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Effects of Blade Deformation on the Performance of a High Flow Coefficient Mixed Flow Impeller

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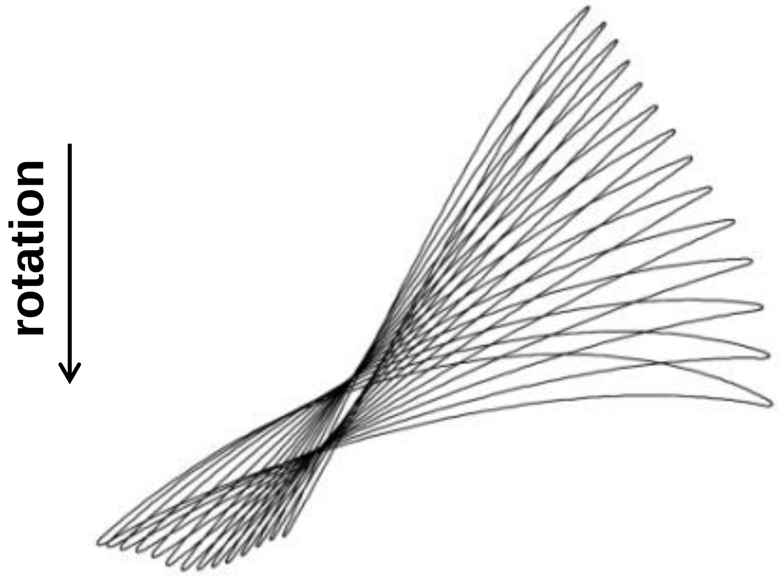
Outline of this talk

- Blade deformation in axial and radial compressors
- Objectives and research approach
- Test results
- Numerical investigations
- Conclusions

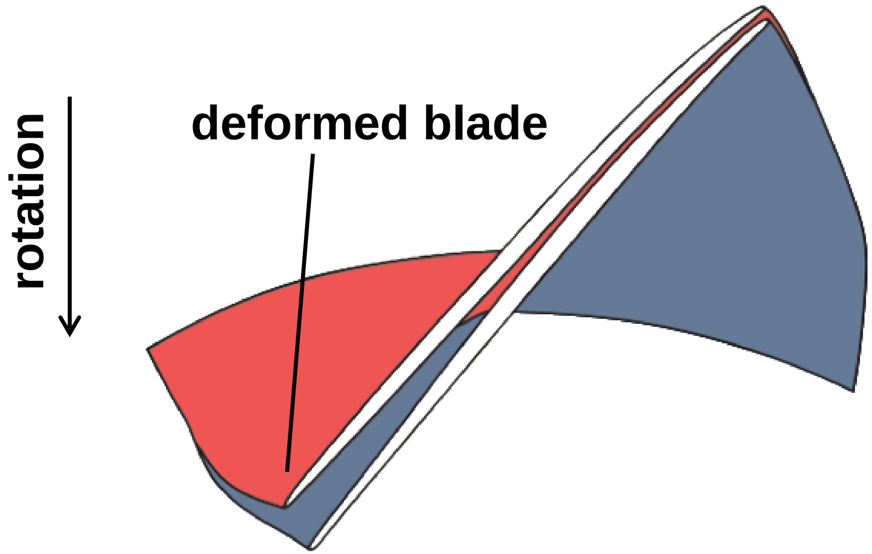
Blade deformation in axial fans

- The blade sections are normally **stacked along the centre of gravity**
- The higher stagger angle at the blade tip results in **positive lean** (lean in the direction of rotation) **in the front** part and negative lean in the rear part



Blade deformation in axial fans

- Under centrifugal loads, the tip section moves opposite to the direction of rotation
    - Reduced stagger and increased throat area (blade "**untwist**")
- **"Pressure untwist"** at low mass flow rates

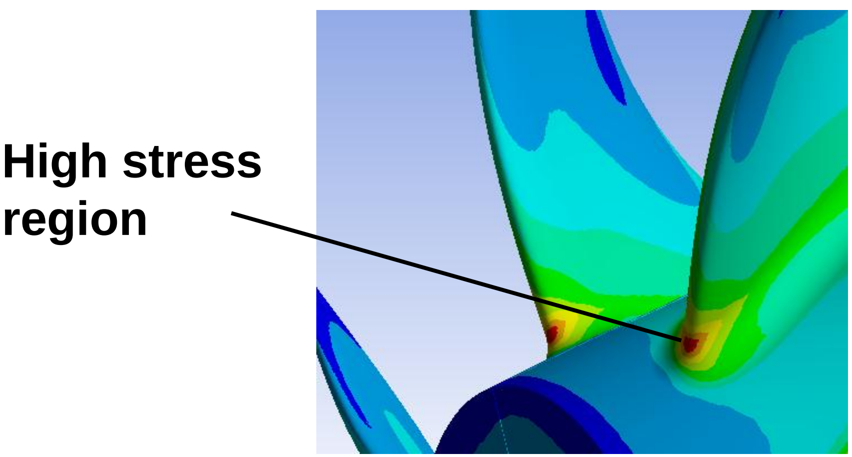


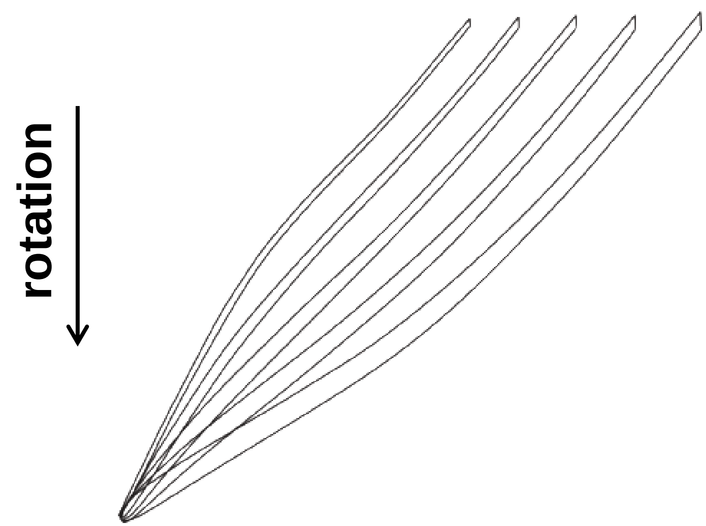
Blade deformation in axial fans

- Why is this important?
  - It affects the performance by changing the position of the shock at the tip
  - It affects the flow capacity by changing the throat area
- Knowledge of geometry under running conditions is essential
- Prediction of “unrunning” manufacturing geometry is a routine practice

