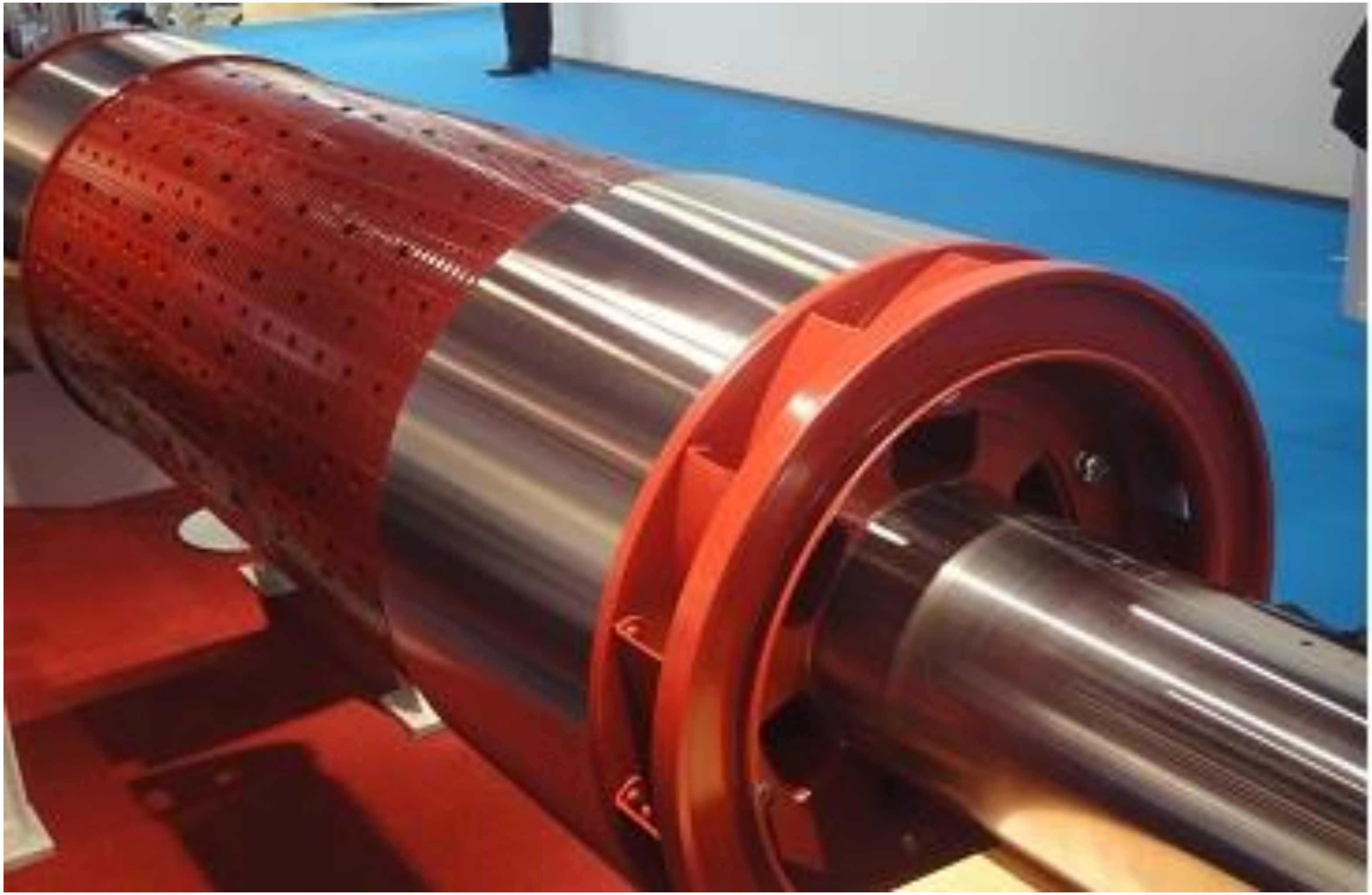
Shaft-mounted radial fan for the cooling of an electrical motor

Dipl.-Ing. Karim Segond
http://e-cooling.com/

FloEFD Simulation Conference 2017

E-COOLING
3D Simulations for Electro Cooling

Introduction
Picture of a shaft-mounted fan motor or generator



Contents

Introduction

- Fan is pressure generator

- Rotor and stator of the motor are pressure drops
  If cooling channels are placed radially in the rotor, the rotor works as be a pressure generator.
  This is state or the art for large hydro generators.

Introduction
Radial Fans

- Also called centrifugal fans
- The ratio of the pressure to the volume flow is normally much higher than for an axial fan
- The choice of an axial or a radial fan also depends on the place constraints
- Due to the relatively small pressure rise, the flow can be seen as incompressible when setting-up CFD calculations

Introduction
Radial Fans

- Either, the fan is designed for the project by the motor manufacturer. Usually, the case when shaft-mounted

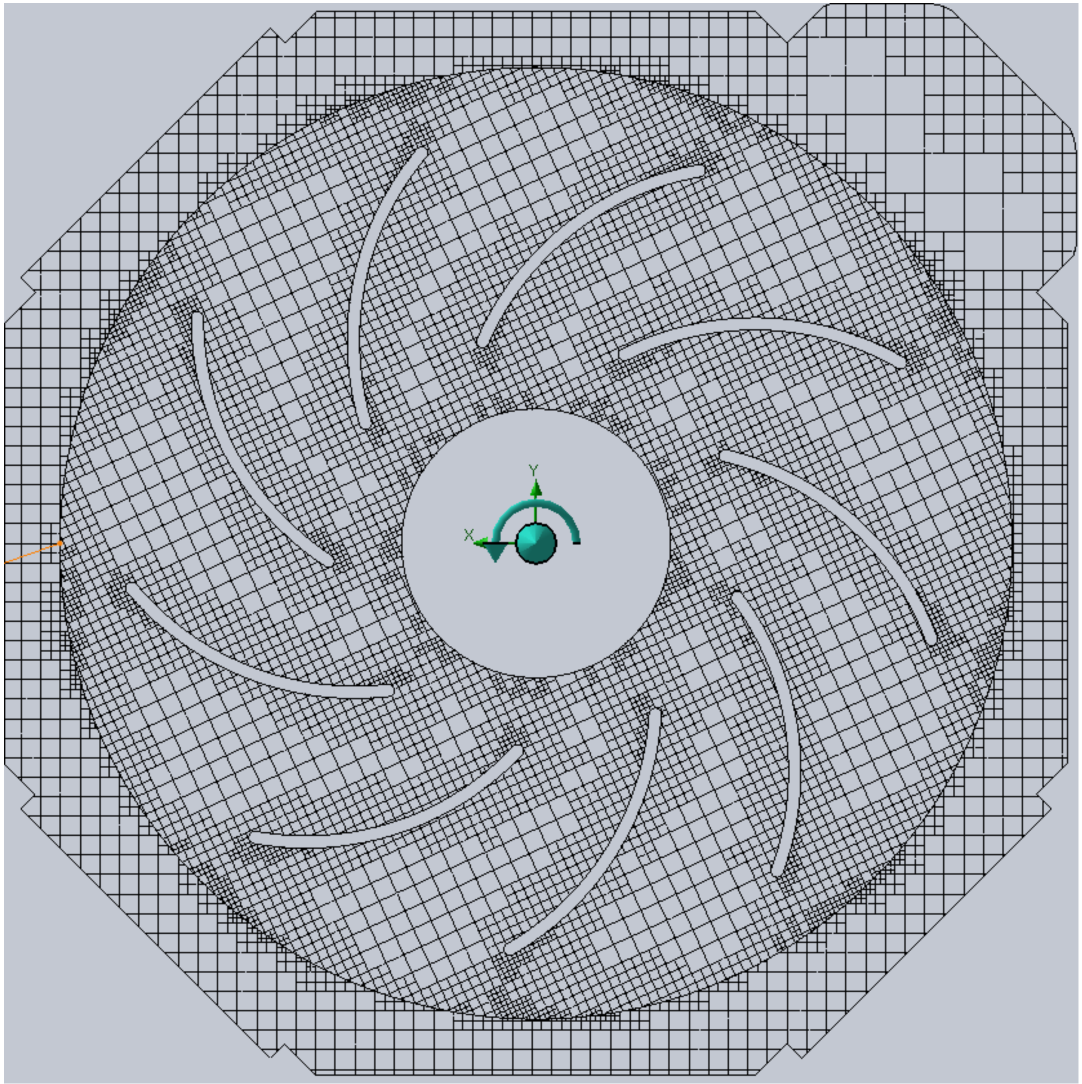
- Or, the fan is supplied by a fan manufacturer.
  Usually, the case when separate driven

The fan curve must be provided by the manufacturer.
The measurements of the curves are standardized according to "ISO 5801 Industrial fans".
These curves are usually too good as they are valid for ideal conditions.

Introduction
shaft-mounted fan

- The fan has the same rotational speed as the rotor
- Main factors for sizing are the inside and outside diameter of the blades
- Back-curved design brings better efficiency:
  Circumferential speed at the trailing edges is reduced → Total pressure also reduced.
  Effect is however reduced when operating with high pressure and low volume flow.

