Application of self-programmed custom features and special meridional contours for the design of multi-stage pumps

1. *Overview*
2. *Design parameters*
3. *Implementation in CAESES to support design process*
4. *Examples*
5. *Conclusion*

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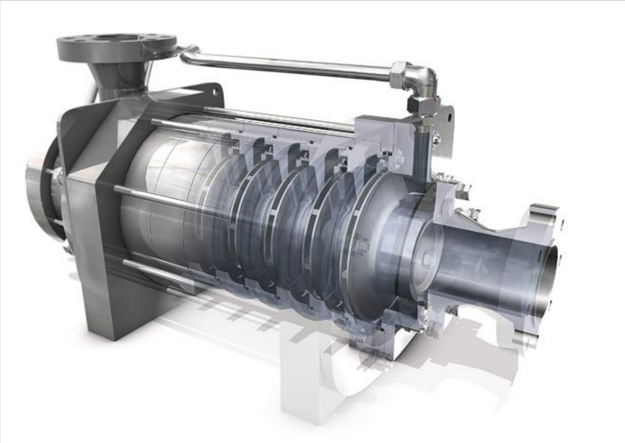
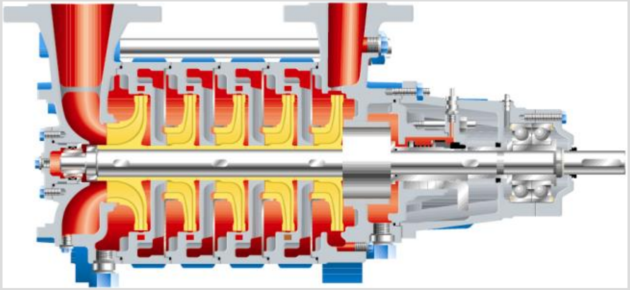
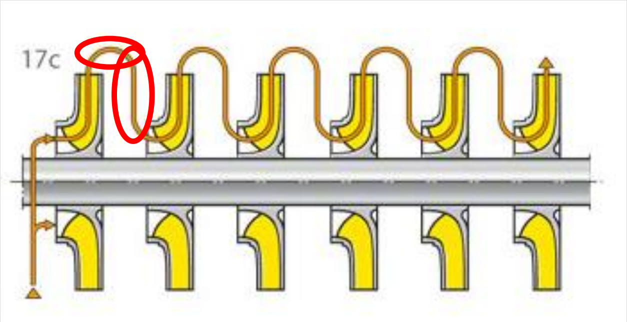






