CAD-based shape optimisation using a discrete adjoint solver

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- Parameterisation is the key to successful optimisation
  - Node-based optimisation interface not well with CAD
  - Full CAD-based approach needs either (1) differentiating the CAD system or (2) solving transformation matrix using finite difference

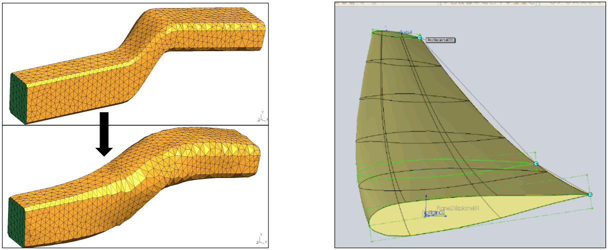

Figure: Node-based (left) v.s. full CAD-based (right)optimisation.

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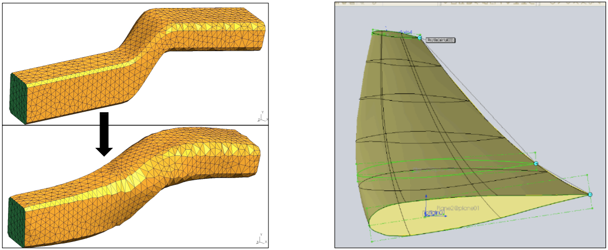

Figure: Node-based (left) v.s. full CAD-based (right)optimisation.

- A more flexible CAD-based optimisation is needed

Motivation

- Use the control points of the boundary representation (BRep) as design parameters

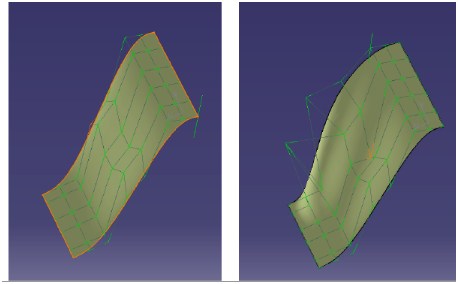

Figure: Surface with control points (C.P.) viewed in CAD.

- Advantages: good interface to CAD, no smoothing/fd
- Challenge: imposition of various constraints

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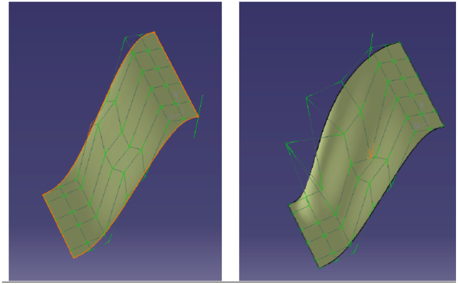

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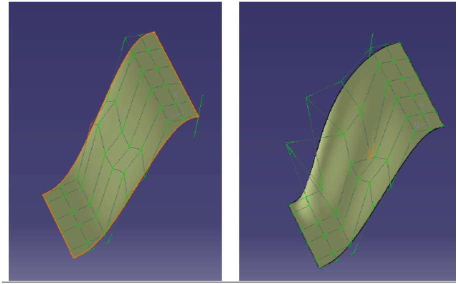

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Boundary representation, definition of NURBS

- Surfaces in CAD systems are NURBS (Non-Uniform Rational B-Spline), defined as follows

$$X_s(u,v) = \Sigma_{i=0}^{n} \Sigma_{j=0}^{m} R_{ij}(u,v) P_{i,j}$$

$$R_{ij}(u,v) = \frac{N_{i,p}(u) N_{j,q}(v) w_{i,j}}{\Sigma_{k=0}^{n} \Sigma_{l=0}^{m} N_{k,p}(u) N_{l,q}(v) w_{k,l}}$$

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Test points for imposing constraints

- Continuity is enforced at test points located along the joint edge

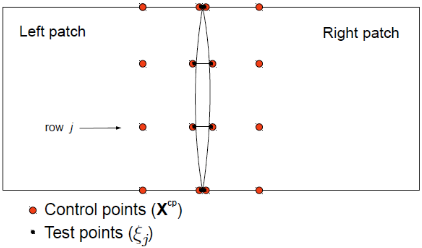

Figure: Schematic of test points distributed along the joint edge.