Blade deformation in radial impellers

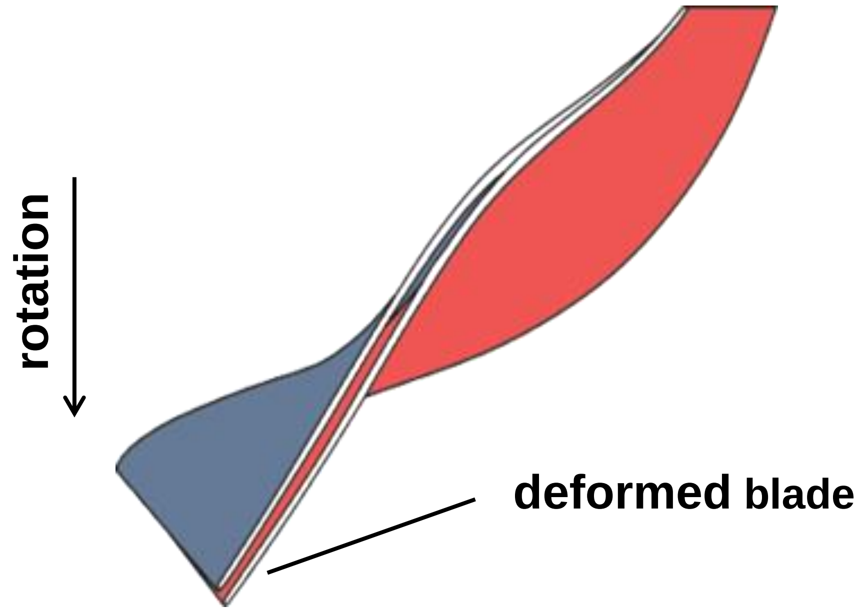
- High stresses can occur in LE/hub corner
- To avoid excessive stress levels, blades are designed with **zero or small lean at the LE**
- Larger inlet blade angle at the tip results in negative lean downstream the LE





Blade deformation in radial impellers

- Under centrifugal loads, the tip section moves in the direction of rotation
  - Increased inlet angle and reduced throat area (blade “**twist**”)
- Pressure forces act similar to that in axial passages (**pressure “untwist”**)



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Blade deformation in radial impellers

- Changes in blade **tip clearance**:
  - Reduced at inlet
  - Reduced or increased at outlet, depending on the design
- The effects of blade deformation are normally ignored in the radial impeller design
  - Manufactured geometry is the geometry analysed in CFD

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- Objectives and research approach
- Test results
- Numerical investigations
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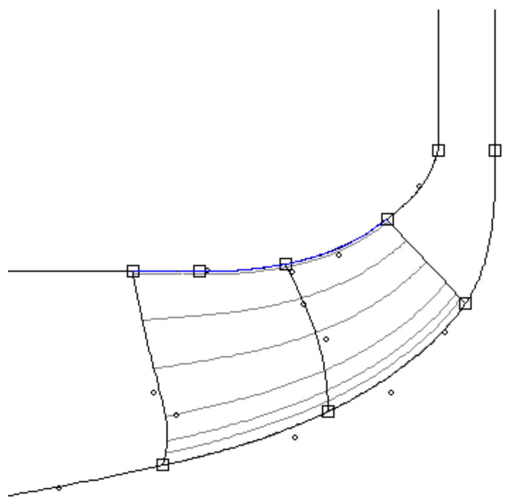
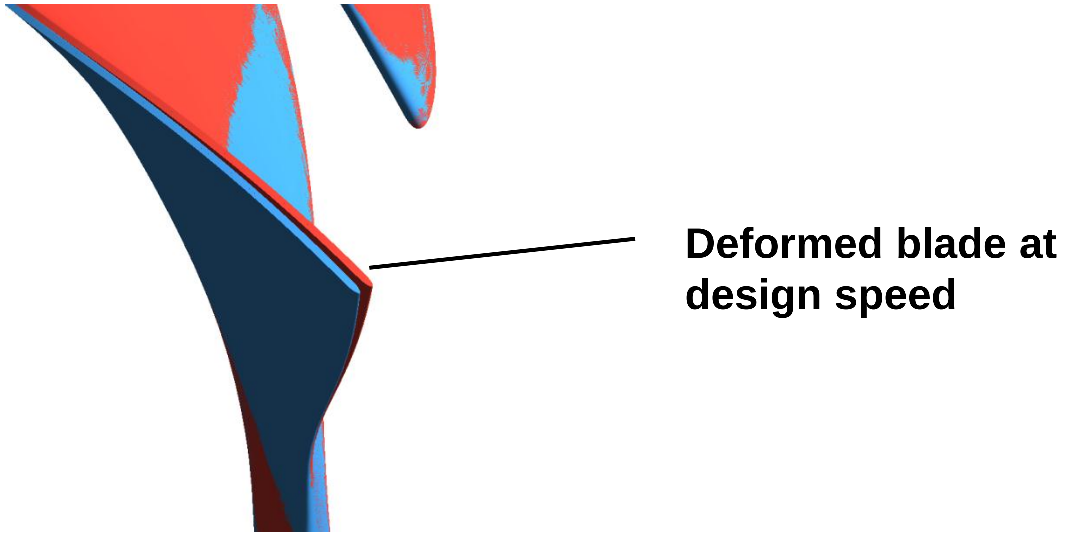
Objectives

- A highly loaded transonic mixed flow impeller, designed to explore performance potentials outside normal design space (GT2014-25378)
  - Forward LE sweep
  - Spanwise optimization of camber and throat area



Objectives

- Large displacements were observed at the tip section, under the effect of centrifugal loads at the design speed
- The effects of blade deformation on performance have not been fully investigated for radial and mixed-flow impellers
- The objective was to investigate these effects in the current impeller



Approach

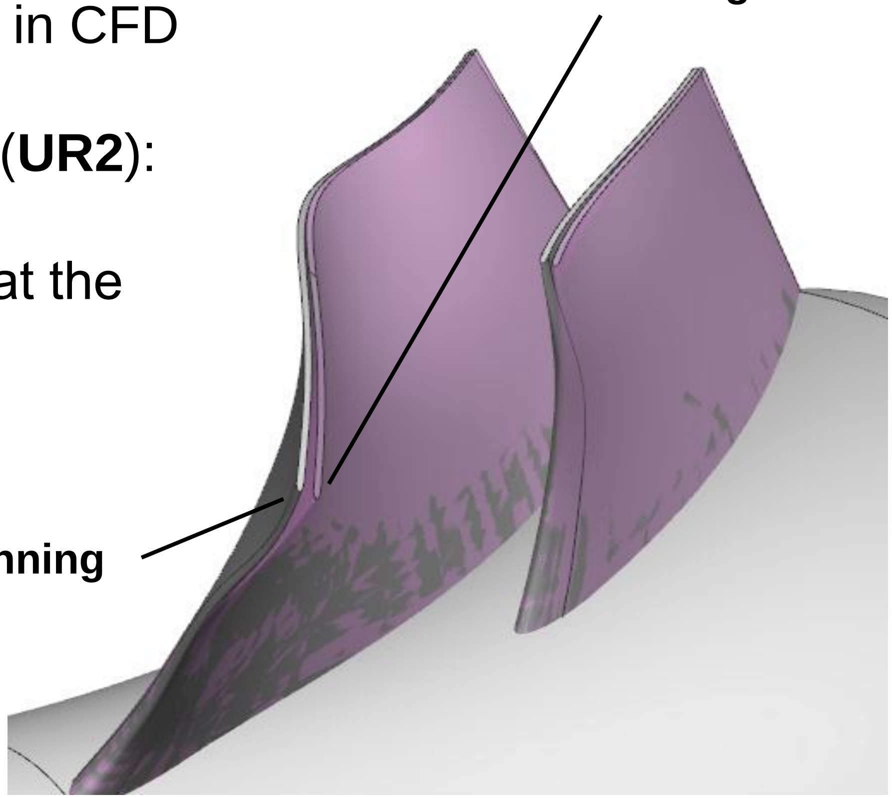
Two impeller geometries have been **manufactured** and **tested**:

1. “**Running**” geometry (**R2**):

   Is the design geometry, analysed in CFD

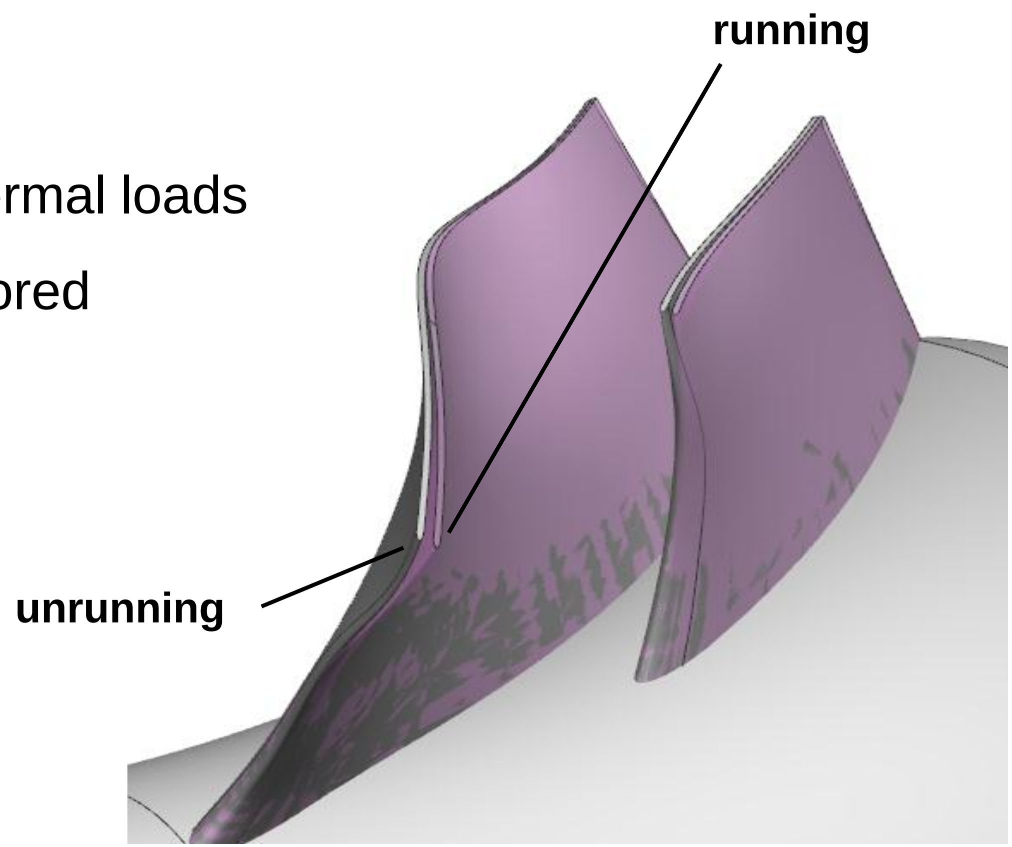
2. “**Unrunning**” or “**cold**” geometry (**UR2**):

   Matches the “running” geometry at the design speed, under the effect of centrifugal loads



"Unrunning" geometry (**UR2**)

- Predicted using in house FE software
- Only centrifugal loads were taken into account
- The effects of pressure and thermal loads on blade deformation were ignored



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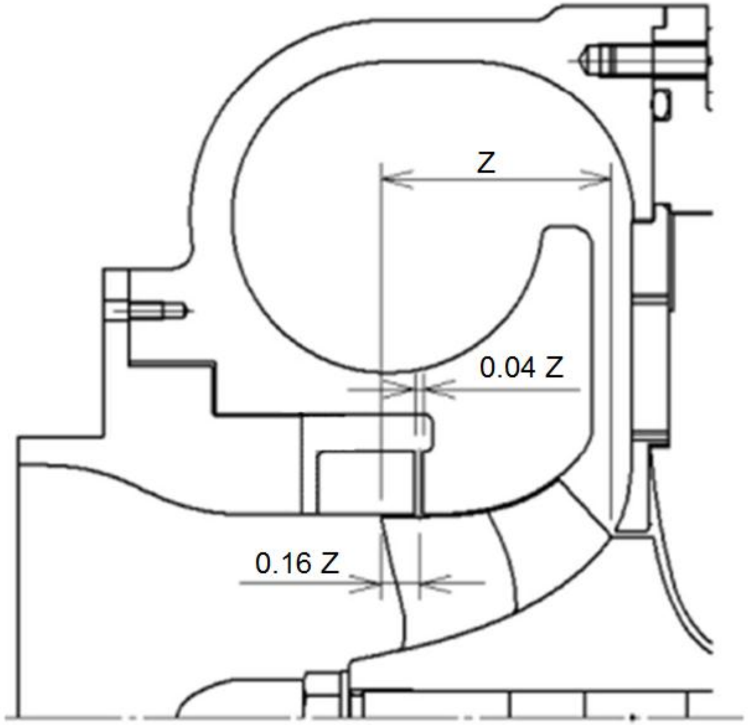
Test procedures