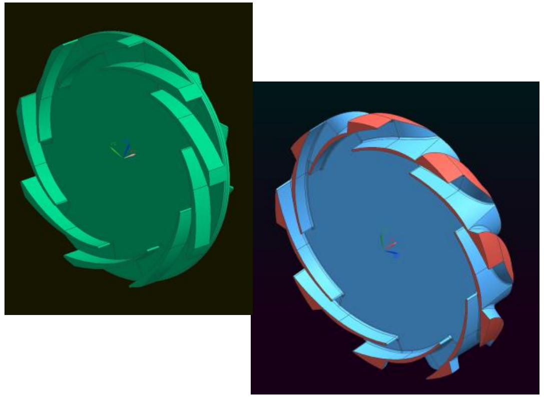
http://www.kreiselpumpenlexikon.de

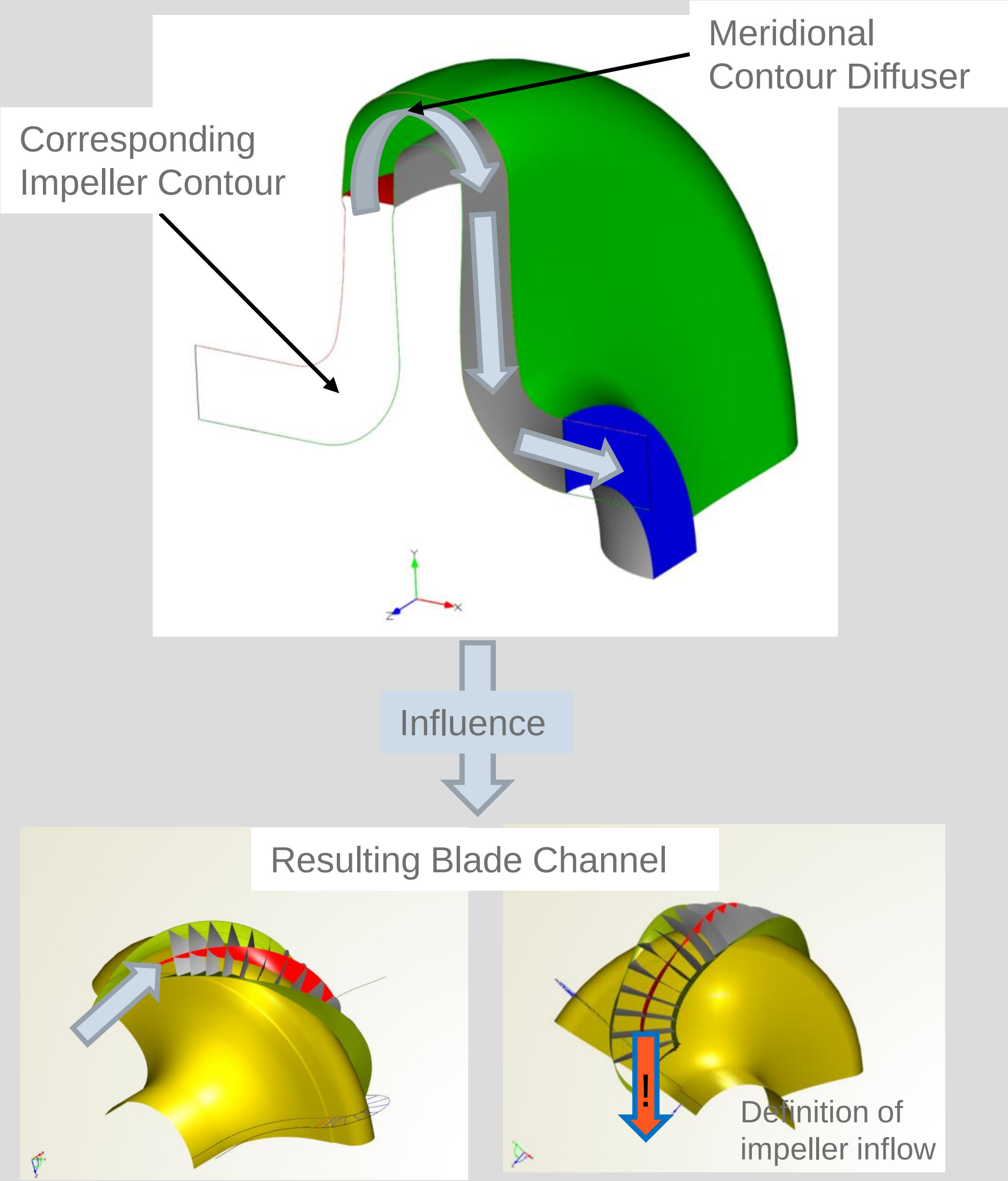
Overview

Multi Stage Pumps

- Tandem arrangements of impellers with serial throughflow to economical increase the pump head
- Typically one stage consists of impeller, diffuser vane and back vane
- Serves to collect the impeller outflow, convert the kinetic energy into static pressure and bring it back to the impeller of the next stage

- At requirement of small outer pump diameter diffuser- and back vane can be combined to a continuous flow channel





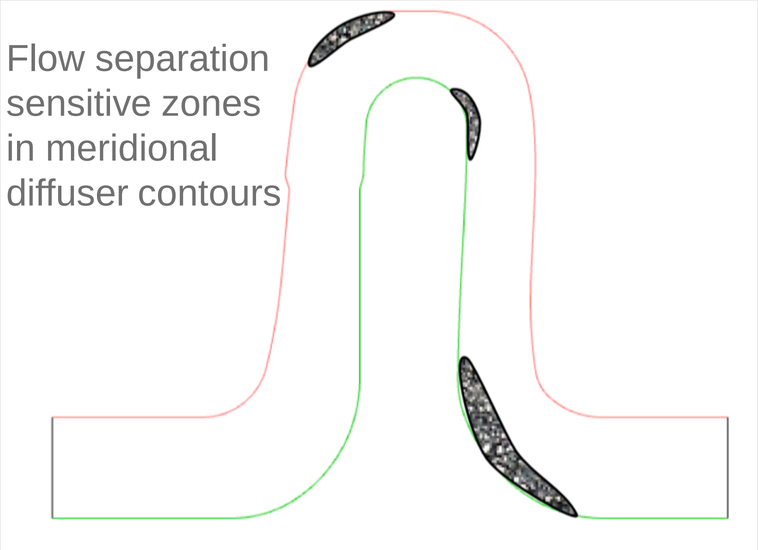
Meridional contour design
Overview

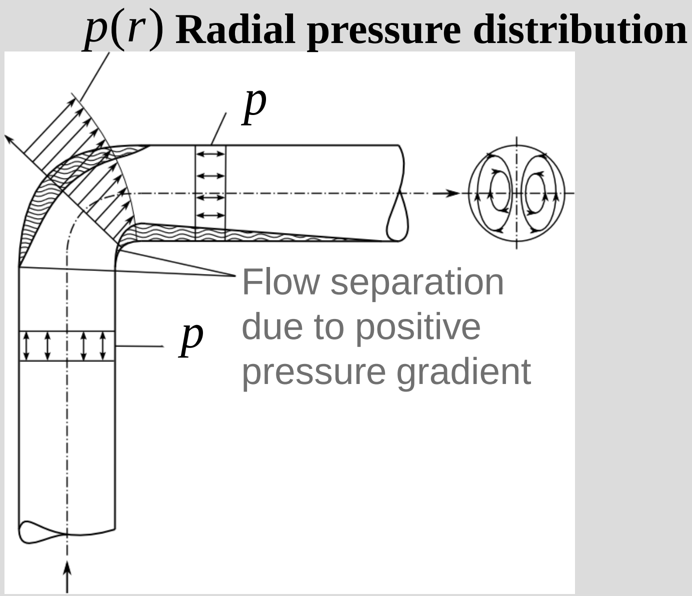
- Basis of centrifugal pump design
- Defines main dimensions of the pump and fluid flow characteristics in the blade channel

- Meridional contour is influencing blade channel design
- Optimal values of blade variables for a certain meridional contour maybe different if another contour was given

Question: What are suitable design criterias for meridional contours?