Introduction
The fan



Rotational speed=
1500 cycles per minute

Number of blades = 9

Inside diameter = 200 mm
Outside diameter = 400 mm

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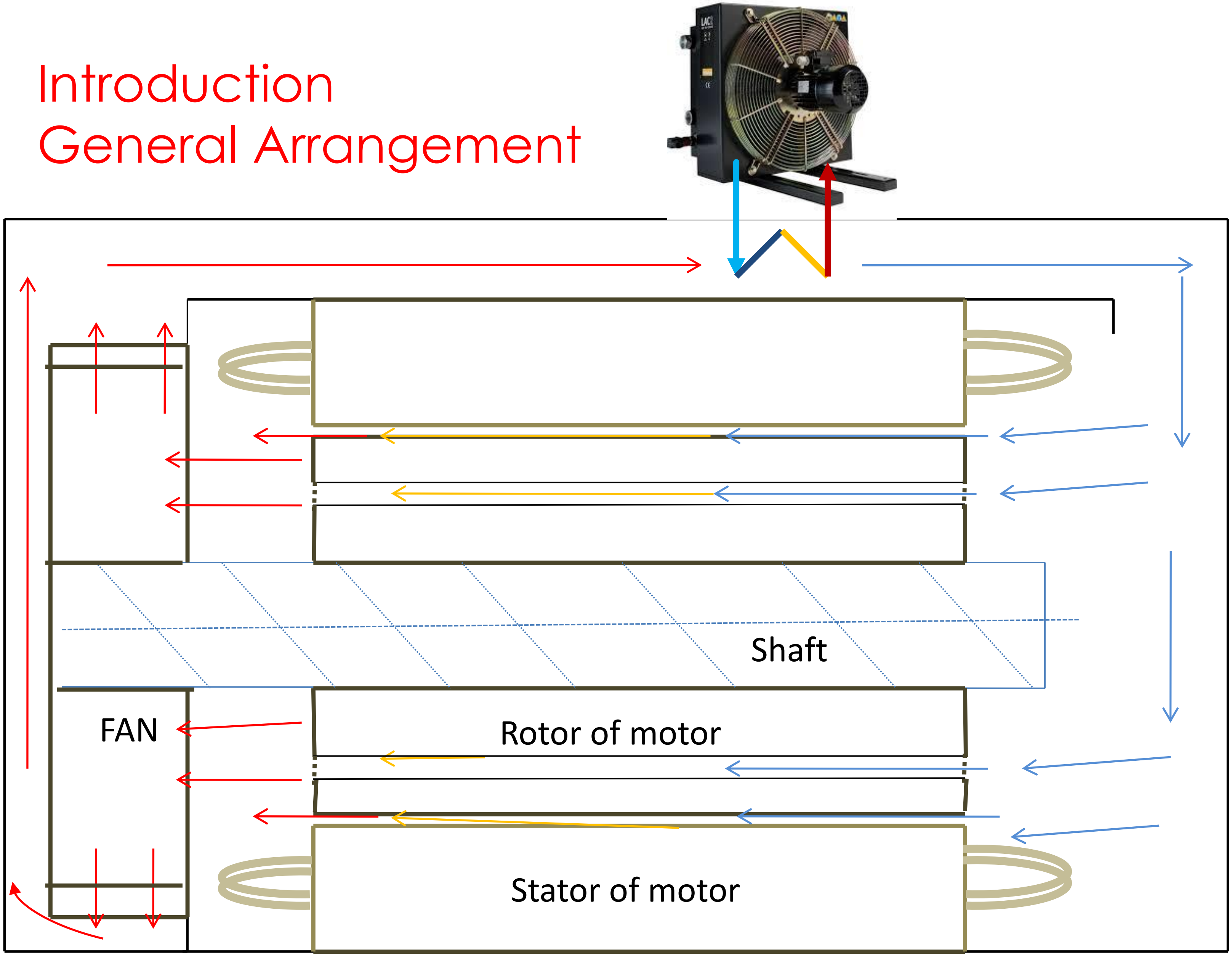
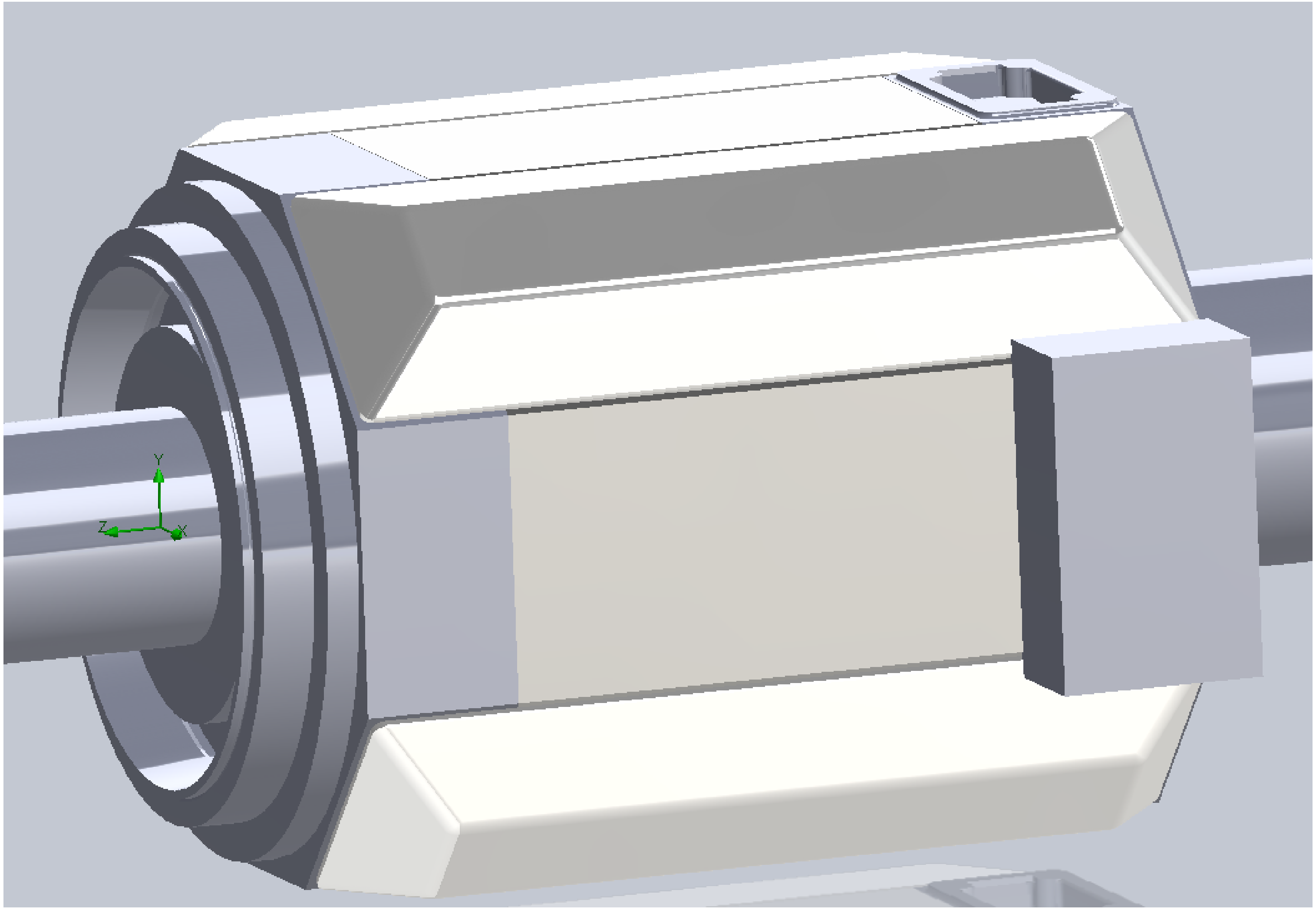
Introduction
General Arrangement



Introduction
The casing



Introduction
Table of calculations

1- Fan design calculations

Geometry check

Only the fan is rotating, rotor of the motor is not rotating

Estimation of the overall volume flow

Estimation of the fan curve

2- Overall flow calculations

Fan and motor are rotating

Overall very fine mesh

3- Thermal calculations

Overall volume flow is input in order to save calculation time

Fan casing is filled with a solid part

Fan design
Simulation of the fan rotation

Necessary for

- developing the fan
- estimation of the fan curve

The complete CAD-geometry including the blades is mandatory

Definition of an axisymmetrical rotating region with own rotating coordinate system.

Influence of the Coriolis and centrifugal forces are considered in the equations of movements.

Fan design
Local Region (averaging)

- Local Region (averaging)