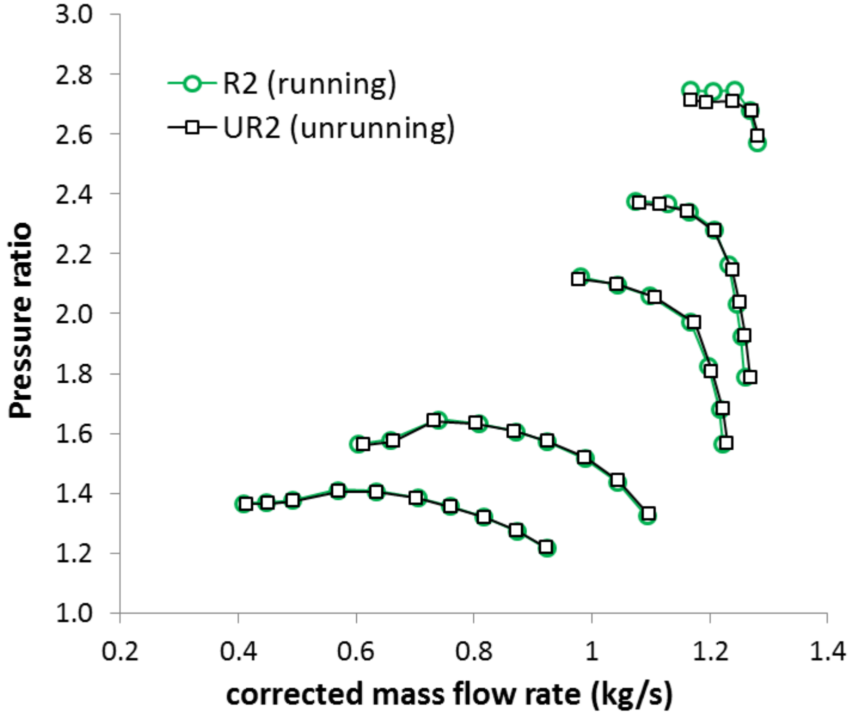
- Strong effects of the recirculating casing treatment on the impeller performance were expected

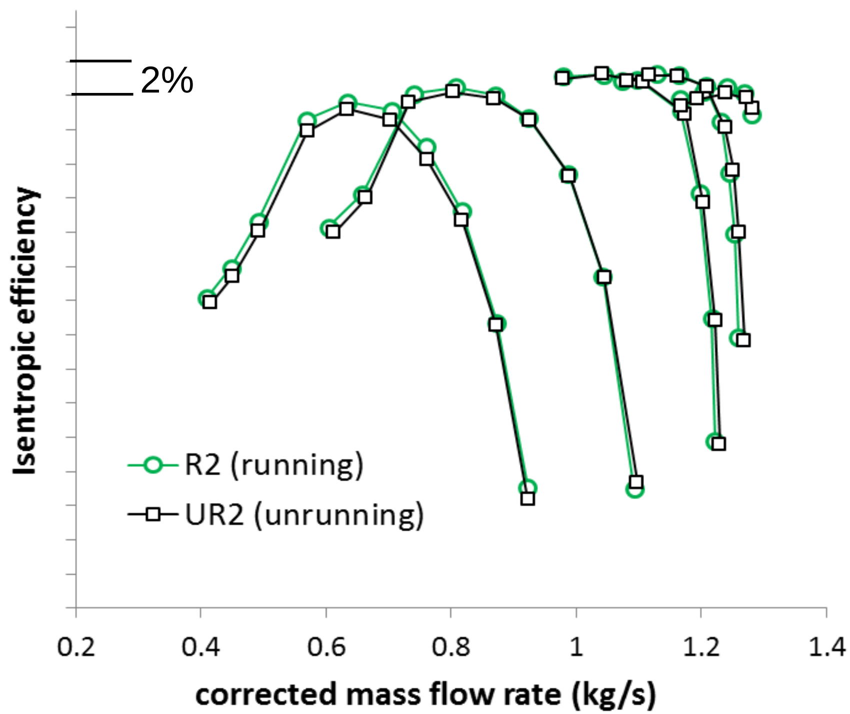
- Both impeller geometries were tested **with** and **without** casing treatment



Performance tests with **smooth casing**

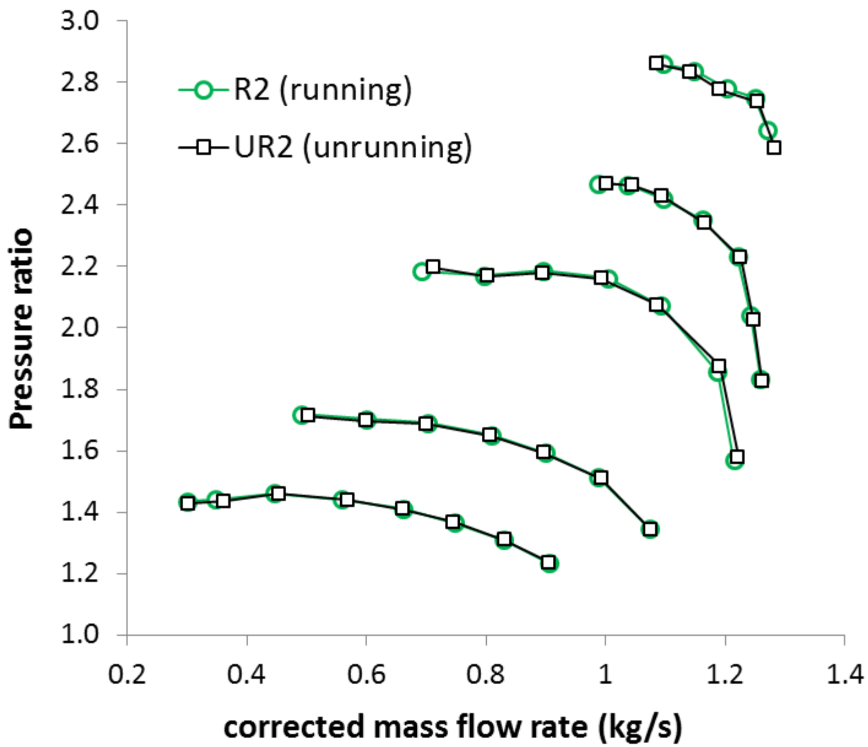
- **Unrunning** impeller geometry
  - 1.4% lower pressure ratio and 0.38% lower efficiency at design speed
  - Same pressure ratio but 0.4% lower efficiency at low speed

