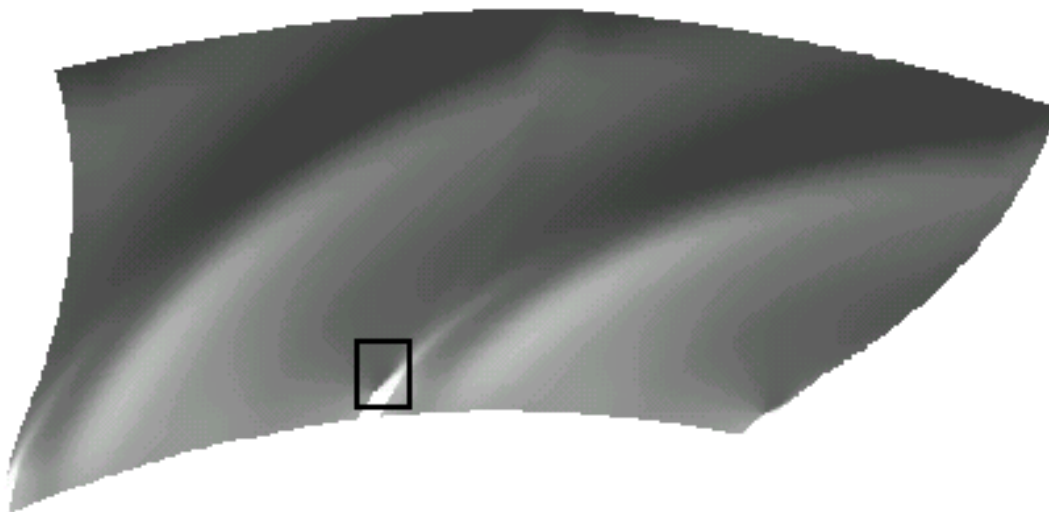
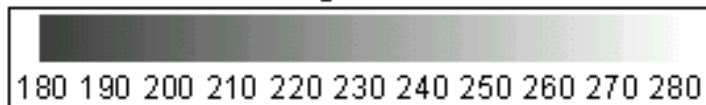