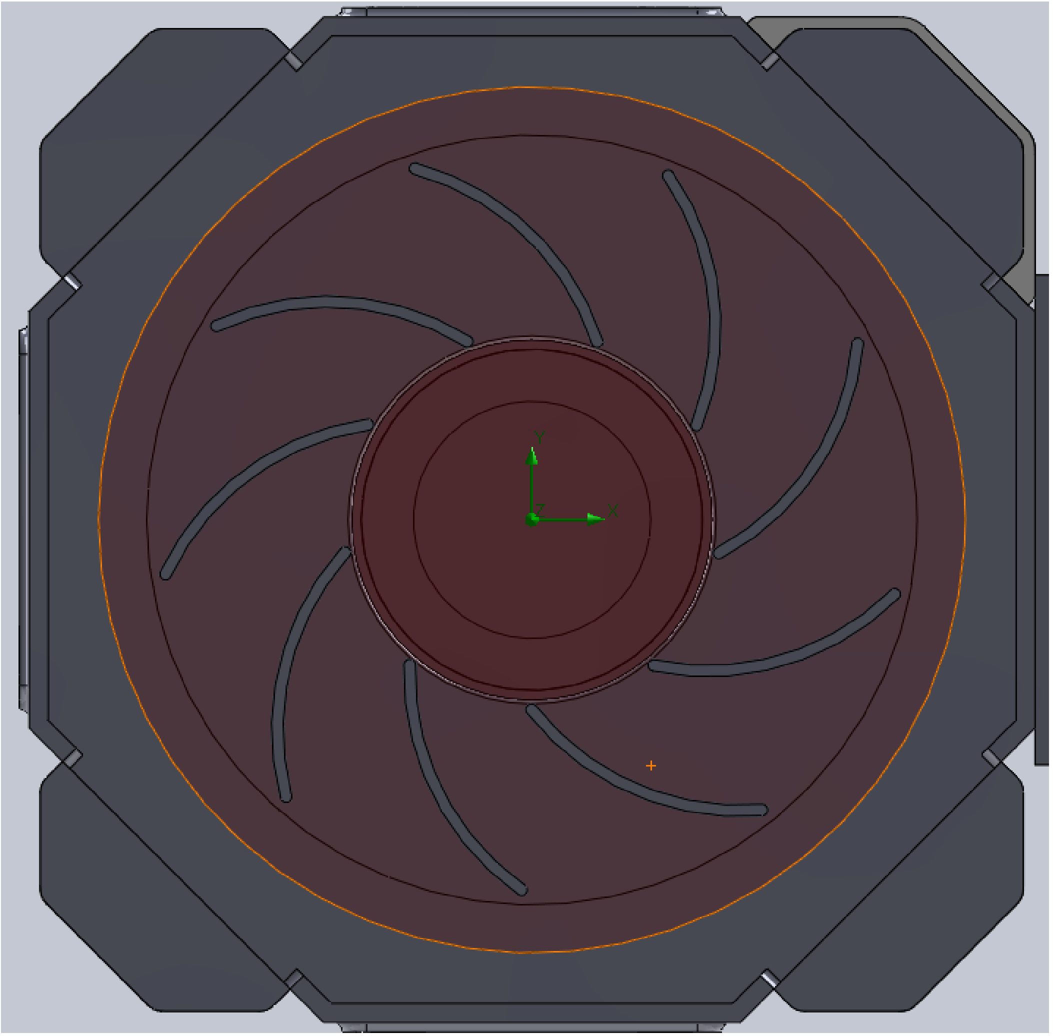
also called Moving Reference Frame

Usually steady-state calculation

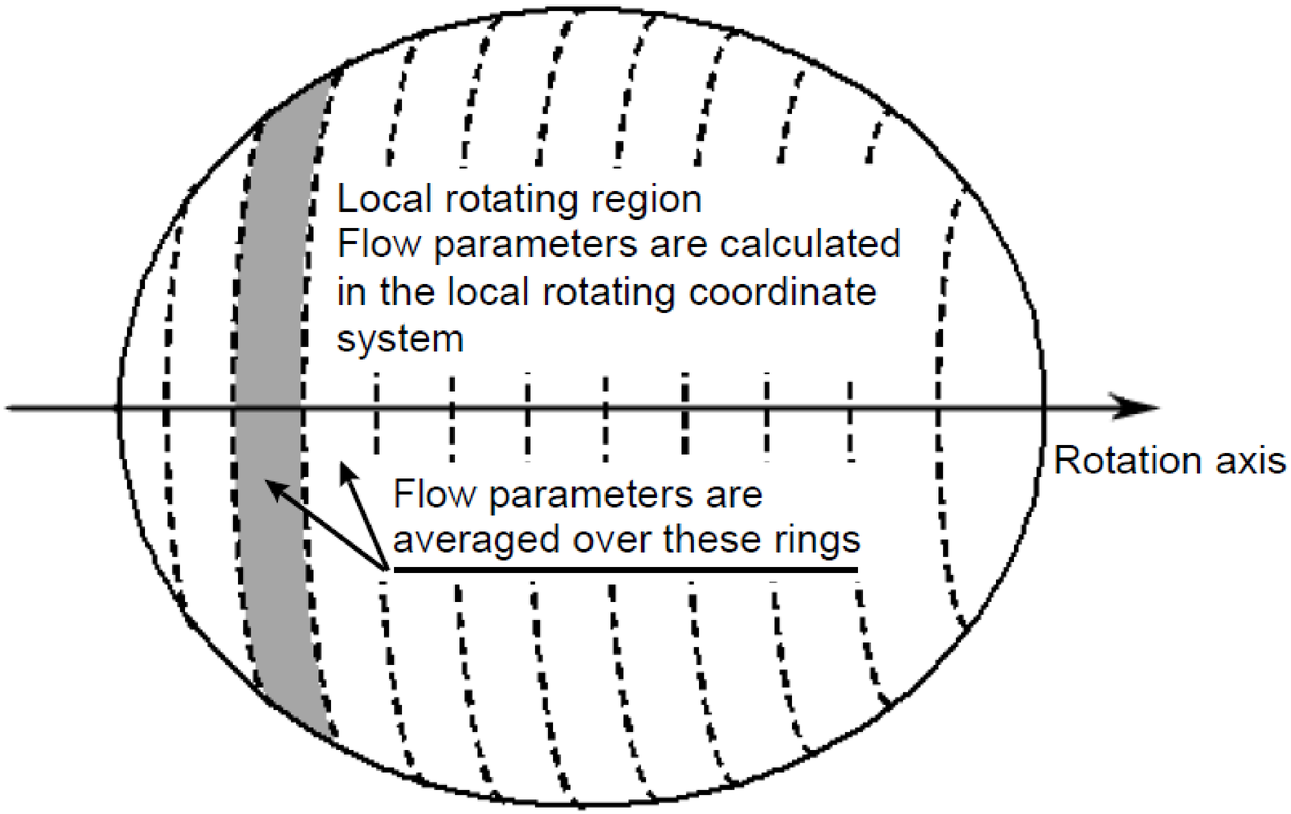
The connection between rotating and stationary blocks is done with Internal boundaries.

Needs many iterations to reach meaningful results

Fan design
Definition of the rotation domain



Fan design
Local Region (averaging)



Fan design
Sliding Mesh

- Sliding Mesh

also called moving mesh

time-dependent (transient)

When the geometry is not axisymmetric and the rotor-stator interaction is strong

The input of the time step is main convergence parameter

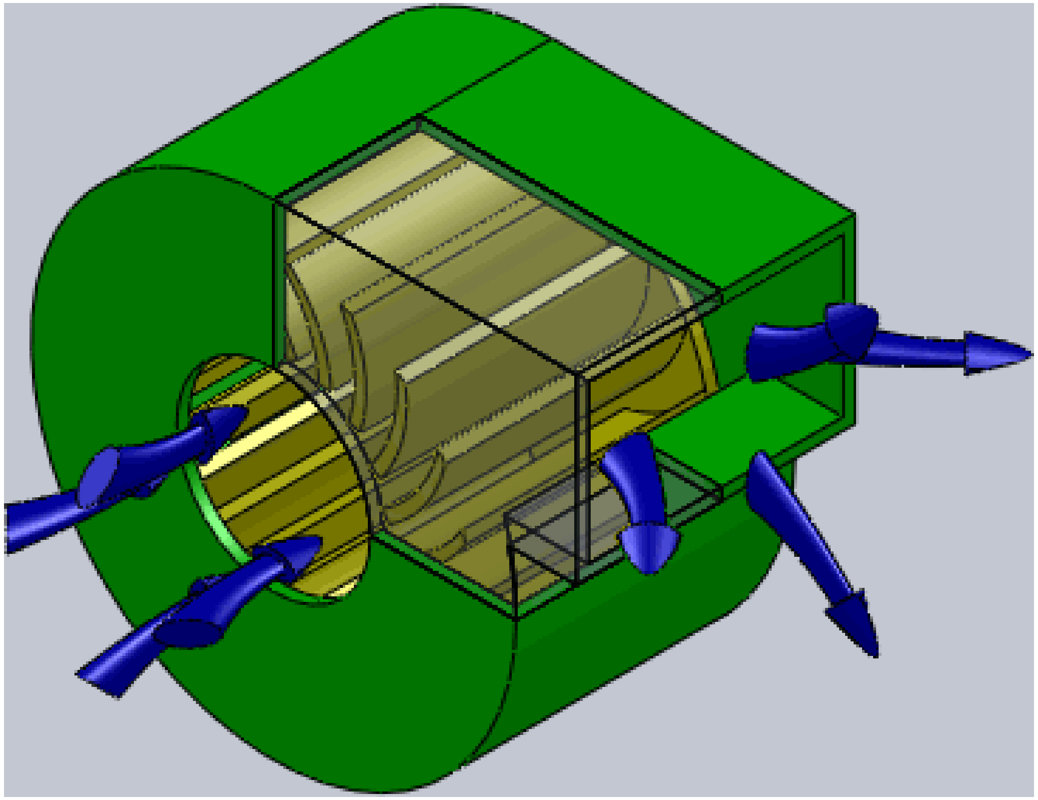
<u>My experience:</u>

Different convergence behaviour as Local Region (averaging).

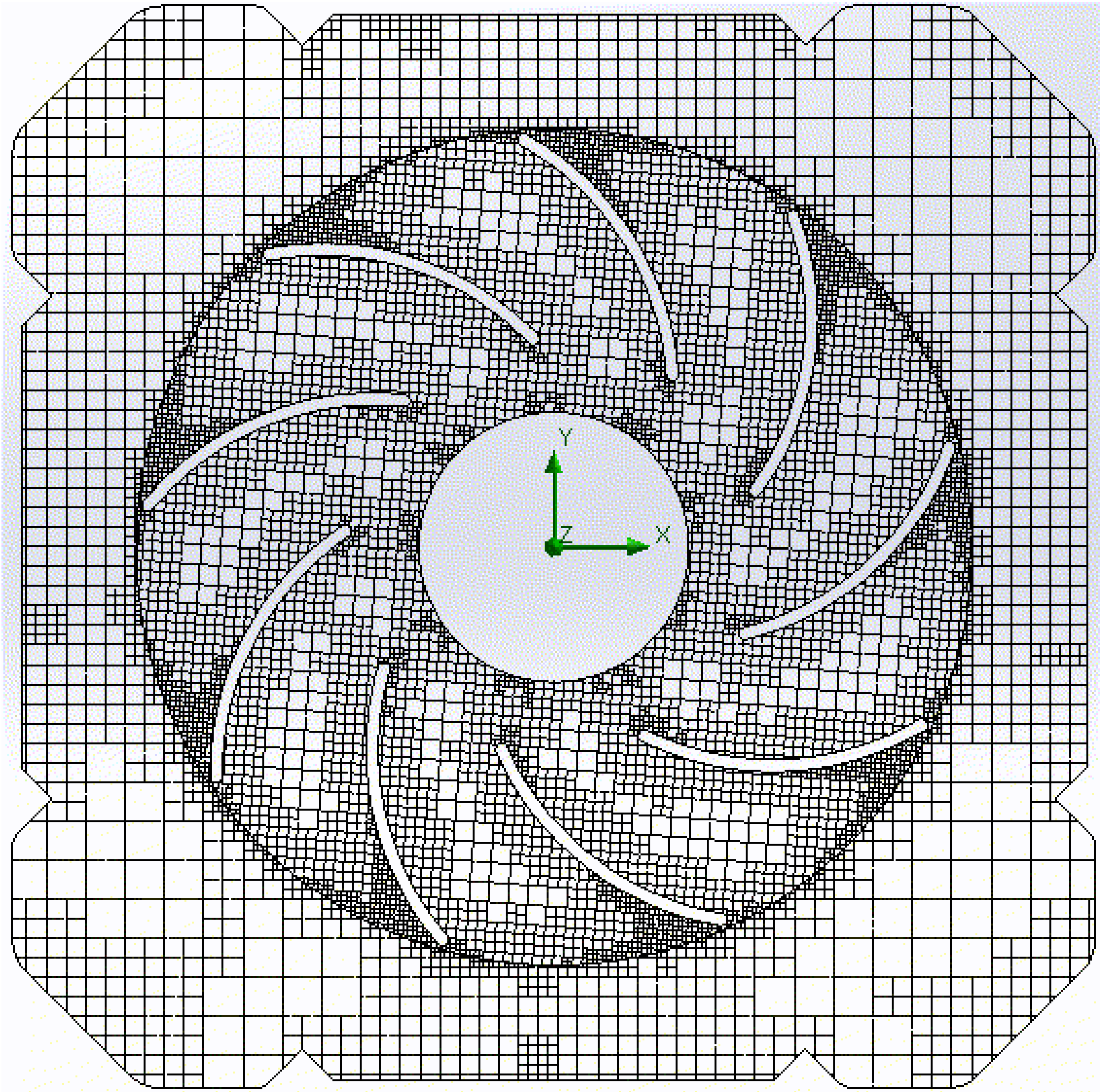
Calculation time is longer but can be reduced by setting the time steps in an appropriate way.