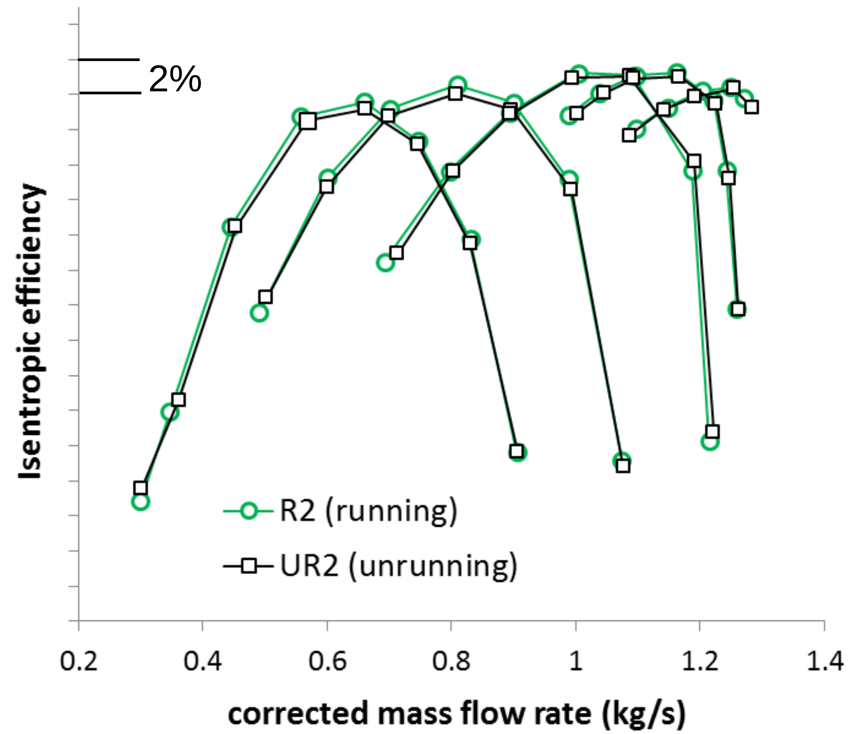




Performance tests with **casing treatment**

- **Unrunning** impeller geometry
  - No significant difference at the design speed
  - Same pressure ratio but lower efficiency at low speed





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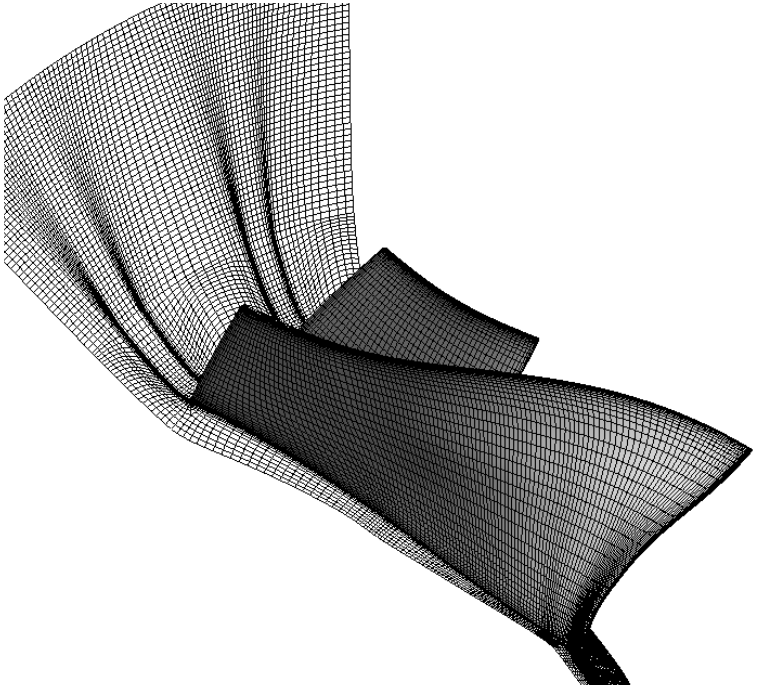
Numerical setup

- Single passage steady state calculations were performed using ANSYS CFX
- Structured mesh with 450000 nodes and 6 points inside the tip gap was generated using ANSYS Turbogrid
- k-ε Turbulence model with scalable wall functions



Geometry definition in CFD

Manufactured **R2** and **UR2** geometries → **No blade deformation** → **CFD**

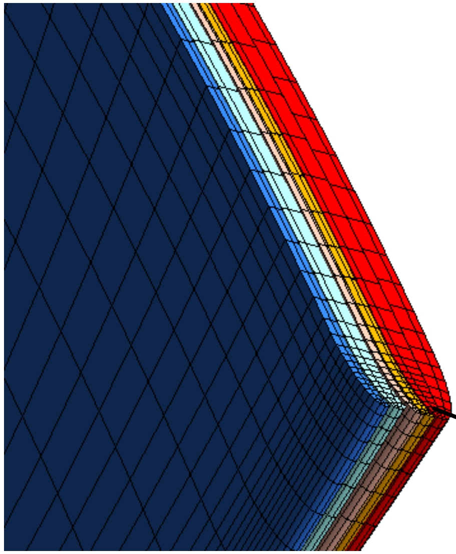
Geometry definition in CFD

Manufactured **R2** and **UR2** geometries

CFD

Deformed at each measured speed

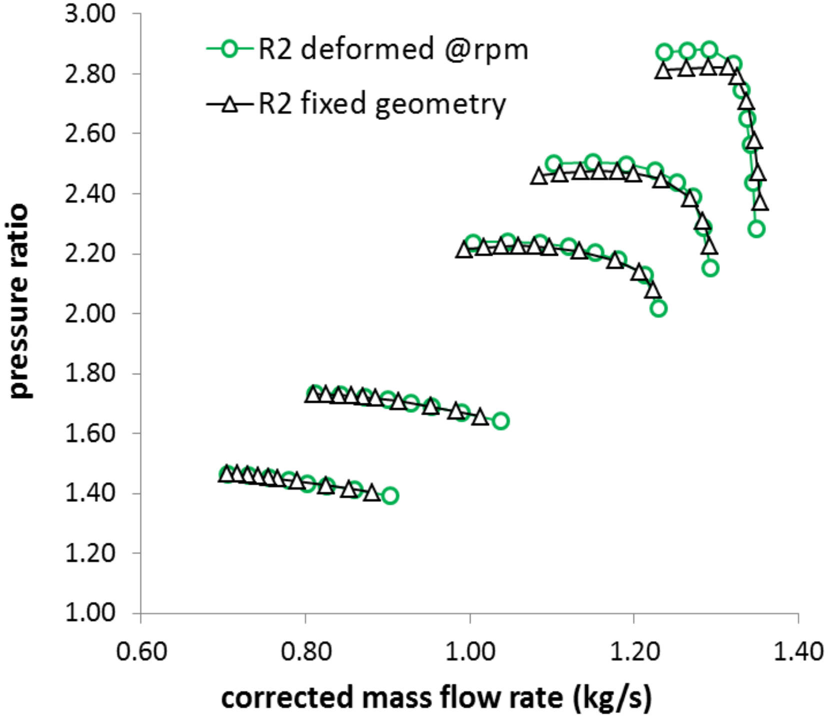
- **Blade twist**
- **Tip clearance change**