Design Criteria for Meridional Contours
Basics

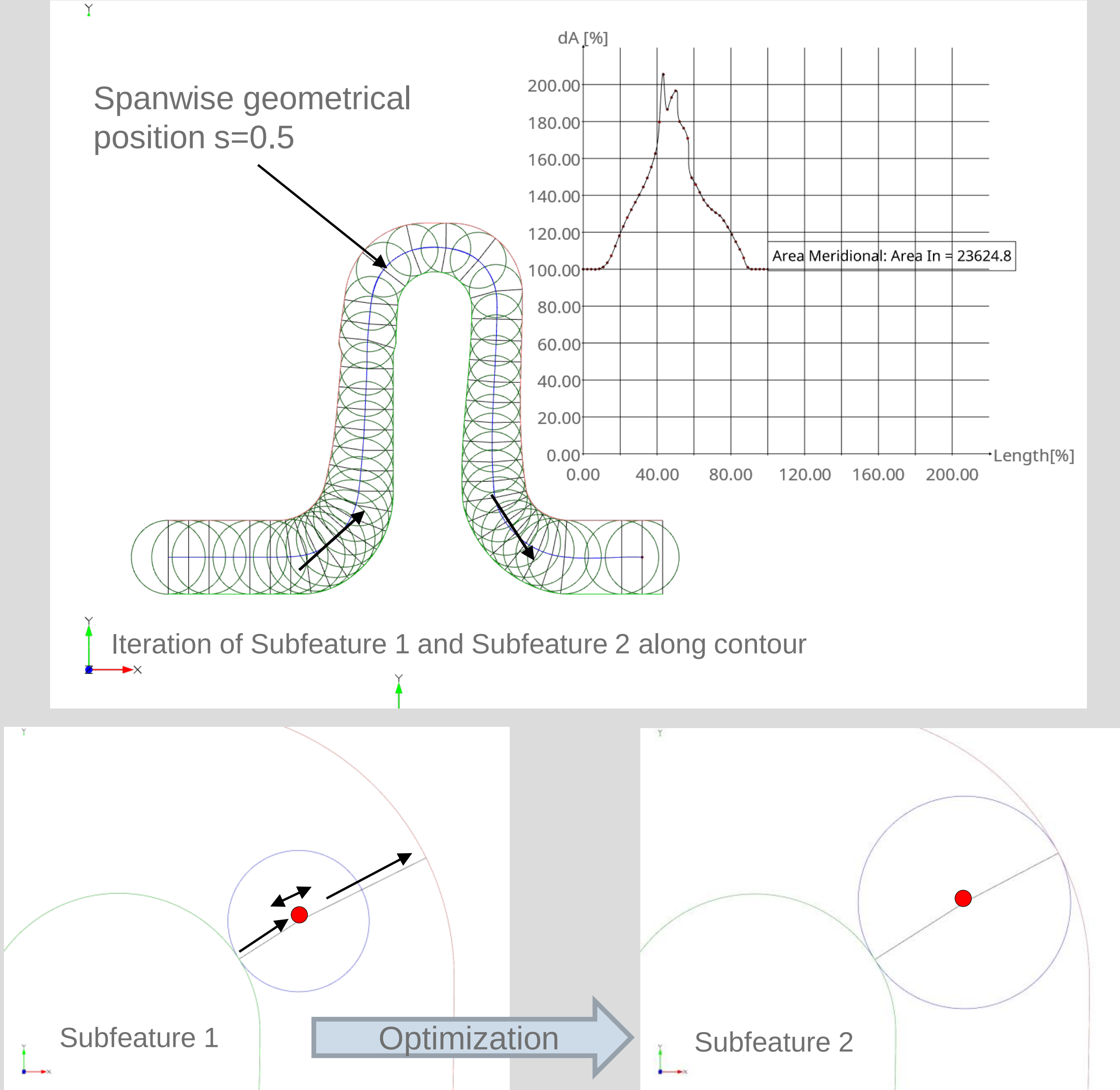




Flow characteristics:

- Comparable to serial elbow flow arrangements
- Due to curved flow path non-uniform flow is generated

- Avoid large pressure gradients by:
  1. Defining hub and shroud by a given smooth meridional cross section distribution between inlet and outlet
  2. Reduce flow channel curvature



Implementation in CAESES

1. Changing in Cross Section Area

- If flow directly follows the meridional contour shortest distance between hub and shroud at given points along contour is needed

Implementation:

- Define point normal to hub and find parameter of shortest distance to shroud curve
- Optimization of circle center position
- Feature iteration along contour
- Queries to find correct point offset direction:
  - Change of curvature algebraic sign
  - Curves with no curvature
- In case of spanwise curved blades interpolation curve of circle center points gives additional pathline