Best method for any geometry of radial fan!

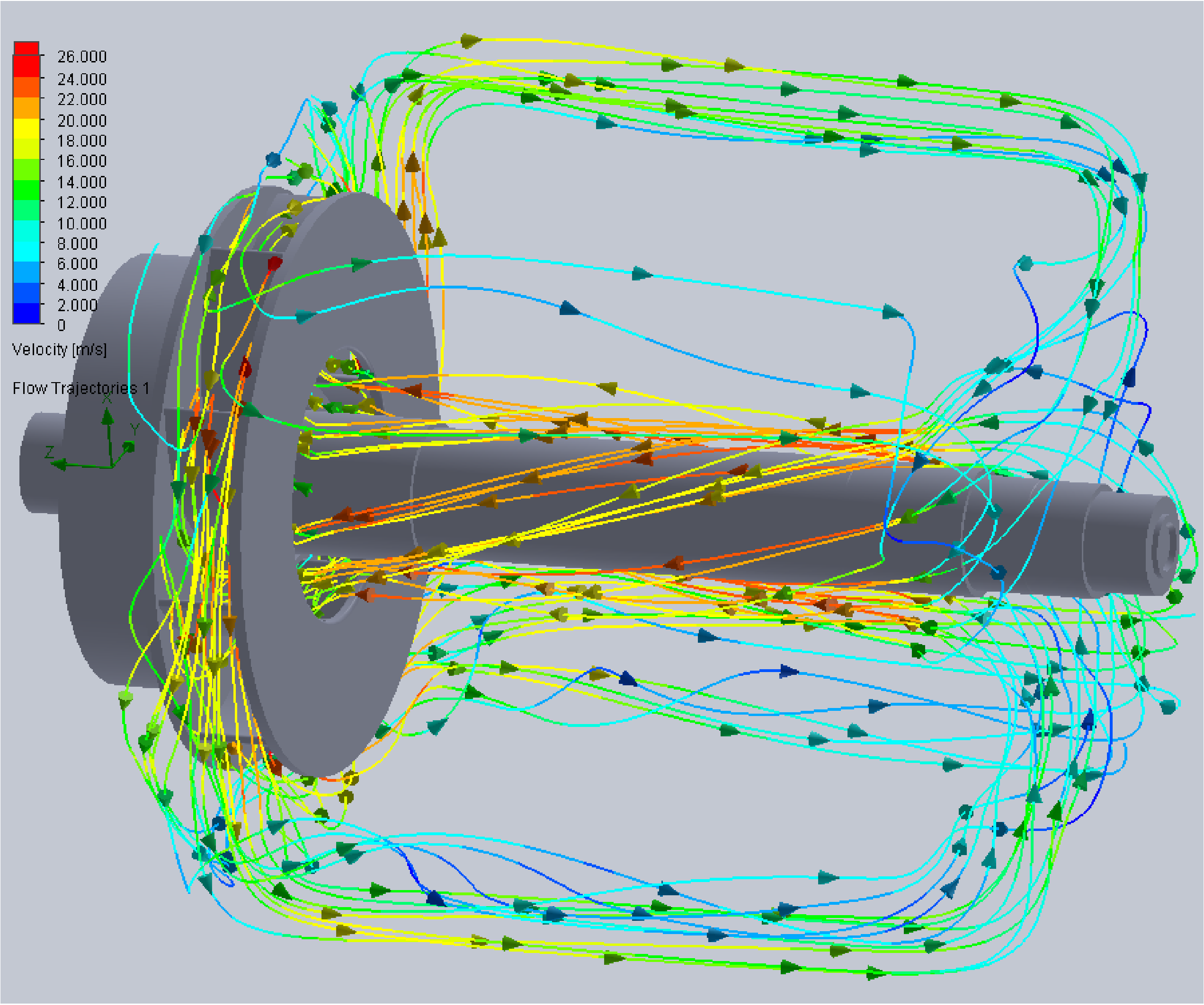
Fan design
Example of non axissymetrical rotation



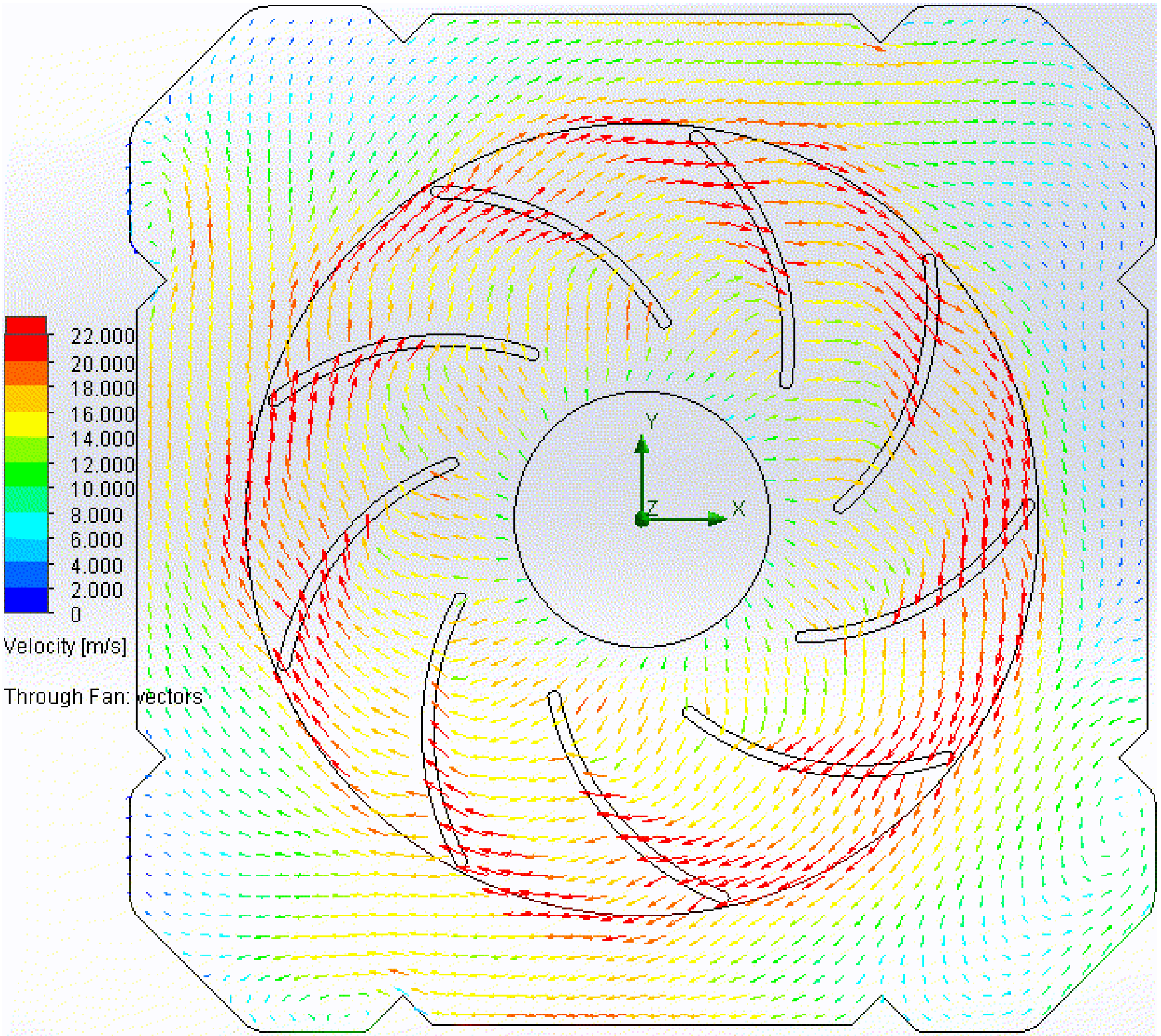
Fan design
Sliding mesh



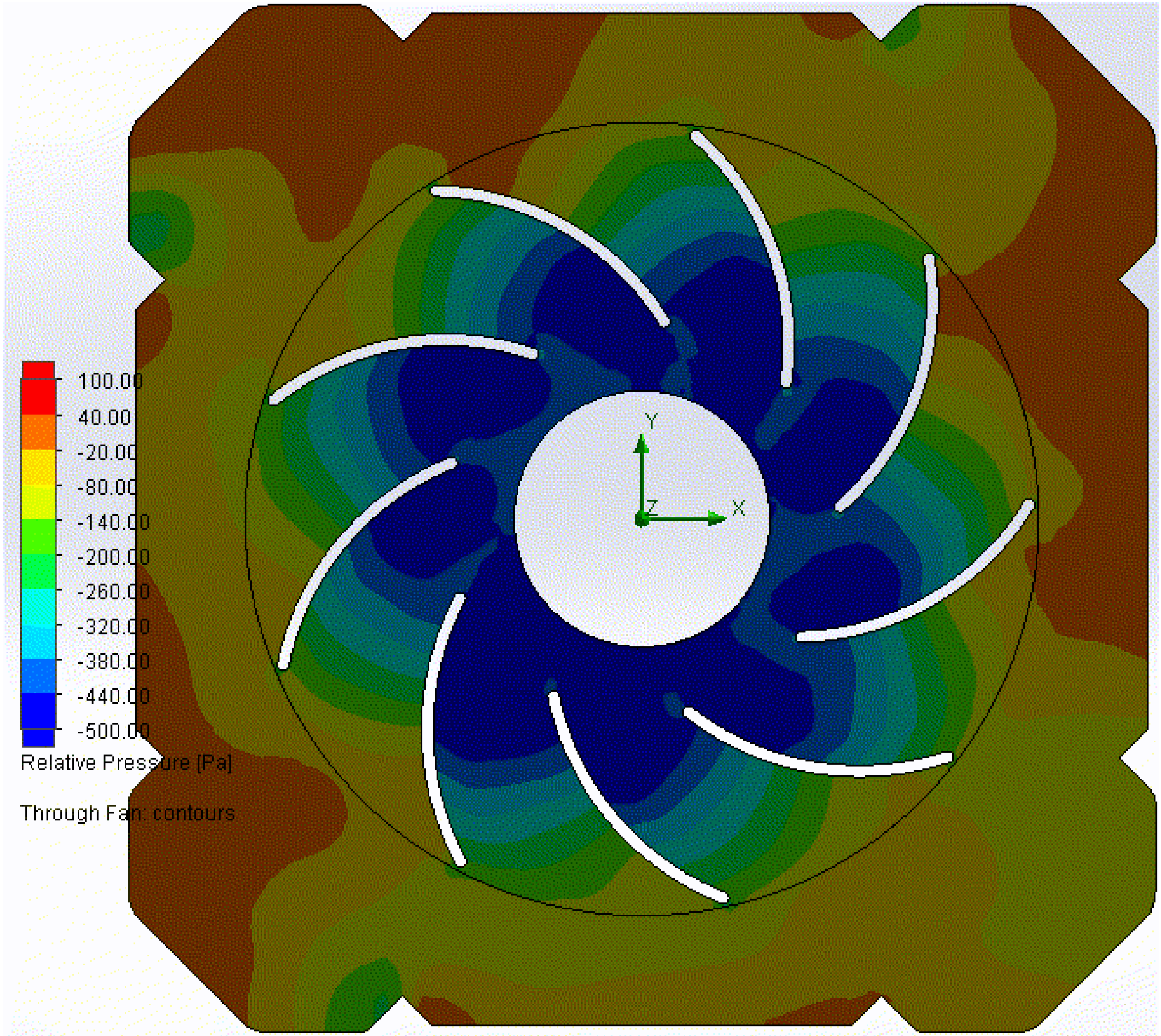
Fan design
Four channels case: streamlines



