Optimierung einer Fluidenergiemaschine auf Basis der *Computational Fluid Dynamics* (CFD)

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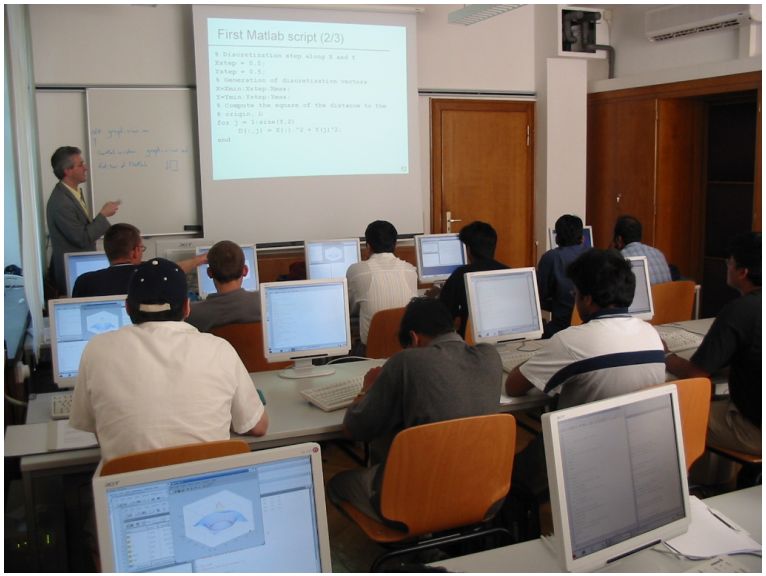
LSS: Verantwortung in der Lehre

- Für die gesamte Universität ist der Lehrstuhl verantwortlich für alle Lehrveranstaltungen:
  - ➔**Strömungsmechanik I** (Grundlagen: Bachelor)
  - ➔**Strömungsmechanik II** (Fortgeschrittene: Master)
  - ➔**Fluidenergiemaschinen**
  - ➔**Numerische Strömungssimulation** (CFD)
  - ➔**Rheologie**

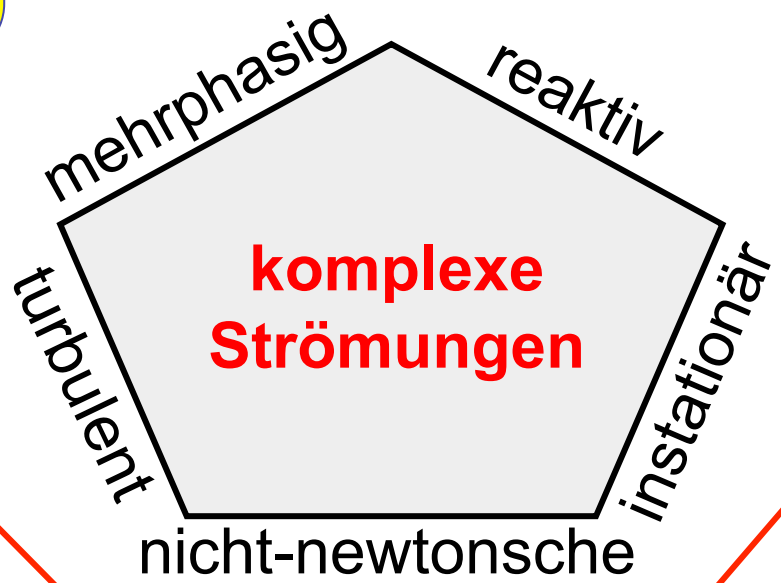


- Auf Ebene der Fakultät für Verfahrens- und Systemtechnik:
  - ➔**Messtechnik**

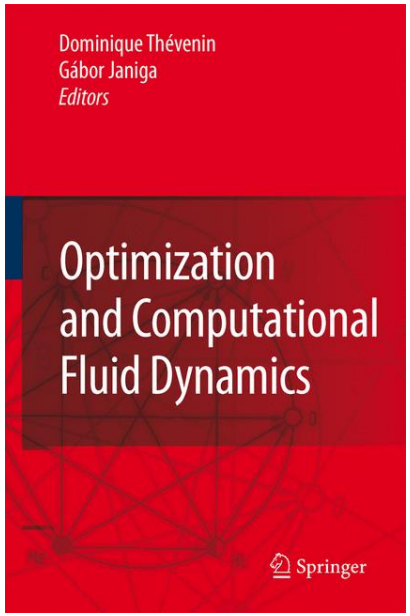
LSS: Methoden und Ziele in der Forschung

Quantitative, berührungslose **experimentelle Untersuchungen** (PIV, LIF, PDA, PTV...)