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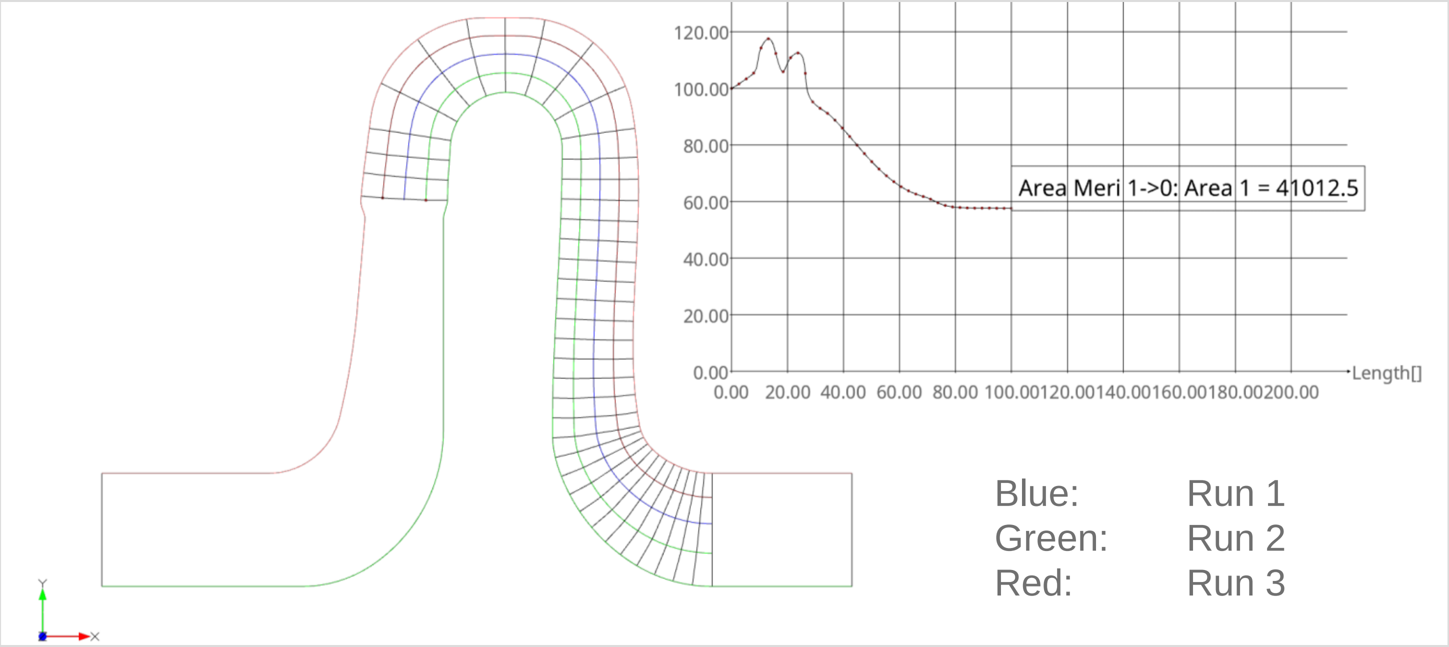
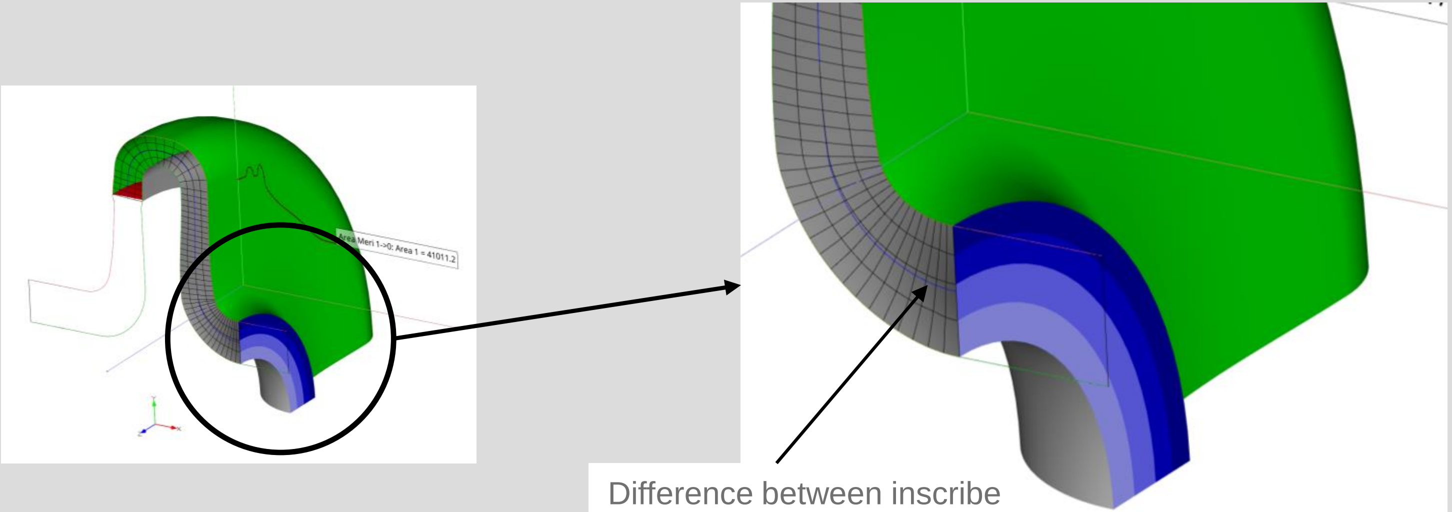
Implementation in CAESES

Flow Channels of Constant Mass Flow





Difference between inscribe circles and constant area

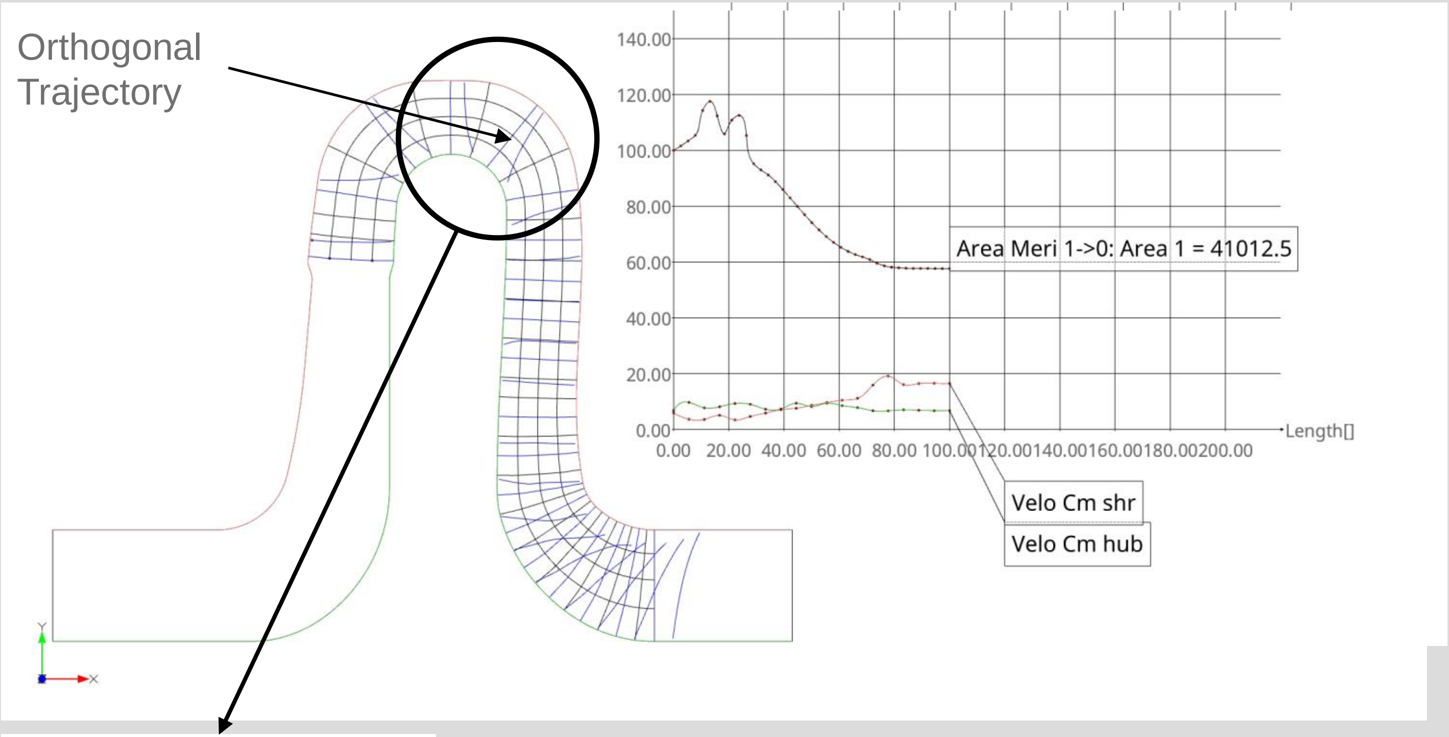
- In case of pumps with higher specific speed blade description with more than 3 pathlines is necessary
- Transition from geometrical pathline description to a velocity dependent approach is realized
- Aim is to have const. velocities along each pathlines