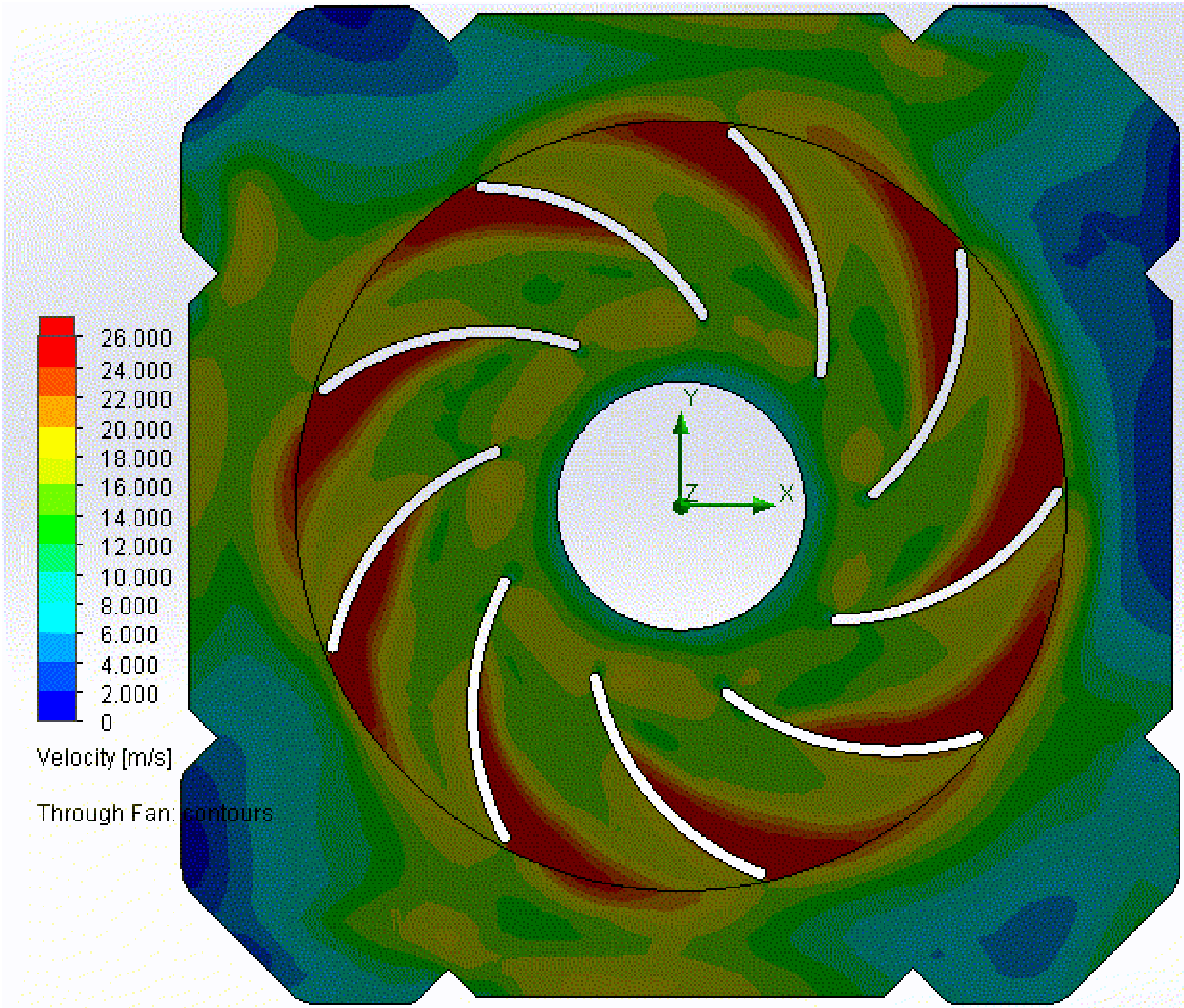
Fan design
Four channels case: Velocity vectors with sliding mesh



Fan design
Four channels case: Pressure contour with sliding mesh

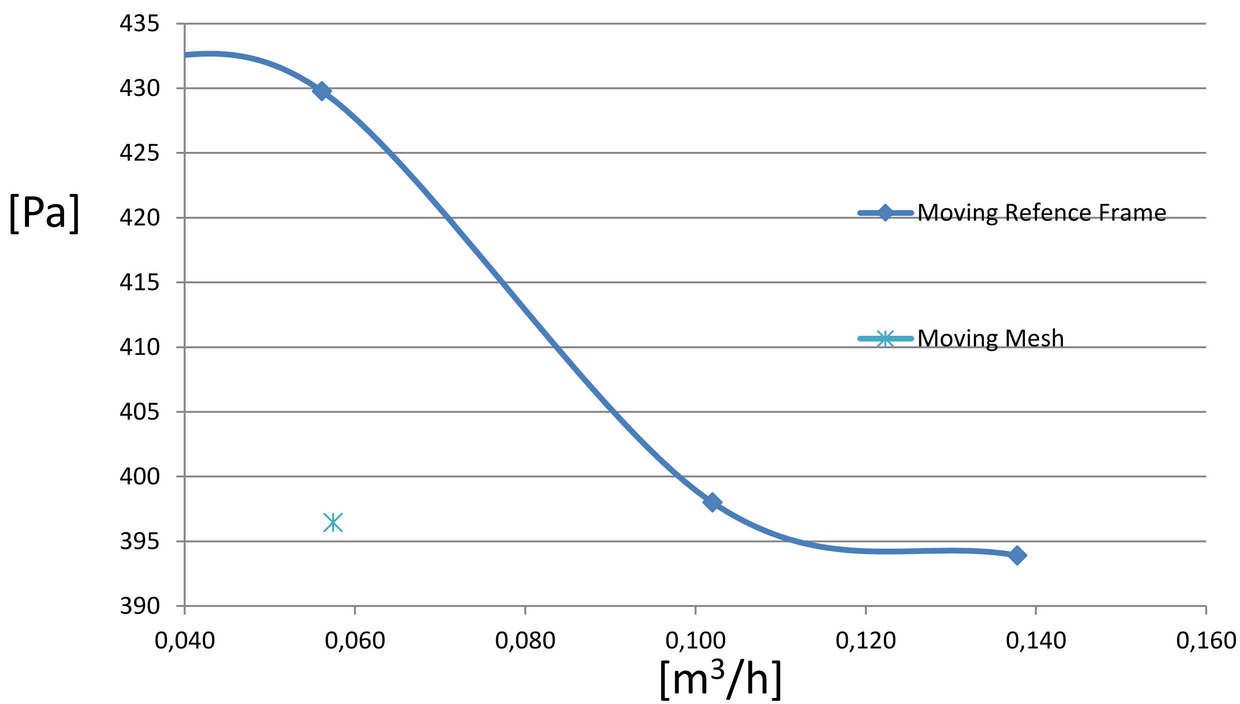


Fan design
Four channels case: Velocity contours with sliding mesh



Fan design
Moving reference frame vs sliding mesh

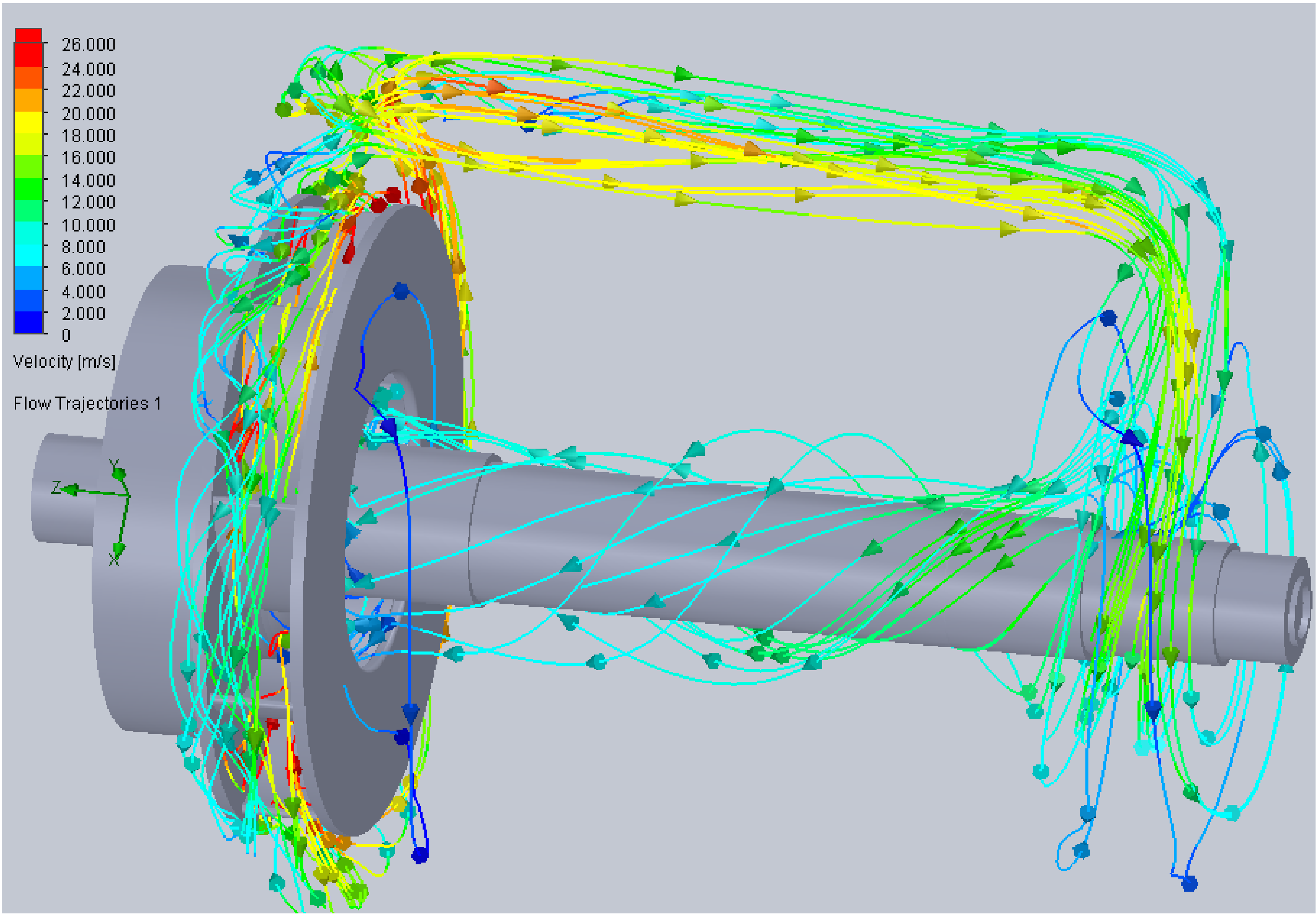
In order to create the complete curve of the fan with the mrf method, the geometry has been changed in order to increase and to decrease the pressure losses.