No tip-clearance

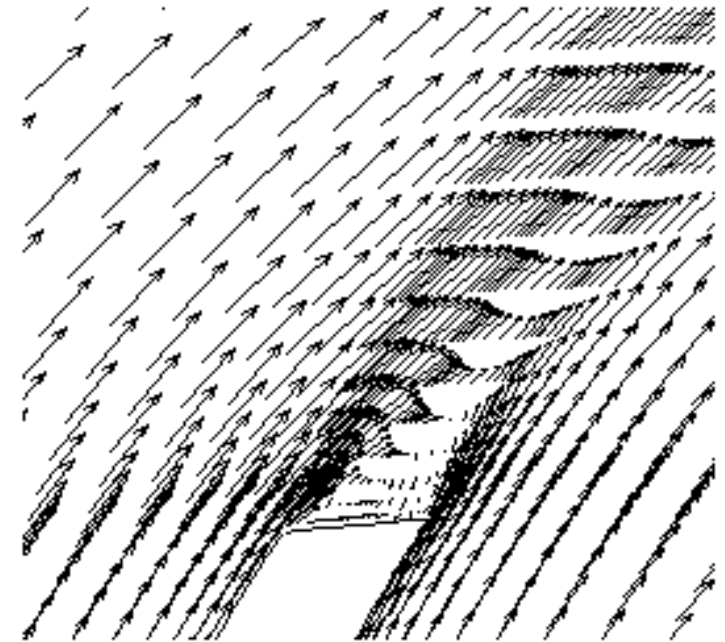
*Experiment**Results of computations*

Vaneless diffuser flow

meters per second



Distribution of absolute velocity at mid-width diffuser section



Relative velocity vectors near blade trailing edge

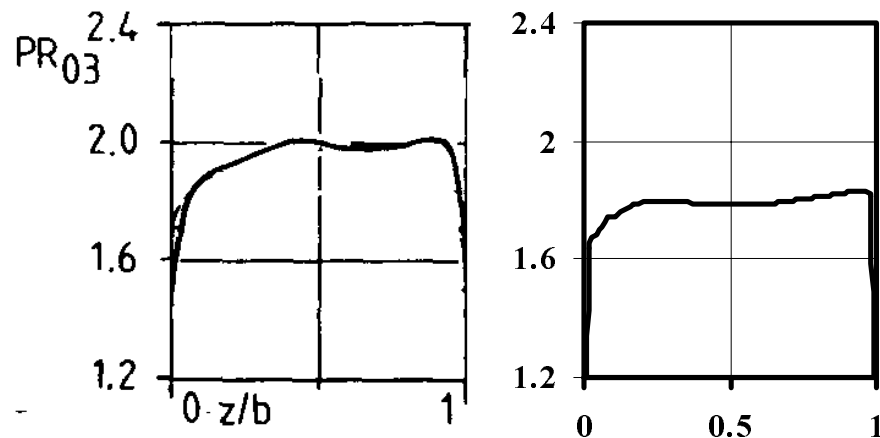
Comparison of integral characteristics

	Pressure ratio	Efficiency
Experiment	1.91	88.6%
Computations:		
Full tip-clearance	1.81	92.9%
50% tip-clearance	1.84	93.8%
No tip-clearance	1.87	95.1%

$$PR_{03} = \frac{P_{1.075R_2}}{P_{in}}$$

$$\eta_{s,03} = \frac{k-1}{k} \cdot \frac{\ln PR_{03}}{\ln \frac{T_{ex}}{T_{in}}}$$

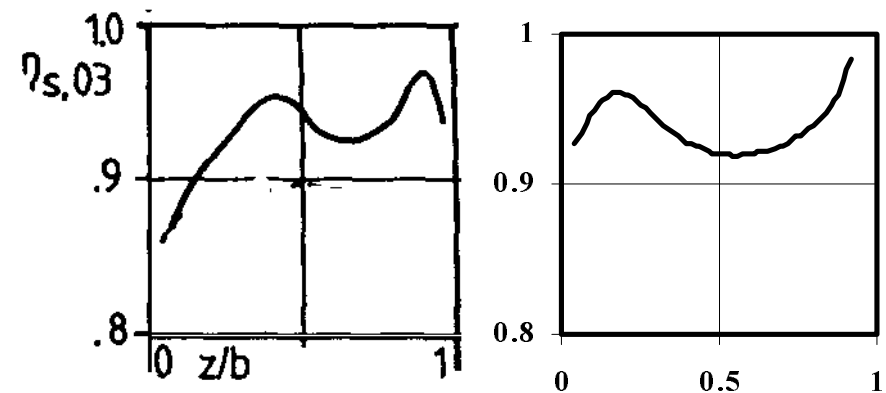
Total pressure profiles at impeller discharge