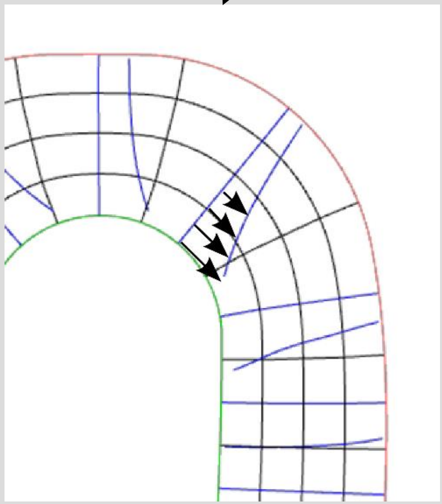
Implementation:

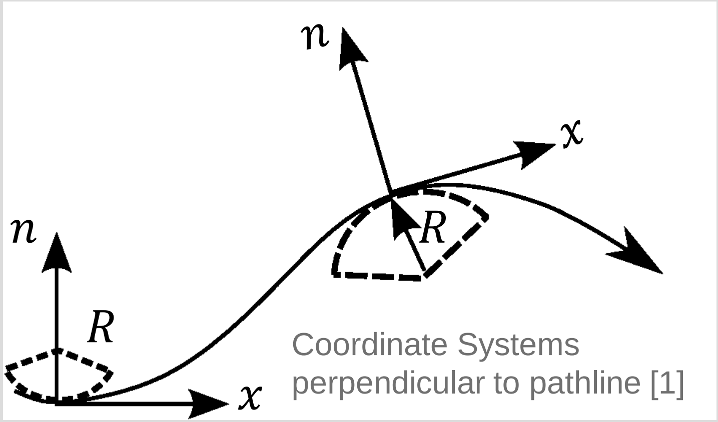
- Optimization criteria: Constant cross section area of generated flow channels
- Feature to generate pathlines has to be applied 3 times

Implementation in CAESES

2. Curvature Dependent Velocity Distribution





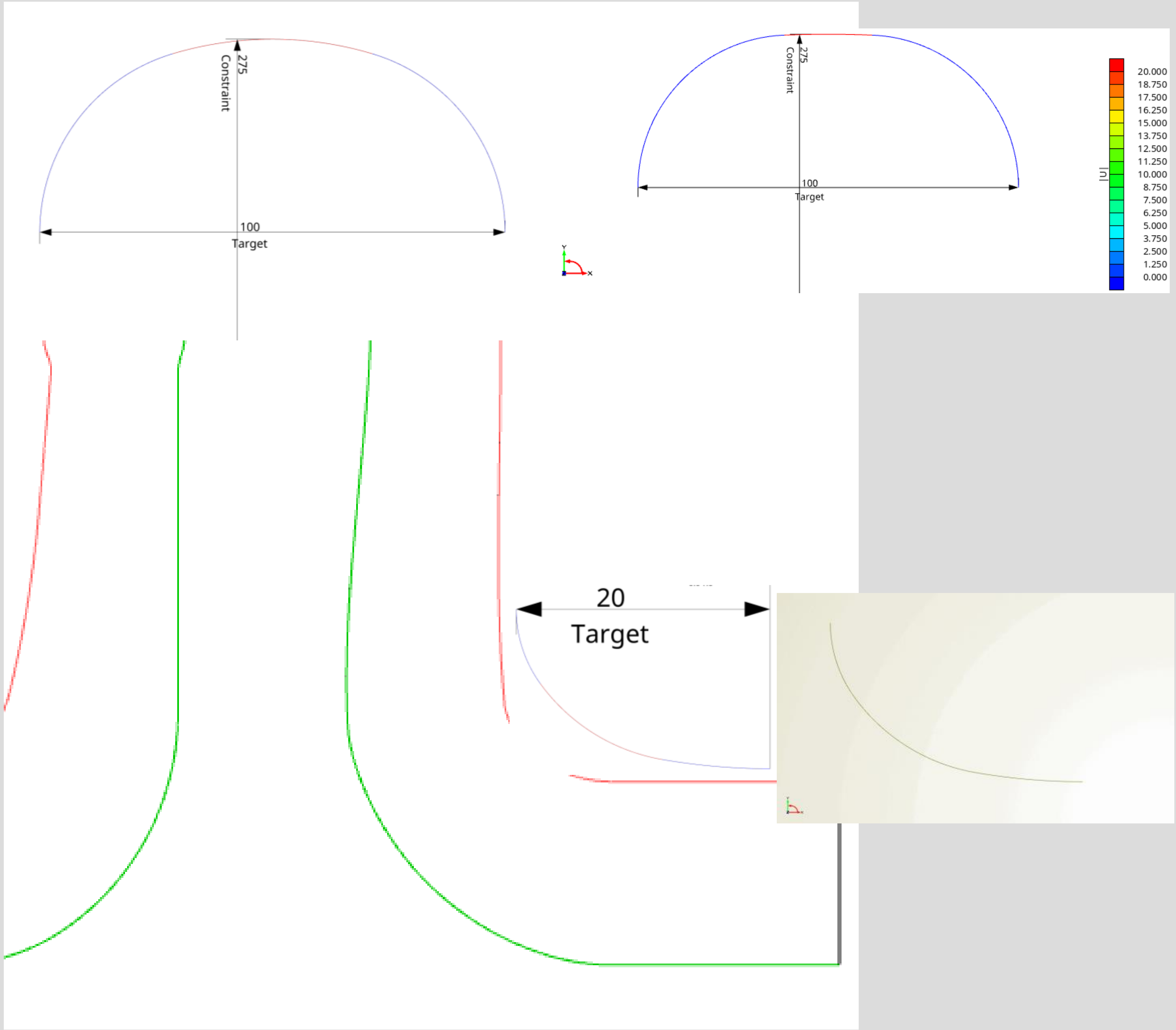


Coordinate Systems perpendicular to pathline [1]