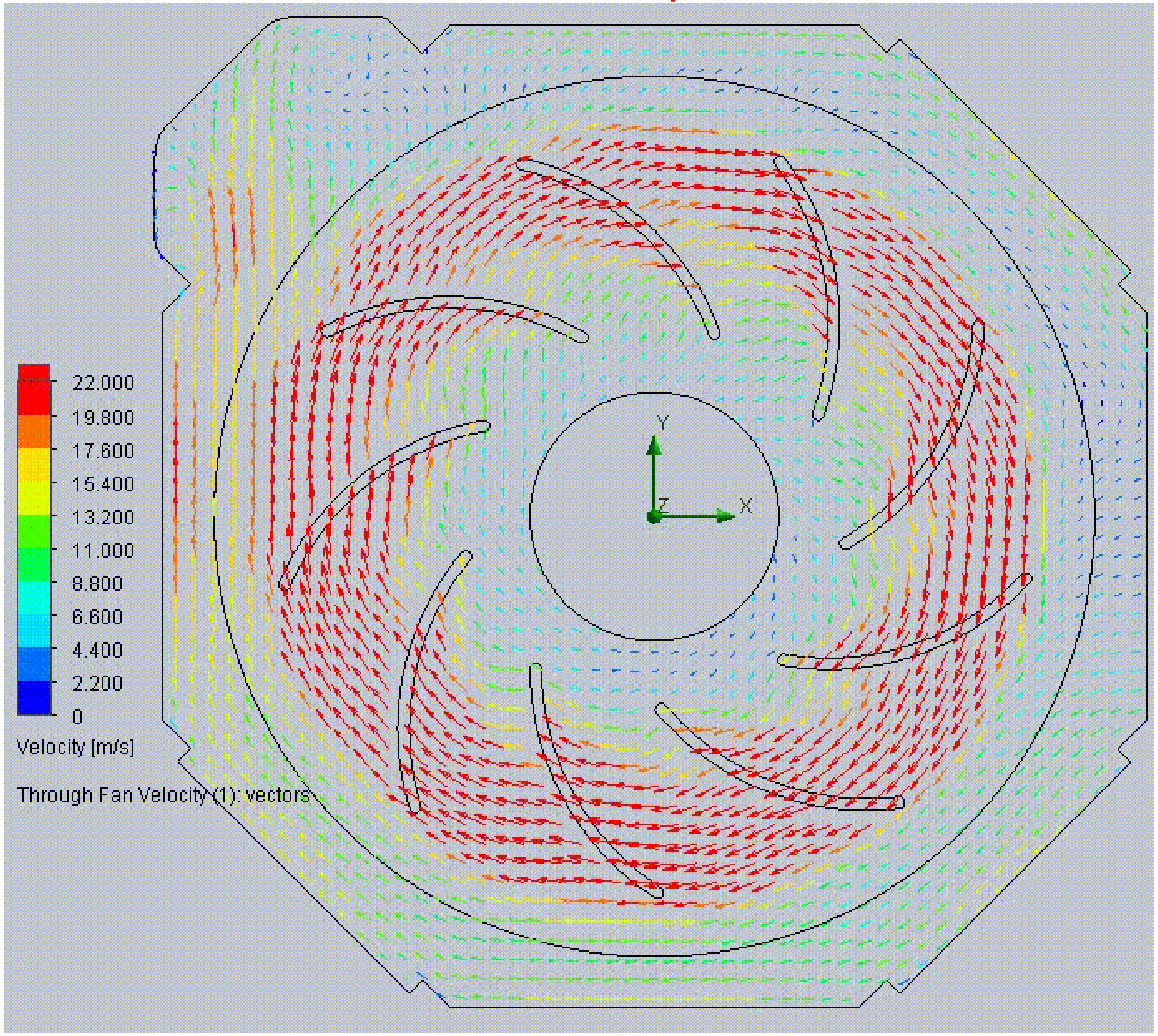
the fan is operating with a high-pressure difference. By slightly reducing the flow resistance, the volume flow could be massively increased.

Pressure generation over volume flow for the cooling of a generator

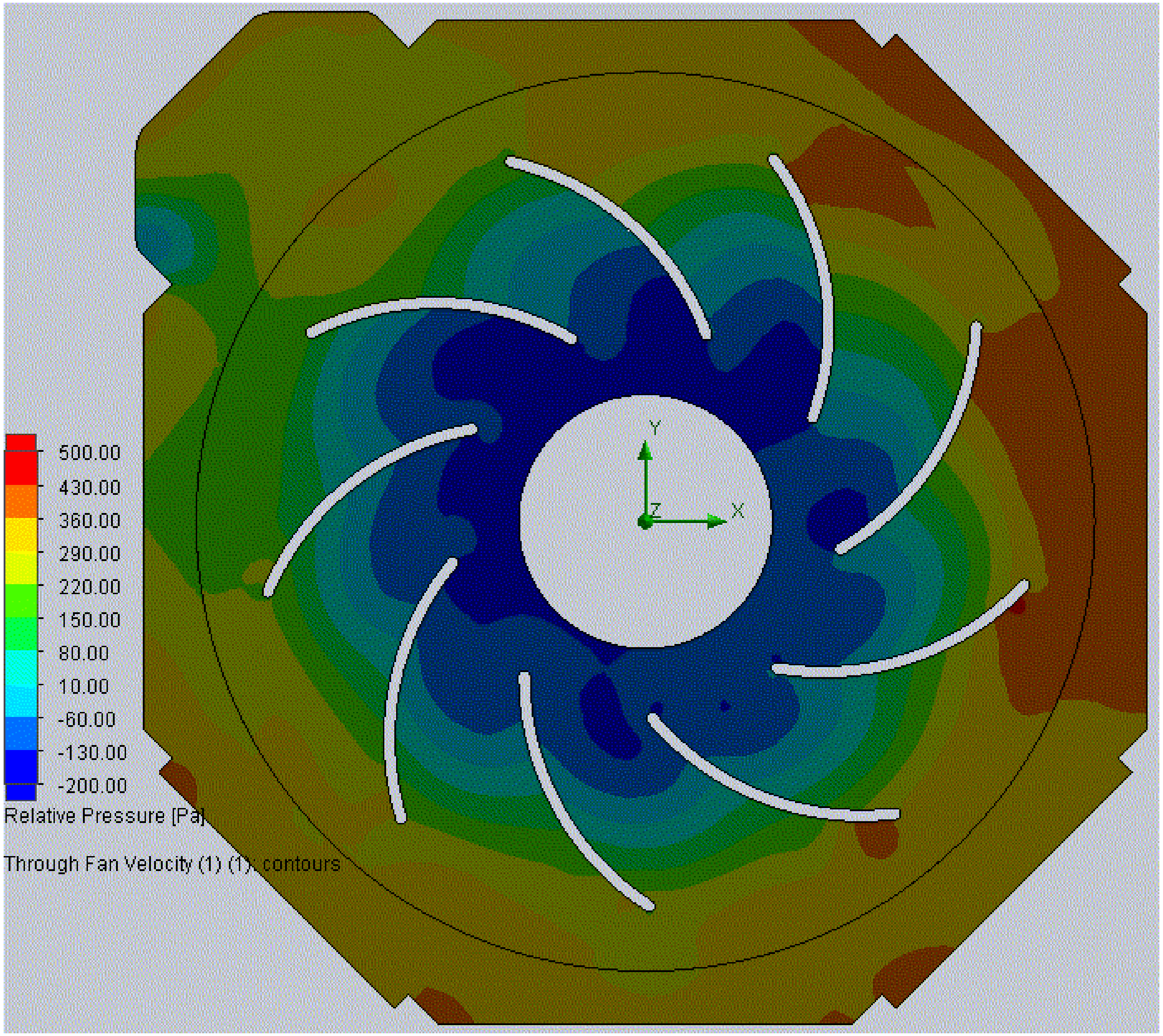
Fan design
One channel case: streamlines