- Constraint functions evaluated at test points

$$C_{G0} = (X_s)_{left} - (X_s)_{right} = 0$$
$$C_{G1} = (\vec{\tau})_{left} \times (\vec{\tau})_{right} = 0$$
$$C_{G2} = (k)_{left} - (k)_{right} = 0$$

Imposing continuity constraints using nullspace

- Control points are only allowed to move within the nullspace of the linearized constraint equations

$$\frac{\partial C_{Gi}}{\partial P_i} dP_i = 0 \ (i = 0, 1, 2)$$

$$\Longrightarrow \delta \vec{P} = \mathrm{Ker}\left(\frac{\partial C_{G0}}{\partial P}, \frac{\partial C_{G1}}{\partial P}, \frac{\partial C_{G2}}{\partial P}\right) \delta \vec{\alpha}$$

- Nonlinear constrains $G1$ and $G2$ can be dealt with
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S-bend shape optimisation, case parameters

- Geometry parameterisation: 30 NURBS patches, with 8 patches for "S" with 288 C.P.
- 203 design variables, 313,925-cell mesh, Re_H=300
- Solver: in-house incompressible discrete adjoint solver

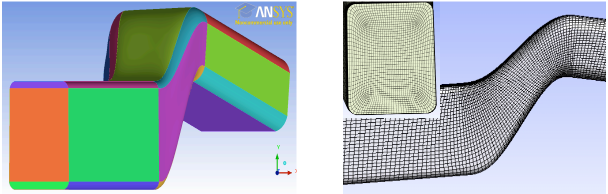


Figure: NURBS patches (left) and all-hex mesh (right).

(Ref: D. Jones, J.-D. Müller and S. Bayyuk, CFD Development with Automatic Differentiation, AIAA-2012-573)

S-bend shape optimisation, primal validation

- Small separation bubble about to reach pressure outlet
- Flow speed contour plots at outlet indicate complex secondary flow

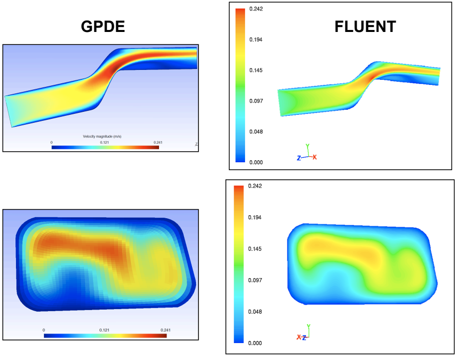
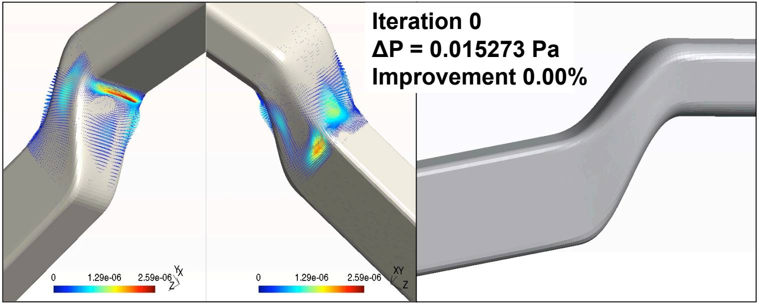


Figure: Flow speed contour plots in medien plane and outlet boundary plane, GPDE v.s. FLUENT.

S-bend shape optimisation, results



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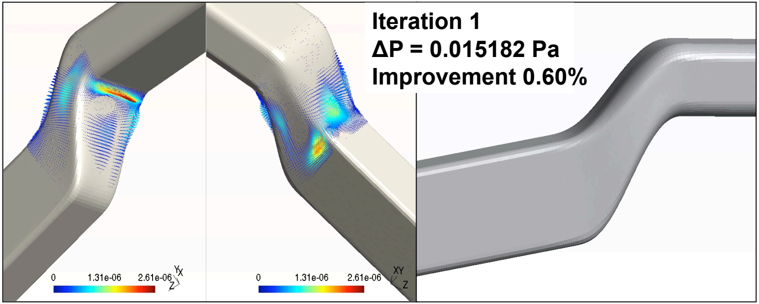

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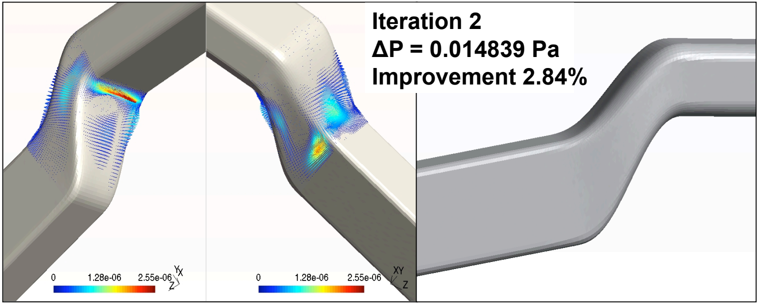