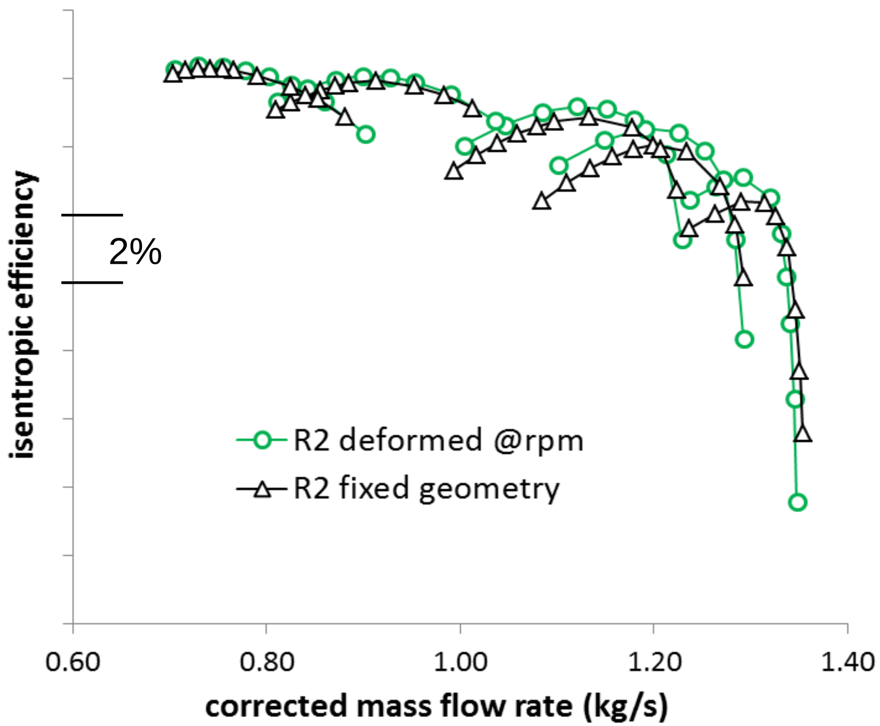


Impeller geometry at different speeds

“running” geometry

- Effects of blade deformation:
  - At the design speed, the deformed impeller has 2.5% higher pressure ratio and 0.7% higher efficiency





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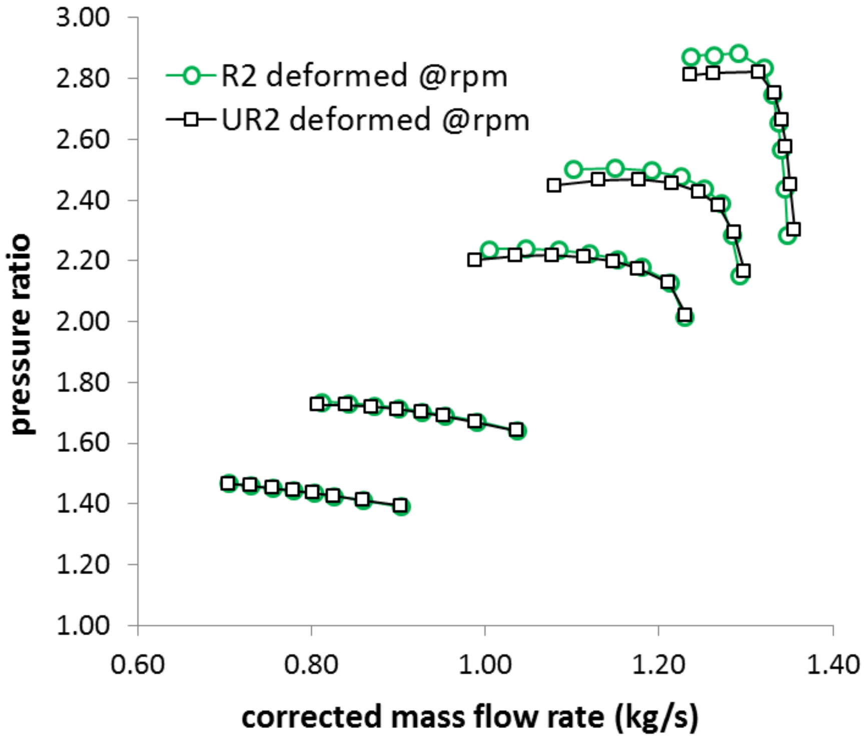
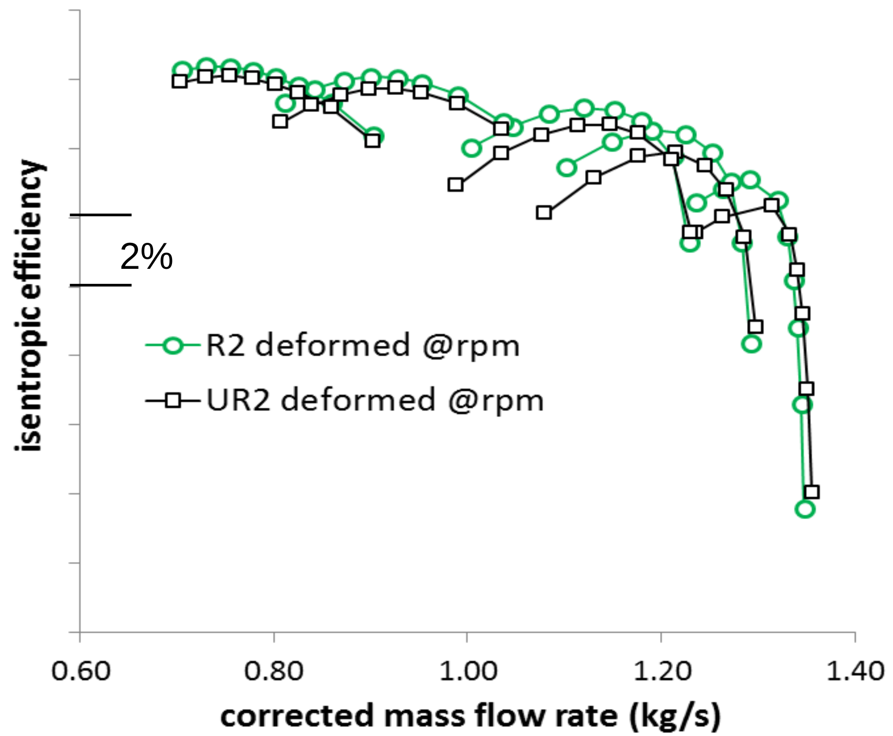
"**running**" vs. "**unrunning**" geometries