- Basis orthogonal grid to pathlines
- Along orthogonal trajectory calculation of the curvature dependent velocity distribution is possible
- Equation derived from Potential Flow Theory [1]
  $$-\frac{c}{R}-\frac{\partial c}{\partial n}=0$$
- In a coordinate system normal to the pathlines velocity distribution depends only on local curvature and the velocity gradient
- Solving differential equation by discretizing the pathline curvature along the orthogonal trajectory
- $c_i = c_0 \cdot e^{curv_i(n)\cdot\Delta n_i}$ $Q = \sum_{0}^{i} A_i c_i$

/1/ W. Albring, Angewandte Strömungslehre

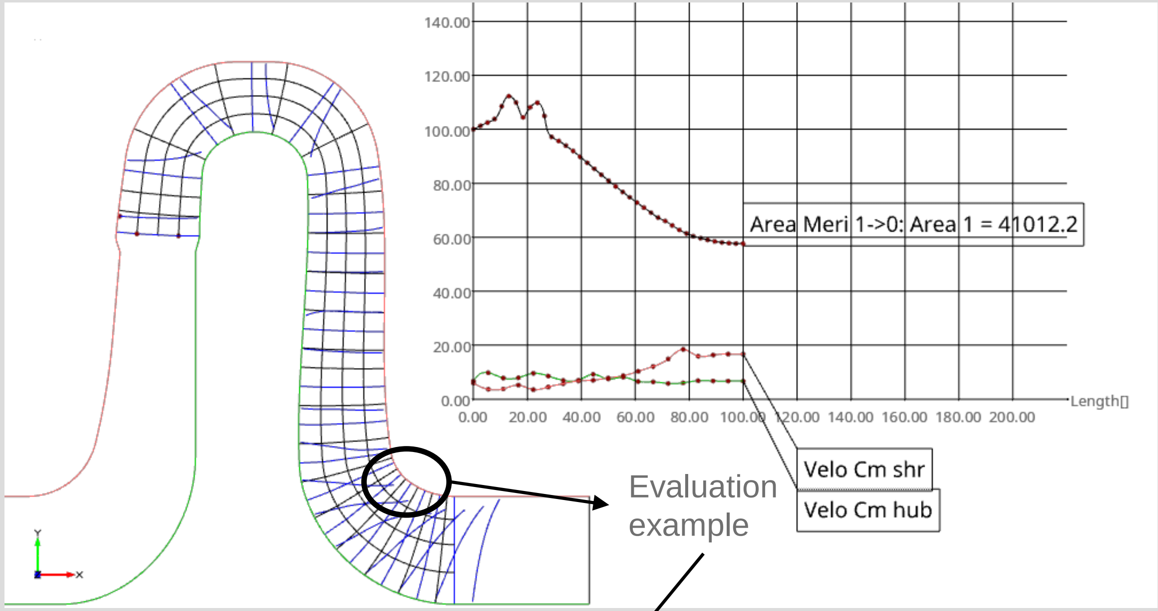
Meridional Contour
Functional Design

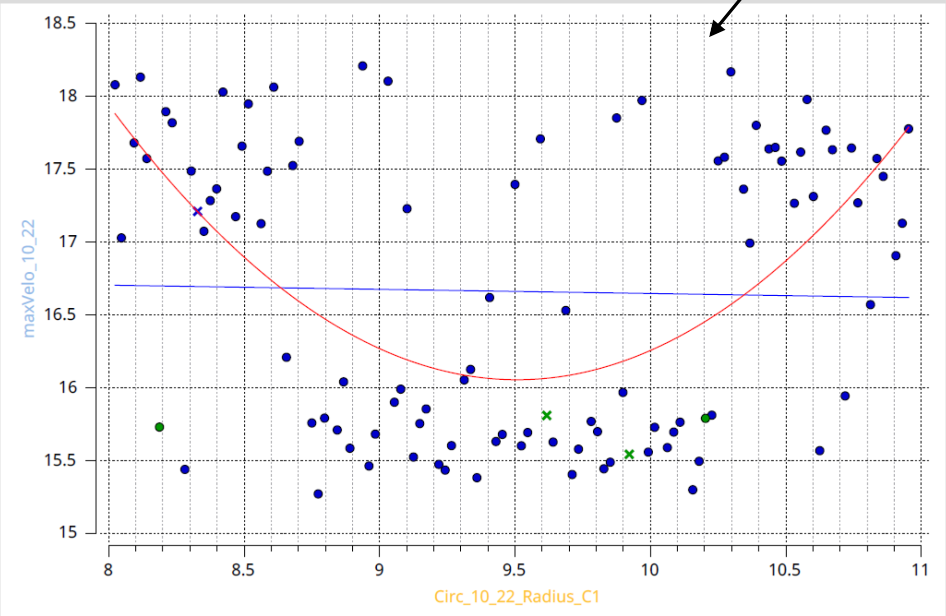


- For cause of reproducibility and documentation reason realization with as less splines as possible
- To have similar degree of freedom combination of three circles to define curvature
- Application of geometry constraints via design engines

Meridional Contour
Design Examples

- 19 design variables varied by Sobol Design Engine
- Evaluating criterias are course of meridional cross section area and velocity distribution at hub and shroud
- Not always clear dependencies between design variables and evaluation criteria's