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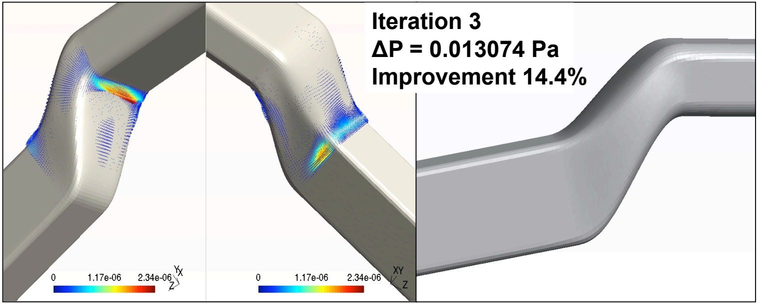

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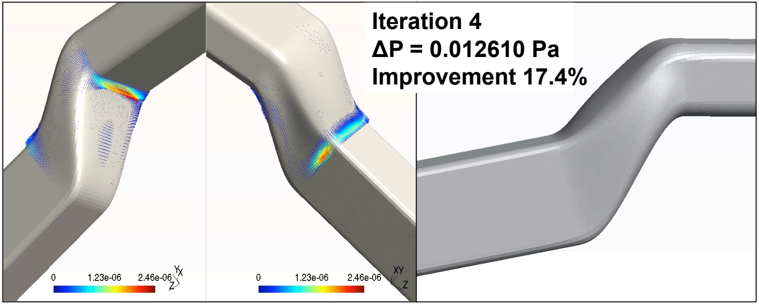

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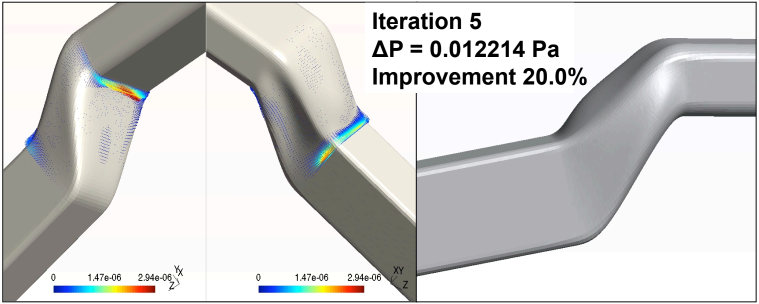

S-bend shape optimisation, results

- Unexpected shape at 6th iteration

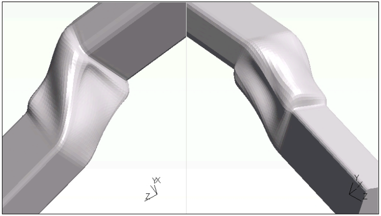

Figure: Updated shape at 6th iteration.

- Possible cause for failure
  - Interference from non-vanishing large sensitivity at S-bend throat $\Rightarrow$ allow the throat to deform

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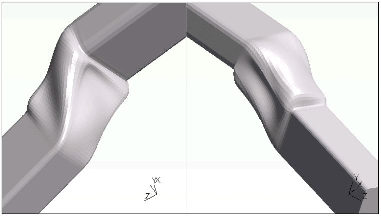

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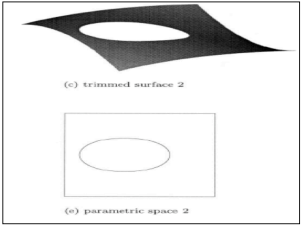
Summary

A novel CAD-based optimisation method is developed, using the control points of the boundary representation (BRep) for parameterisation

- Good interface with CAD
- Continuity constraints easy to impose
- Extendable to more complex geometry
- Cost is negligible compared to flow solver

Future work

- Short-term (Apr. 2012)
  - Implementation of G2 constraint
  - Extend to more complex geometries



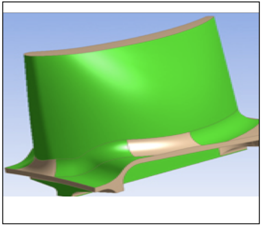


Figure: Examples of more complex geometric entities.

- Long-term (May 2011- May 2013)
  - Apply to turbomachinery components, such as compressor/turbine blade shape optimisation

Thank you! Questions?