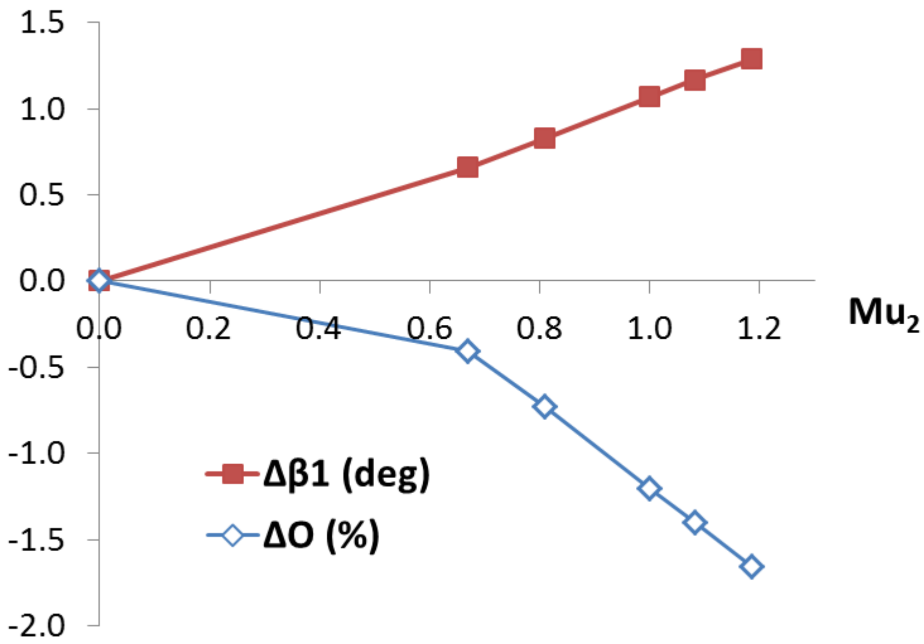
- The trend of variations is consistence with measurements
- **Running** geometry has 2.5% higher pressure ratio and 0.7% higher efficiency at design speed

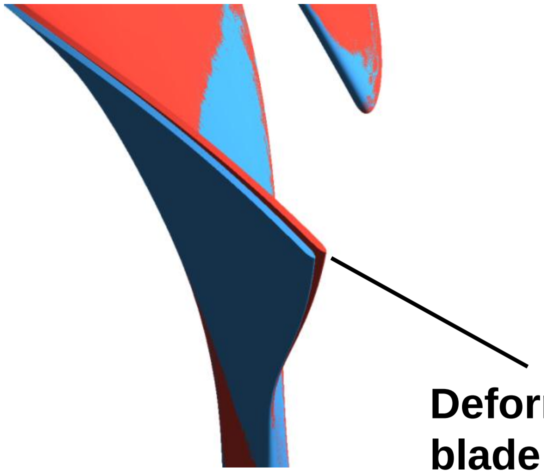




Effect of rotation on blade twist

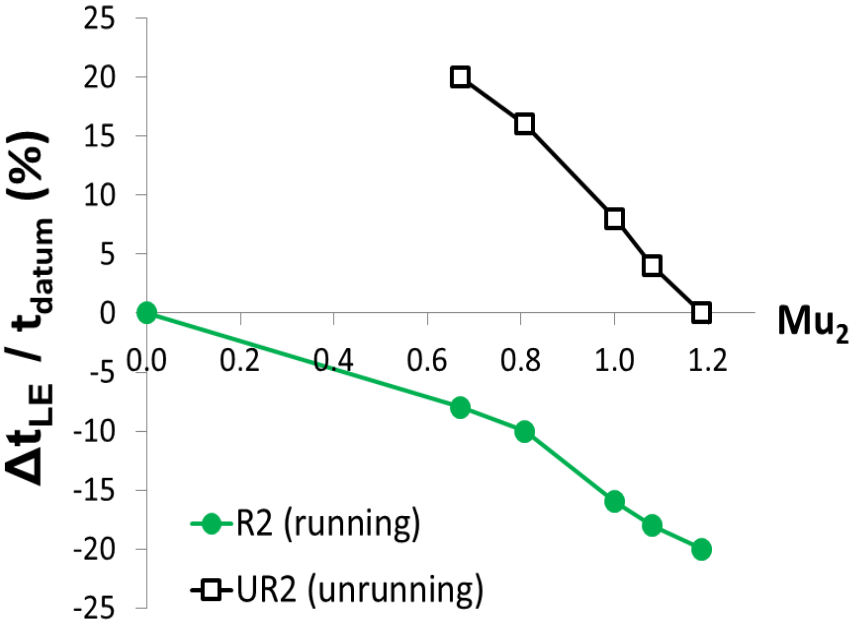
- Deformation at tip section of impeller R2 at design speed
  - 1.3^{o} increase in inlet blade angle
  - 1.6% reduction in throat width at the tip