Experiment

Computations

Efficiency profiles at impeller discharge



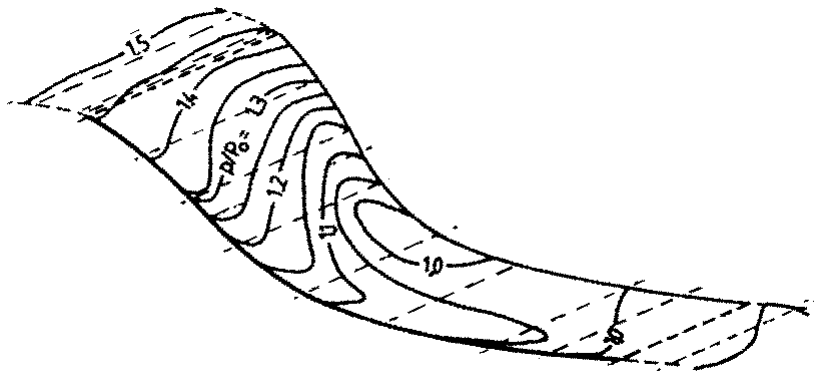
Experiment

Computations

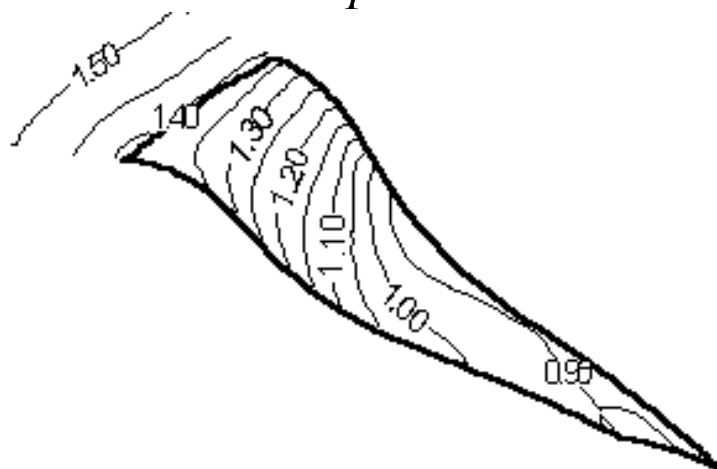
Pressure fields for the flow with 50% tip-clearance

(values referred to inlet total pressure)

Static pressure on the shroud

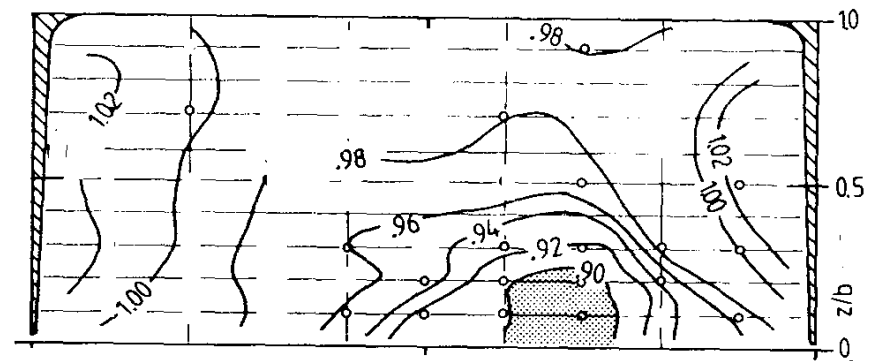


Experiment

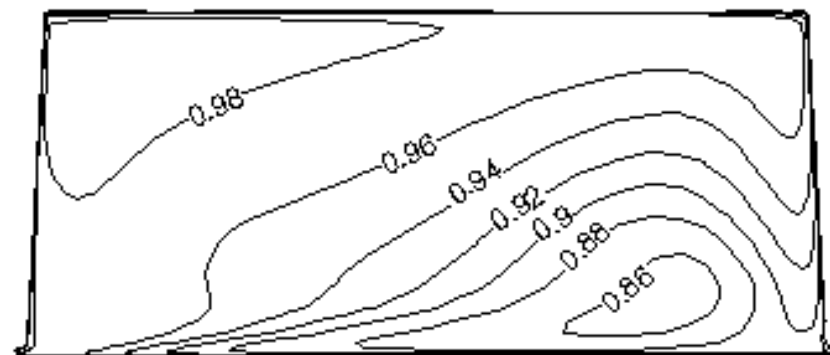


Computations

Relative total pressure distribution
at impeller discharge



Experiment



Computations

Conclusions

- Parametric computations of three-dimensional turbulent flow in a high-speed centrifugal compressor backswept impeller were performed.
- Computational results for local and integral characteristics were compared with data of widely known experiments.
- The tip-clearance width, varied in the present computations, has a small influence on overall performance. Efficiency is overpredicted, and the outlet-to-inlet pressure ratio is underpredicted in all the cases computed.
- The best agreement between the measured and computed velocity fields was achieved when the tip-clearance value was set to 50% of the value measured in the experiments under non-rotating impeller conditions.