TEC Tecnológico de Costa Rica

Modeling the Swirling Flow of a Hydrocyclone

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Presentation overview

- Swirling flows in hydrocyclones
- Experimental values of the simulated flow
- Physical model and governing equations
- Numerical results
- Conclusions

Swirling flows in hydrocyclones

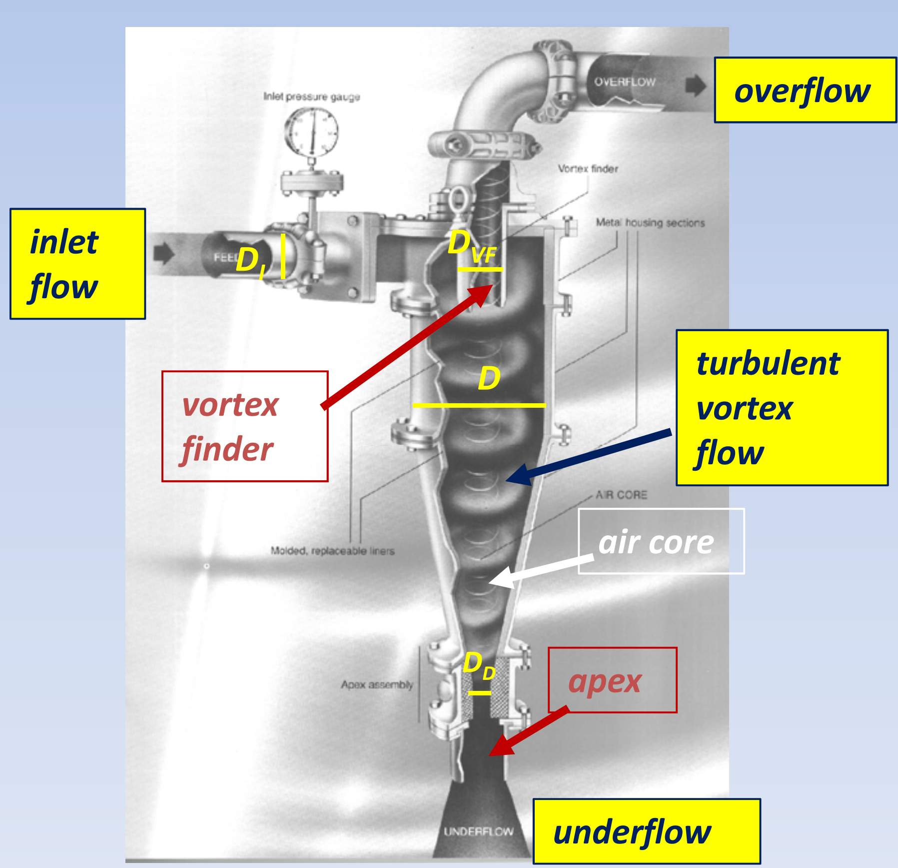
3D swirling flow confined in cylinder-conical geometries [1,2,3,4,5]

- Tangential velocity v_θ → **Rankine vortex**
  $v_\theta = k_1 r$ *forced vortex* (rotation of a rigid body)
  $v_\theta = k_2 / r$ *free vortex* (potential vortex)

- Axial velocity v_z → **two opposite flows**
  a flow direct to the apex and a reverse flow direct to the vortex finder