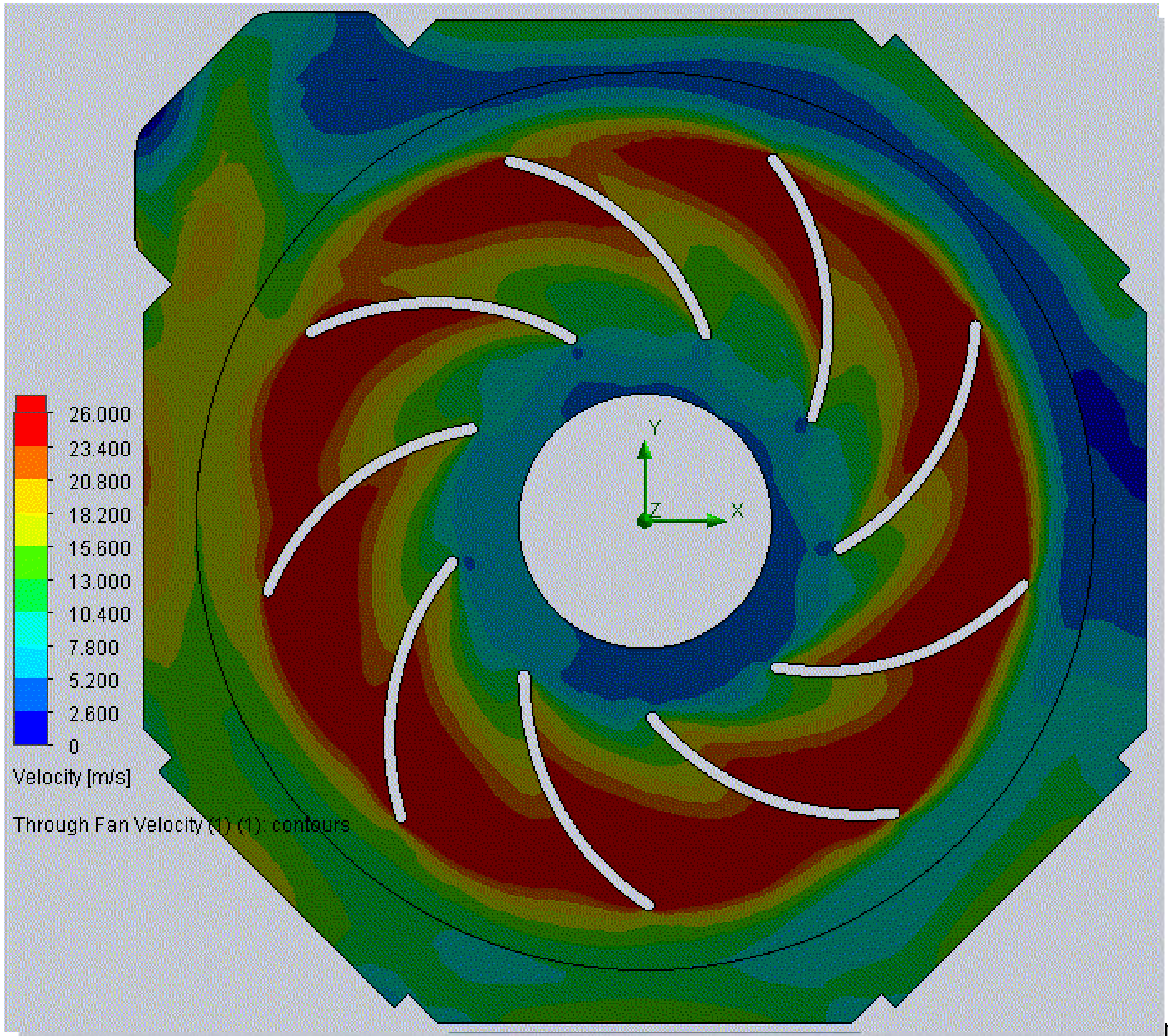
Fan design
One channel case: Velocity vectors with sliding mesh



Fan design
One channel case: Pressure contour with sliding mesh



Fan design
One channel case: Velocity contours with sliding mesh



Overall flow calculation
Volume flow or pressures as input

- Inlet volume flow and exit atmospheric pressure
- Inlet and outlet pressures

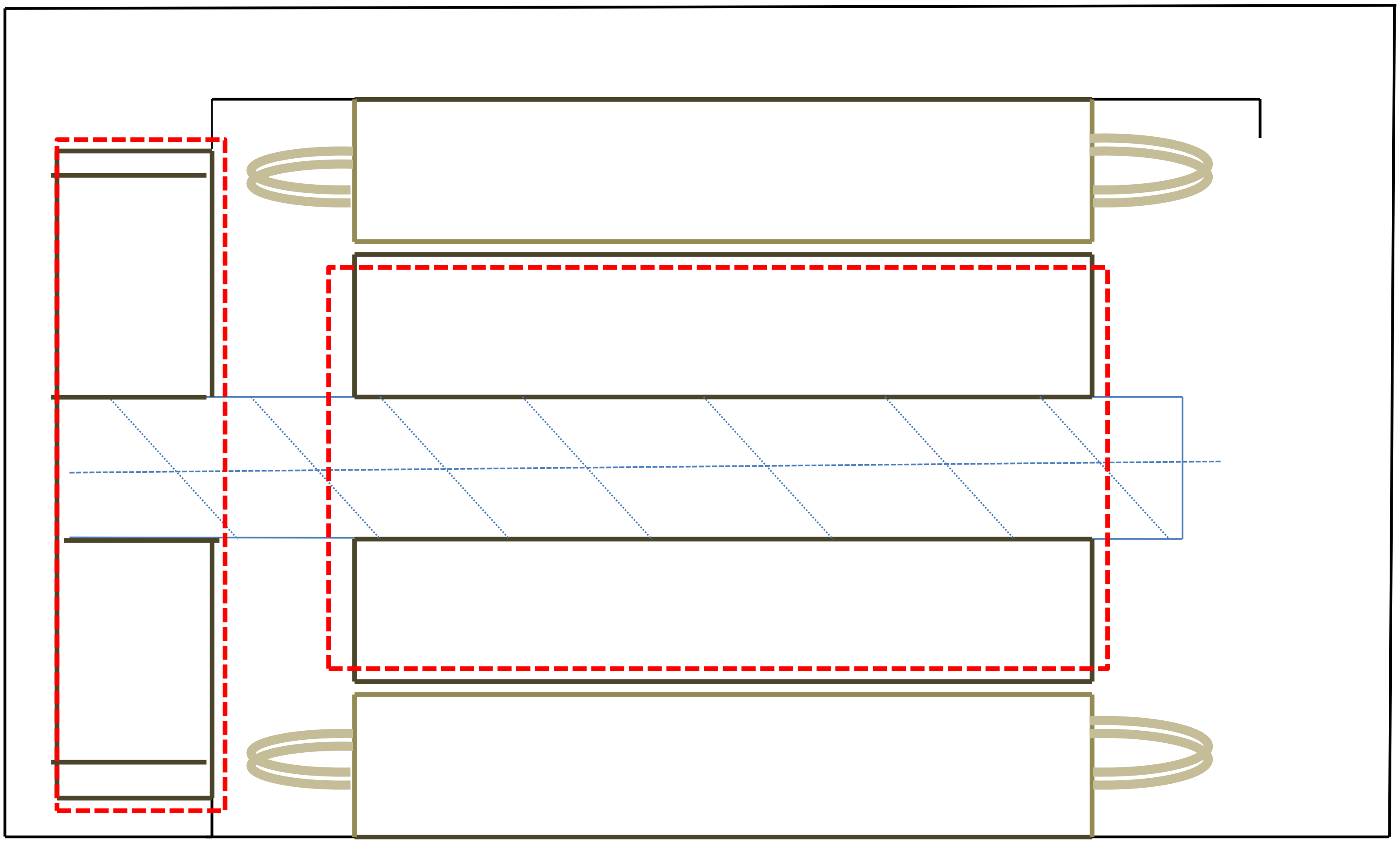
If the calculated overall pressure drop or volume flow is not as expected, the inlet condition should be corrected and the calculation restarted.
For flow optimization calculations with inlet volume flow, pressure drops decrease will not result in volume flow increase.
Good if you know for sure the inlet conditions

Overall flow calculation in comparison with fan design

Radia Fan design	Stationary	Time-dependent
Fan as Local Region (averaging)	×	×
Fan as Sliding Mesh		×

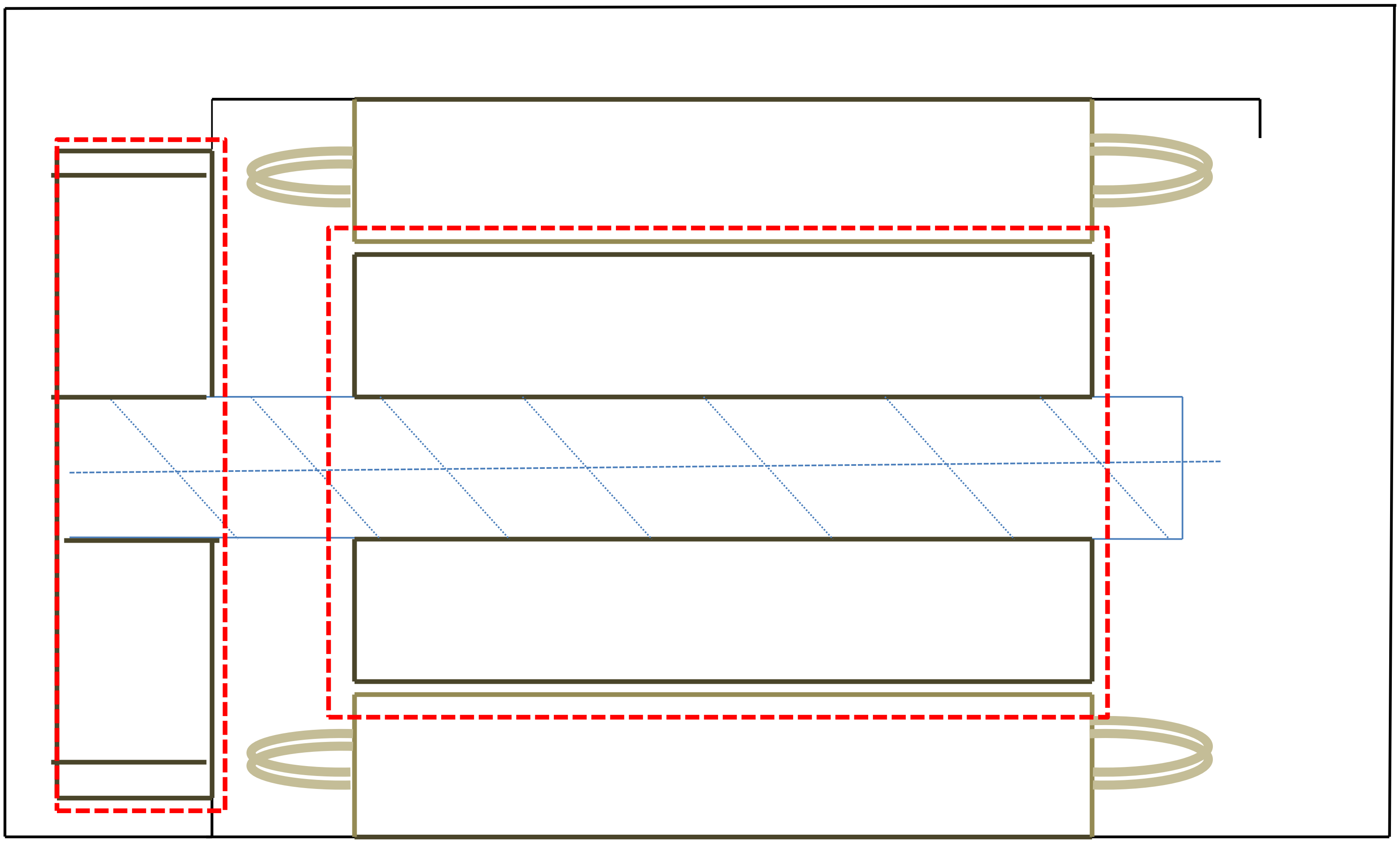
Overall flow or thermal calculations Fan fully modelled or as boundary conditions	Stationary	Time-dependent
Rotor as Local Region (averaging)	×	× Conjugated transfer
Rotor as Sliding Mesh Region (averaging)		× Only flow