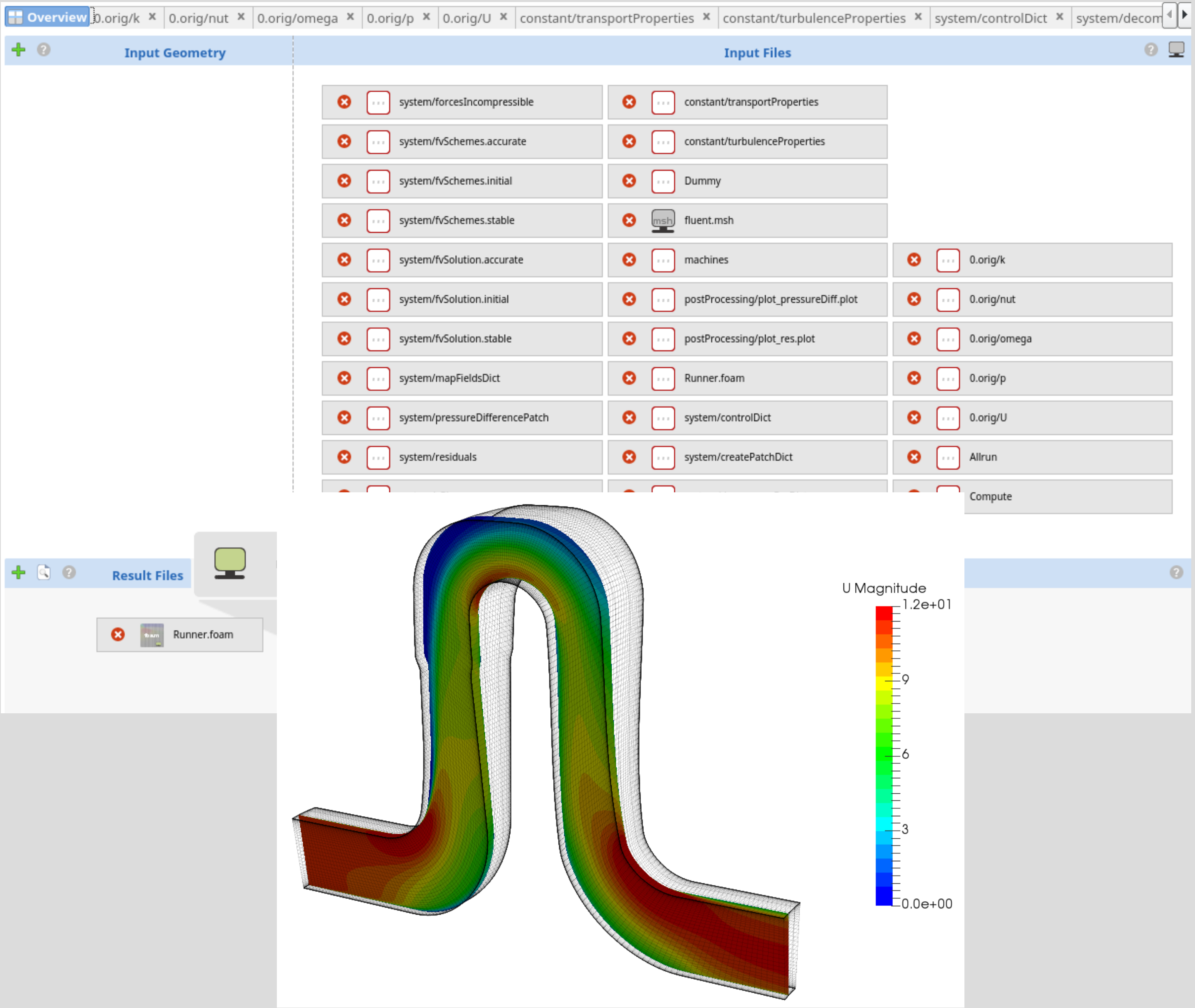




Design Variables

	Design Variable	Lower	Value	Upper	Active
1	Dist_center_00	19	20	20	☒
2	Circ_00_22_Position	0	0.005	0.1	☒
3	Circ_00_22_Radius_C1	35	38	40	☒
4	Circ_00_22_Radius_C2	55	64	65	☒
5	Circ_00_22_Radius_C3	50	53	60	☒
6	Dist_center_10	46	47	48	☒
7	Circ_10_22_Position	0.1	0.2	0.25	☒
8	Circ_10_22_Radius_C1	8	10	11	☒
9	Circ_10_22_Radius_C2	15	17	20	☒
10	Circ_10_22_Radius_C3	25	31	32	☒
11	C1_Radius_00	15	19	20	☒
12	C2_Radius_00	20	20	25	☒
13	C3_Radius_00	12	15.5	17	☒
14	C1_Radius_10	35	39	45	☒
15	C2_Radius_10	0	500	500	☐
16	C3_Radius_10	40	41	43	☒
17	Opt_Radius_00_22	56	57	59	☒
18	Opt_Radius_10_22	20	26	27	☒
19	Span00_OuterRad	248	248.6	250	☒