- Radial velocity v_r → *small (10^{-2} m/s)*

- Air core → controls the liquid splitting to the outlets



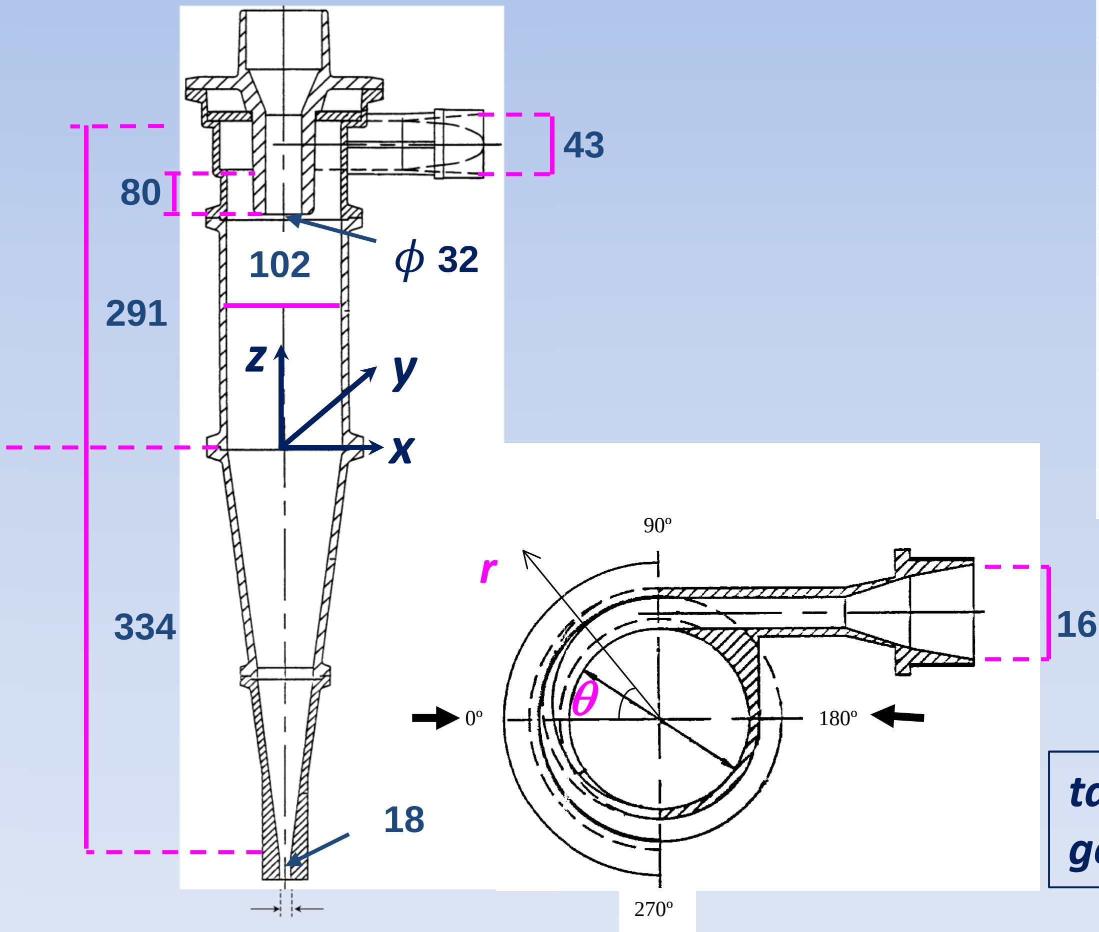
Swirling flows in hydrocyclones

From experimental works (LDV) we know that the flow in a hydrocyclone has the following properties:

- ⇒ **velocity profiles of v_z and v_θ are not completely axisymmetric**
- ⇒ **v_z ,v_θ, and their RMS values σ_z and σ_θ, only change their magnitude with pressure Δp**
- ⇒ **v_z changes with z**
- ⇒ **turbulence is neither *homogeneous* nor *isotropic* : σ_z and σ_θ are different and depend on z and r**
- ⇒ **the position of the air core depends on Δp and the ratio D_{VF}/D_D (vortex finder diameter/apex diameter)**