Overall flow calculation
Definition of rotation domain: possibility 1



The rotor surfaces not included in the rotation domain as well as the shaft are defined as rotating walls

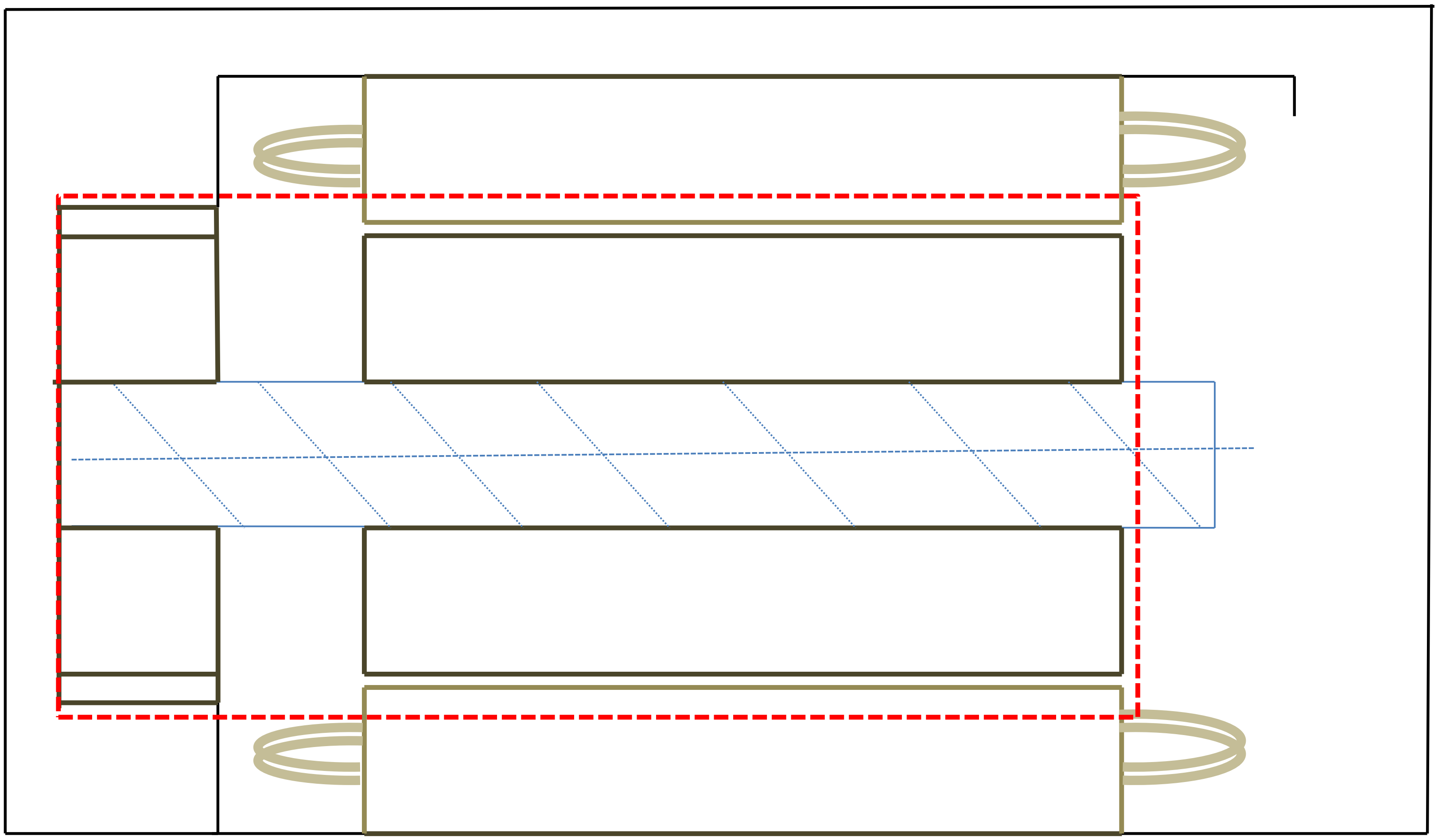
Overall flow calculation
Definition of rotation domain: possibility 2



The stator surfaces included in the rotation domain are defined as stationary walls. Shaft surfaces defined as rotating walls.

Overall flow calculation
Definition of rotation domain: possibility 3

Only if geometry allows it



Overall flow calculation
Definition of rotation domain

- Convergence much more longer and harder with simulation of the rotation
- Position of the rotation is very important for the convergence

Thermal calculation
Input for thermal calculations

Copper losses

also called the winding losses

When a current I circulates through a coil with w windings of cross-sectional area A:

$$R = \frac{w \times l}{\kappa \times A} \qquad Losses = R \times I^2$$

Conductivity of copper: $\kappa = 60{,}76 \cdot 10^6 \times \frac{273.15}{273.15 + \vartheta} \Omega^{-1} / m$

- if the winding temperature had been measured, we can use the temperature to calculate the losses beforehand
- or we can set the winding temperature as a goal in FloEFD and give the dependency of the losses with this goal

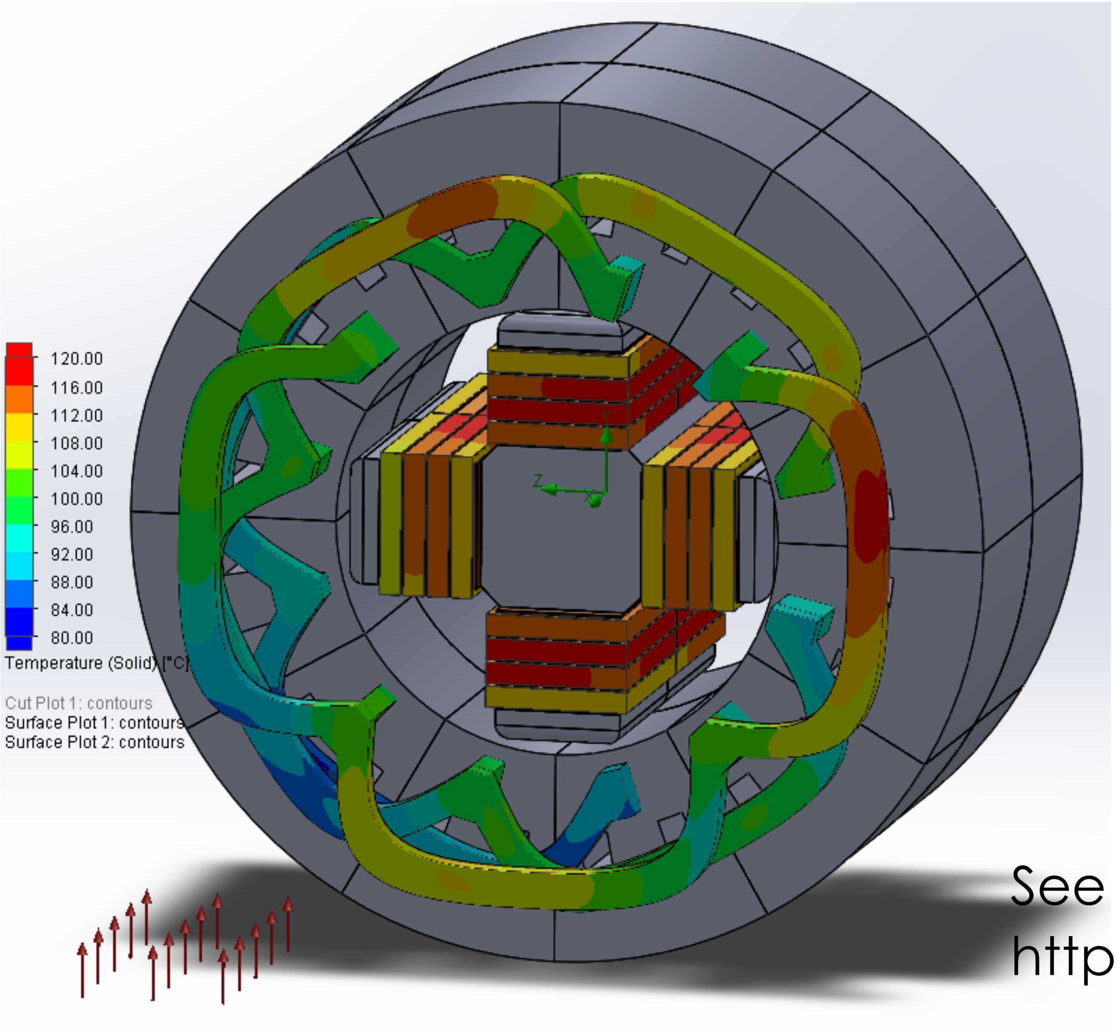
Thermal calculation
Input for thermal calculations

Iron losses

- also called re-magnetization losses
- location can be precisely known through 2D or 3D Finite Elements calculations of the magnetic field
- iron material is slightly temperature dependent; however, iron losses can be considered as constant

No need to do Multiphysics with flow, thermal and magnetic.
Flow calculations of rotating machines & conjugated heat transfer already complex enough.
FloEFD is however very well integrated in the design process as it is embedded in the CAD Tool.

Thermal calculation
Results for different motors



See my previous presentations on http://mentor.com/mechanical

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