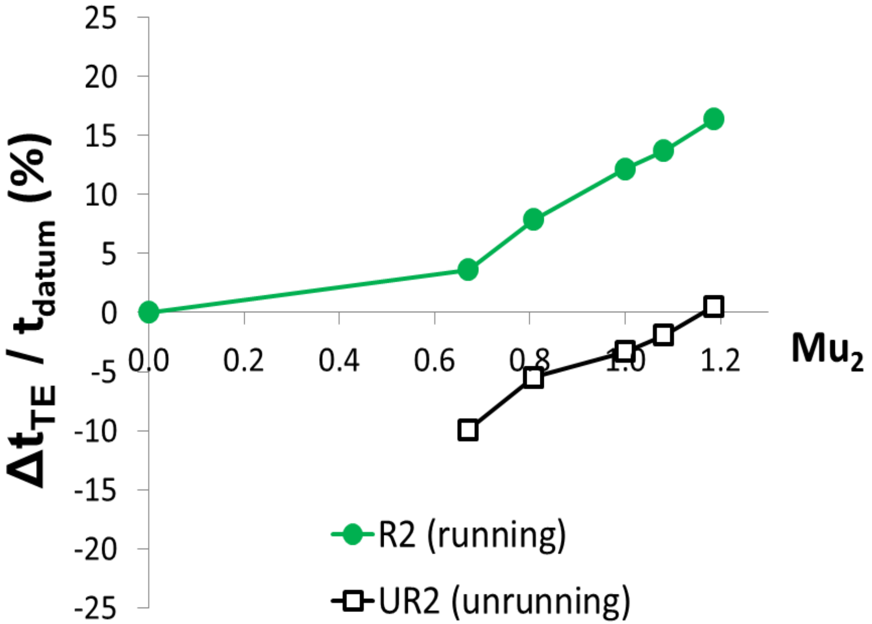




Variation in tip clearance

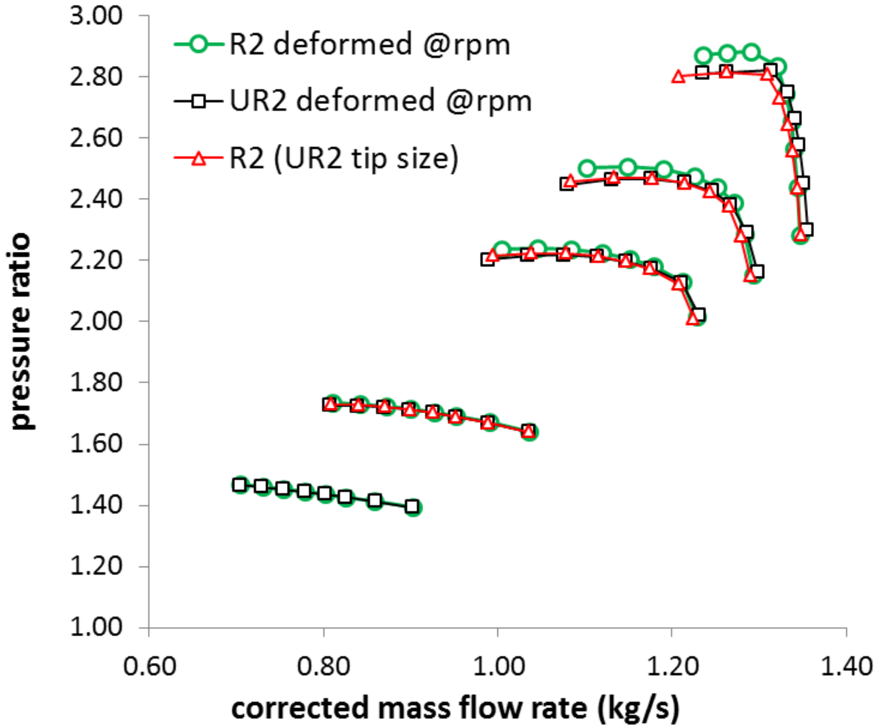
- Effect of rotation on tip clearance
  - Impeller **R2** has a constant tip gap of **0.5mm** at **zero speed**
  - Impeller **UR2** has a constant tip gap of **0.5mm** at **the design speed**

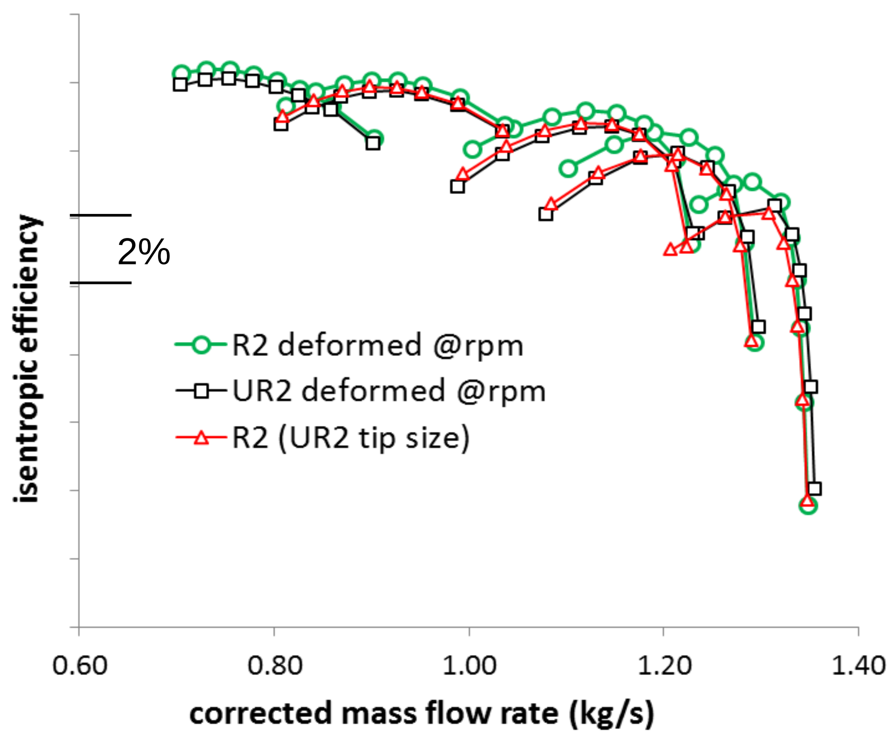




Tip clearance or blade twist?

- The tip clearance size of impeller UR2 was prescribed to impeller R2
  - Impeller flow capacity is affect by twist
  - Peak performance is mainly affected by tip gap size





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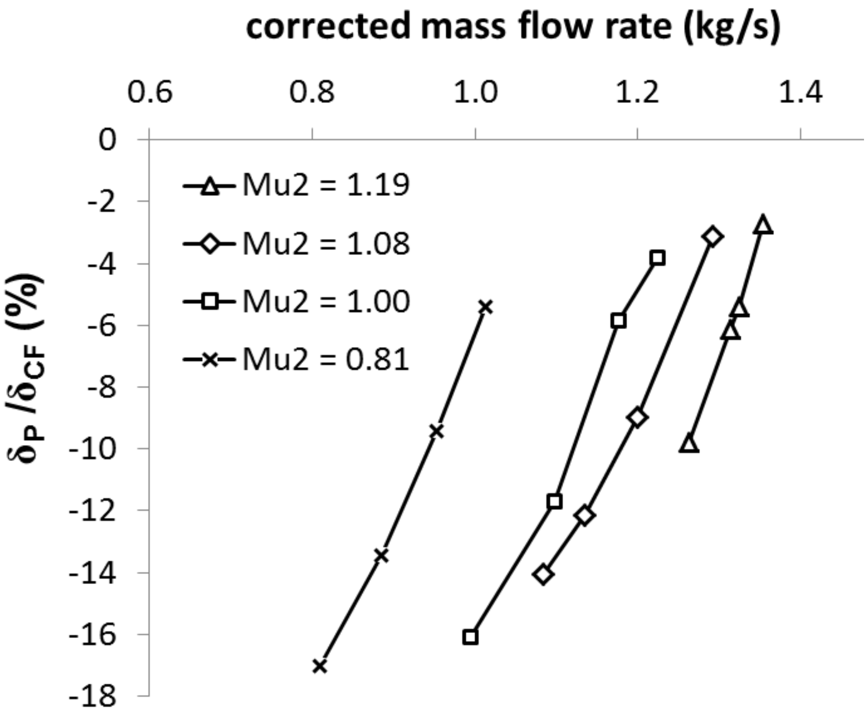
Pressure deformation

- Predicted surfaces pressures were used to calculate the resultant tangential deformation (**δ_P**)at the blade tip
- Centrifugal deformation (**δ_{CF}**) was calculated at each speed

- The effect of pressure deformation increases from choke to surge
- Centrifugal deformation becomes more dominant as the speed increases



Conclusions

- The radial impellers experience “blade twist” as opposed to “blade untwist” in axial compressors due to different lean distribution
- Blade deformation in the current impeller:
  - Increased pressure ratio
  - Increased efficiency
  - Reduced flow capacity
- Changes in peak performance were mainly due to changes in tip clearance size
- Changes in flow capacity were mainly due to the blade twist