Computational work: geometry and experimental values

dimensions of diameters and heights given in mm

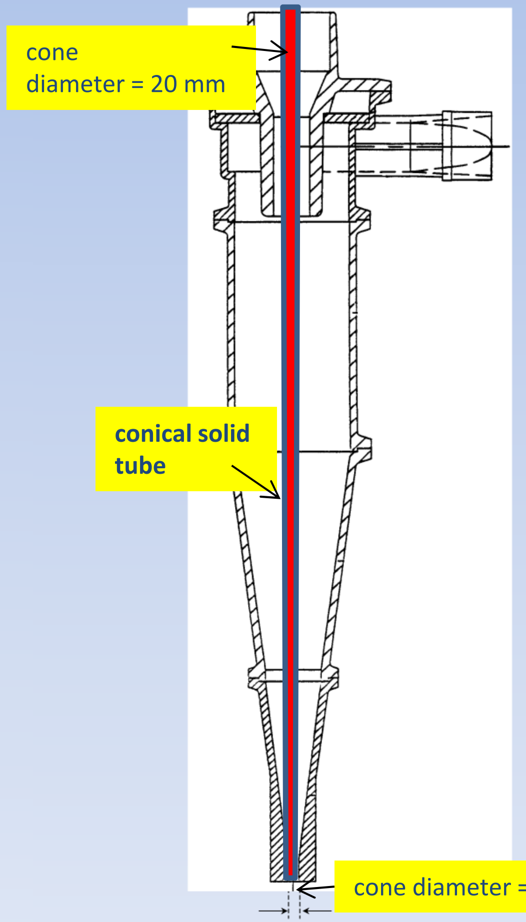


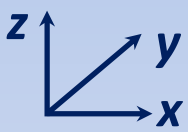
Magnitude	Value
Inlet flowrate Q	2.50 l/s
Inlet area A= 43 mm x 16 mm	0.688×10^{-3} m^2
Inlet velocity V_{in}	3.63 m/s
Pressure drop Δp	62.05 kPa
Water dynamic viscosity μ	10^{-3} Pa·s
Water density ρ	10^3 kg/m^3
Diameter D of the hydrocyclone	102 mm
Mean axial velocity inside the hydrocyclone $V=4Q/\pi D^2$	0.306 m/s
Reynolds number $Re= \rho VD/\mu$	3.12×10^4

tangential inlet :
generation of the vortex flow

Computational work: hypothesis of the model

dimensions of diameters and heights given in mm





- **Model is 3D**
- Flow is **stationary**, **turbulent, single phase, incompressible** and **Newtonian**
- **Air core** is modeled as a **conical solid tube** with known (by LDV) diameters (*water is the only phase in the system*)
- Velocity is specified on the inlet
- **Turbulence** is modeled by the RANS equations, using v2-f turbulence model with default parameters
- **Turbulence intensity** of 5% and **turbulence length scale** of 0.07 D_{eq} are set at the inlet (D_{eq} = equivalent diameter)
- **No slip conditions** are assumed on the solid walls
- **Slip** conditions are considered on the tube walls of the air core
- **Zero normal stress** is the boundary condition at the outlets

Equations: RANS and v2-f turbulence model

$$\rho \nabla \cdot \mathbf{U} = 0$$

$$\rho \mathbf{U} \cdot \nabla \mathbf{U} + \nabla \cdot (\overline{\rho \boldsymbol{u}' \boldsymbol{u}'}) = -\nabla \mathrm{P} + \nabla \cdot \mu\left(\nabla \mathbf{U} + (\nabla \mathbf{U})^{\boldsymbol{T}}\right) + \mathbf{F}$$

$\overline{\rho \boldsymbol{u}' \boldsymbol{u}'}$ is the Reynolds stress tensor

- $\overline{\rho \boldsymbol{u}' \boldsymbol{u}'}$ computed by using the Boussinesq hypothesis and relating it to mean velocity gradients and turbulent viscosity
- v2-f turbulence model assumes turbulent viscosity as based on the velocity fluctuations $\overline{\boldsymbol{v}^2}$ normal to the streamlines, making it possible to represent turbulence anisotropy [15]