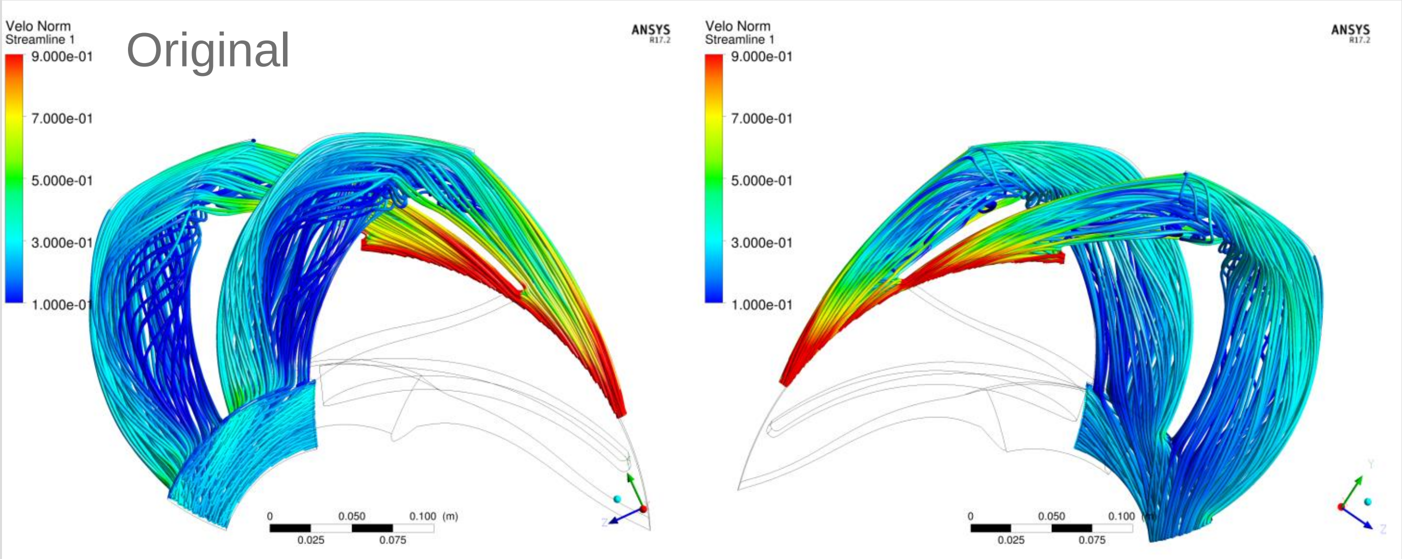
Meridional Contour
Viscous Calculation



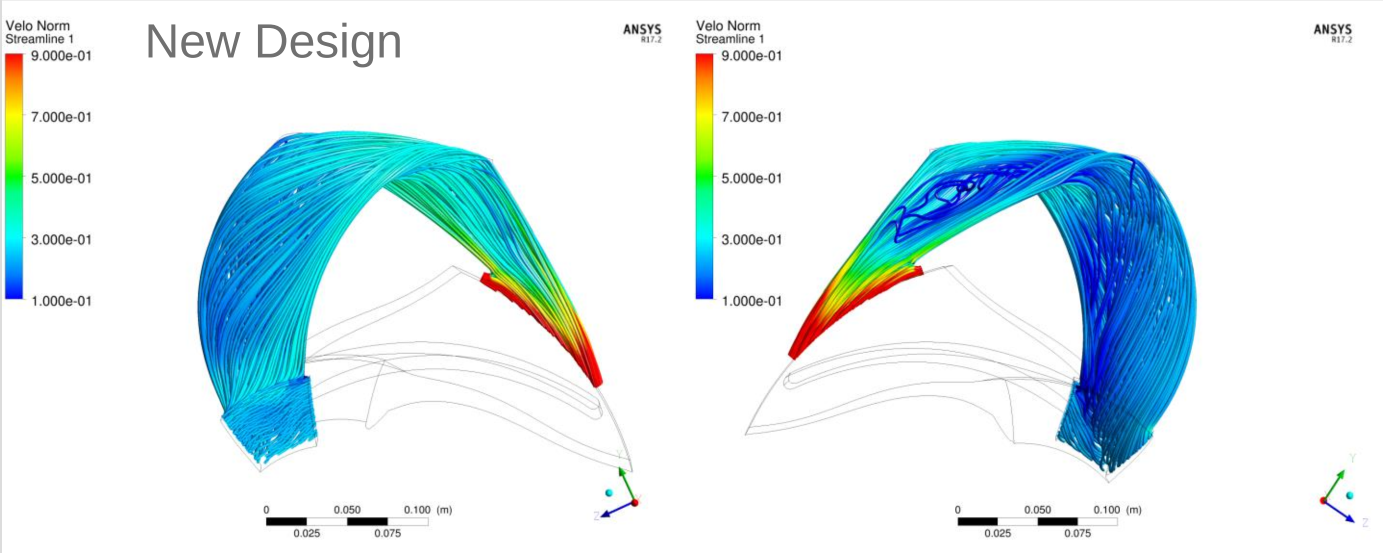
- Ongoing design investigation of promising designs with viscous calculation
- Taken flow separation into account
- Coupling CAESES with ICEMCFD and OpenFOAM to get an additional objective function - pressure loss
- Velocity inlet and pressure outlet boundary conditions

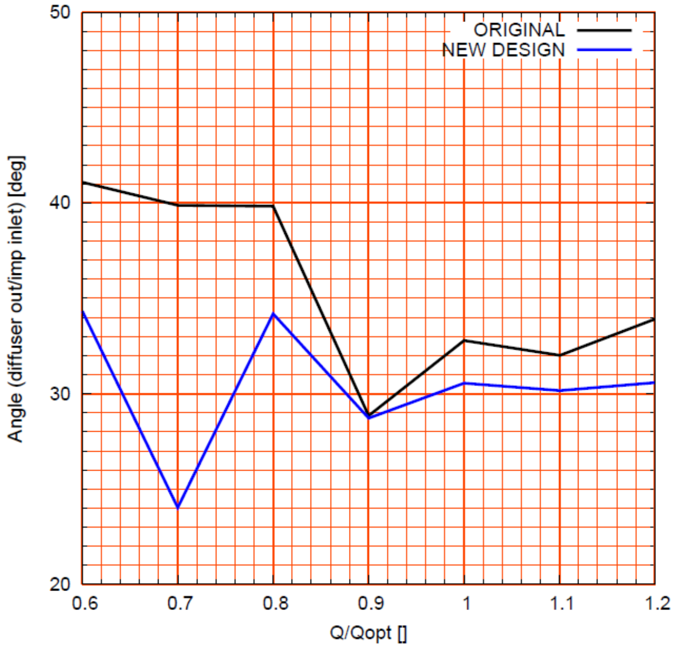
Channel Flow
Improvement

- Similar results at best operating point
- Increase of flow stability in part load
- Decreased swirl at diffuser outlet



$$Q/Q_{opt} = 0.6$$





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Conclusion

- Implementation of tools to design and evaluate meridional contours in CAESES
- Extend these evaluation criteria by coupling CAESES with OpenFOAM for approaching viscous evaluating criteria
- Application in designing diffusers of multistage pumps