Solution with Comsol Multiphysics 5.3a

free tetrahedral volumes, *fine* (size 1) element in the hydrocyclone and *finer* (size 2) element on the solid walls

nine boundary layers on the solid walls, using default values of the software

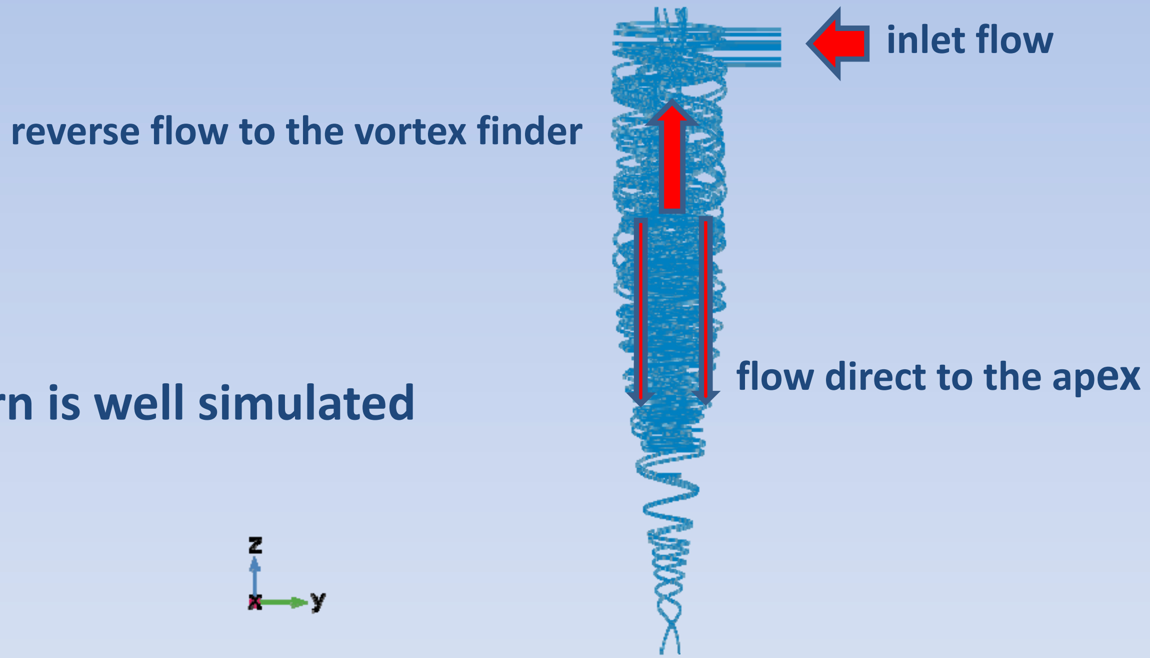
Parameter	Size
maximum element of size 1	6 mm
minimum element of size 1	0.4 mm
maximum element of size 2	6 mm
minimum element of size 2	0.2 mm

- a ***first study*** (*Wall Distance Initialization*) to calculate the reciprocal wall distance of the v2-f turbulence model
- a stationary ***second study*** to compute the swirling turbulent flow

the number of degrees of freedom is 1.2×10^5 for the first study and 9.5×10^5 for the second study

Numerical results: streamlines in the hydrocyclone

the general flow pattern is well simulated

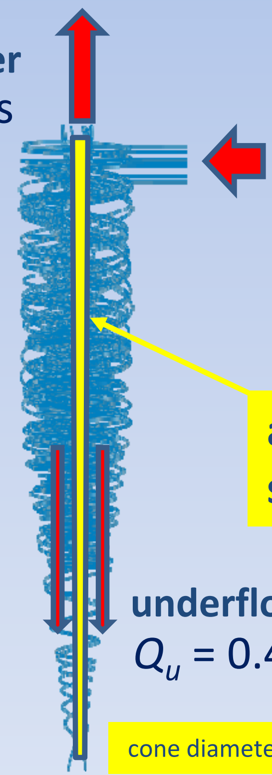


Numerical results: flow split is computed

vortex finder outlet: BC is zero normal stress

overflow to the vortex finder
Q_o= 1.9754 l/s

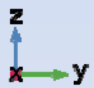
cone
diameter = 20 mm



inlet flow
Q = 2.5 l/s

air core: modeled as a solid cone

flow split computed and not set before
relative error is 1.65%
it depends also on the air core **diameters**

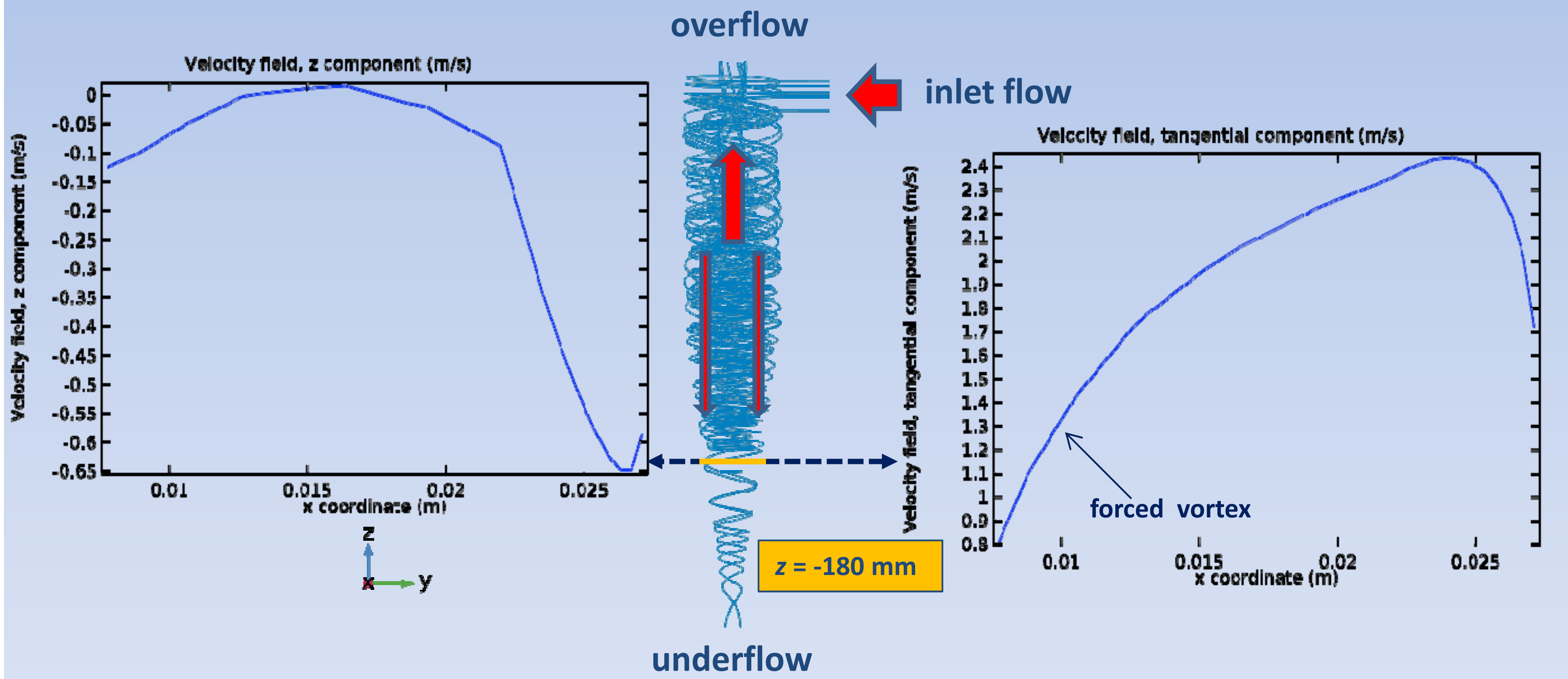


underflow to the apex
Q_u = 0.4833 l/s

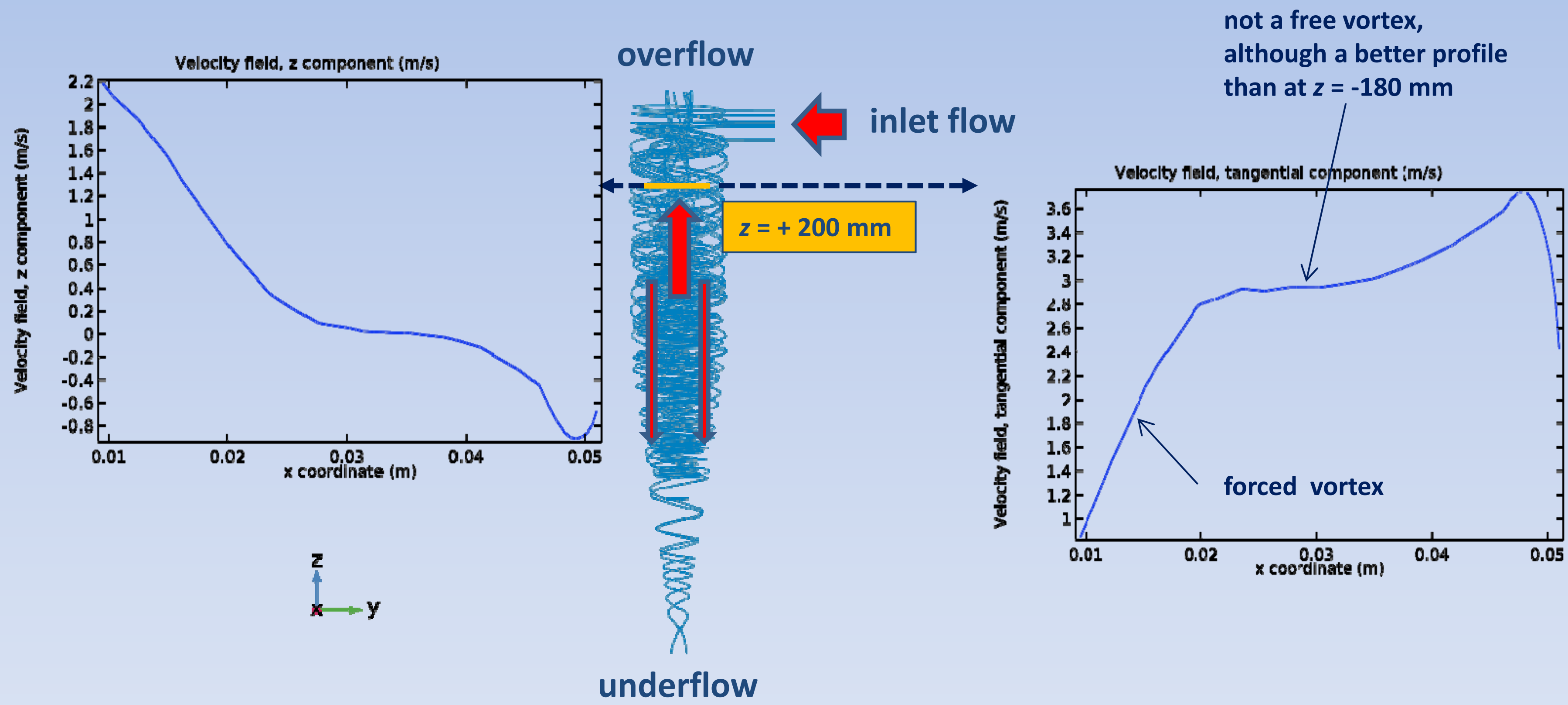
cone diameter = 14 mm

apex outlet: BC is zero normal stress

Numerical computations: velocity profiles

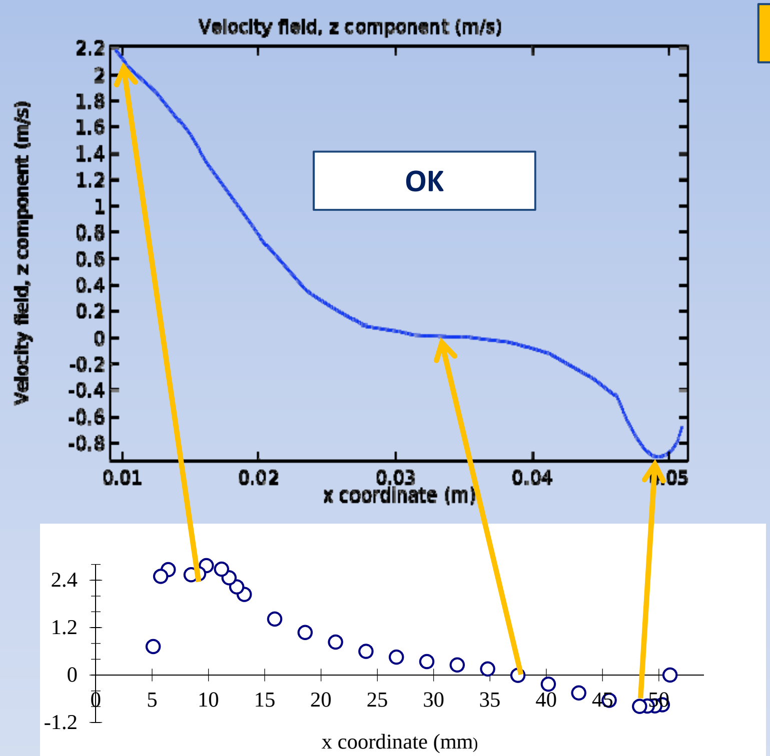


Numerical computations: velocity profiles

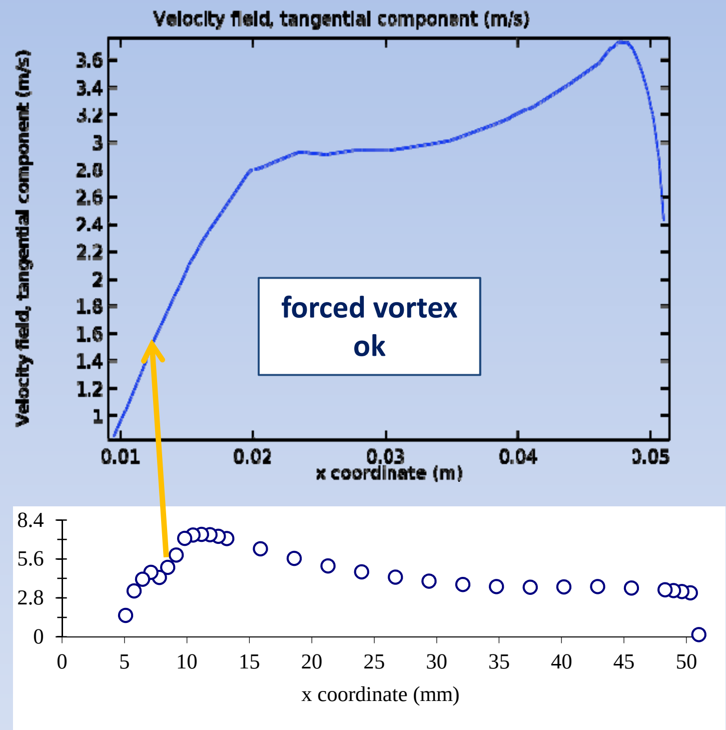


Velocity profiles: comparison with LDV measurements

z = + 200 mm



LDV [14]



- same ***locus*** of zero axial velocity
- very coincident ***upward maximum*** (2.2 m/s) and ***downward maximum*** (0.9 m/s) values of axial velocity, same ***axial flow profile***

- ***forced vortex*** is right
- ***maximum swirl velocity,*** its ***position*** and ***free vortex*** are not predicted

Conclusions

- The swirling flow in a hydrocyclone has been simulated by developing a 3D model of the flow
- The anisotropic turbulence of the flow has been modeled by using RANS and the v-2f turbulence closure
- The general flow pattern is quite well reproduced
- Axial velocity profiles and numerical values are well solved for
- Tangential velocity profiles differ from LDV measurements, the free vortex is not predicted
- A more complete model might be developed, including the modeling of the air core and a better performance of the turbulence (new Comsol feature LES)

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