Akkurate **numerische Simulationen** (DNS, LES, detaillierte Modelle...)



Optimierung



Zusammenfassung

- 5 promovierte Mitarbeiter
- 15 Doktoranden
- 7 Technik- und Verwaltungspersonal

- Eine kleine Gruppe...
- mit vielfältigen Interessen!
- Nur möglich dank

Synergie & Zusammenarbeit!

Gleichgewicht

Lehre
Grundlagen
Experimentell
in Flüssigkeiten

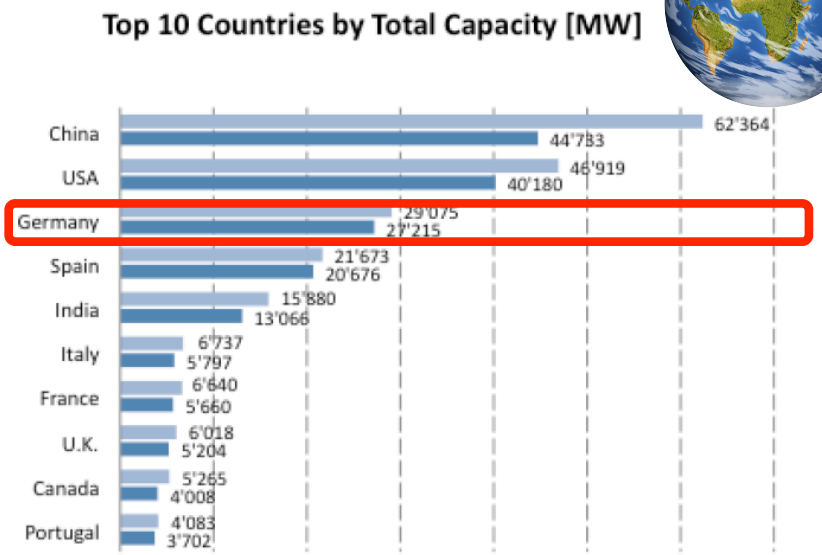
Forschung
Anwendung
Theoretisch/numerisch
in Gasen

Die Reise beginnt hier…

Introduction and motivation

- Wind energy is becoming increasingly important to reduce national dependency on fossil fuels, increase the share of renewable ressources and limit climate degradation

- Particularly true in Germany!

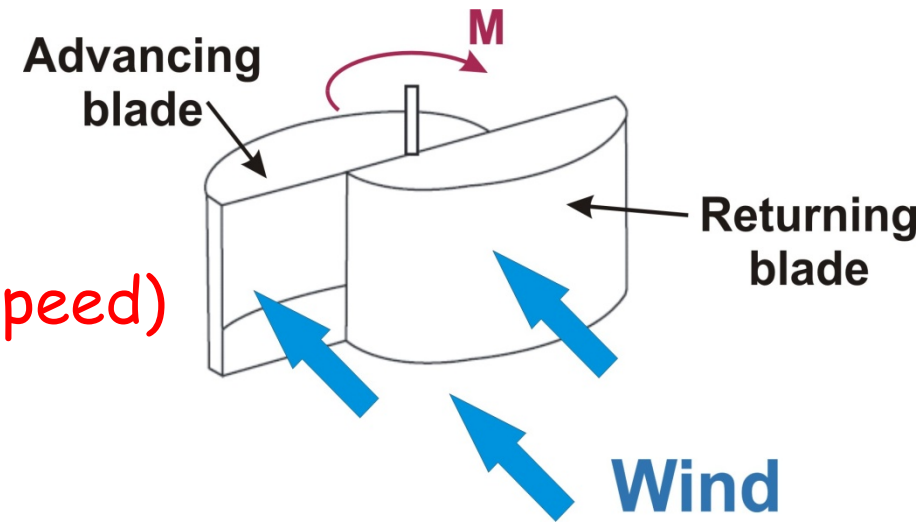


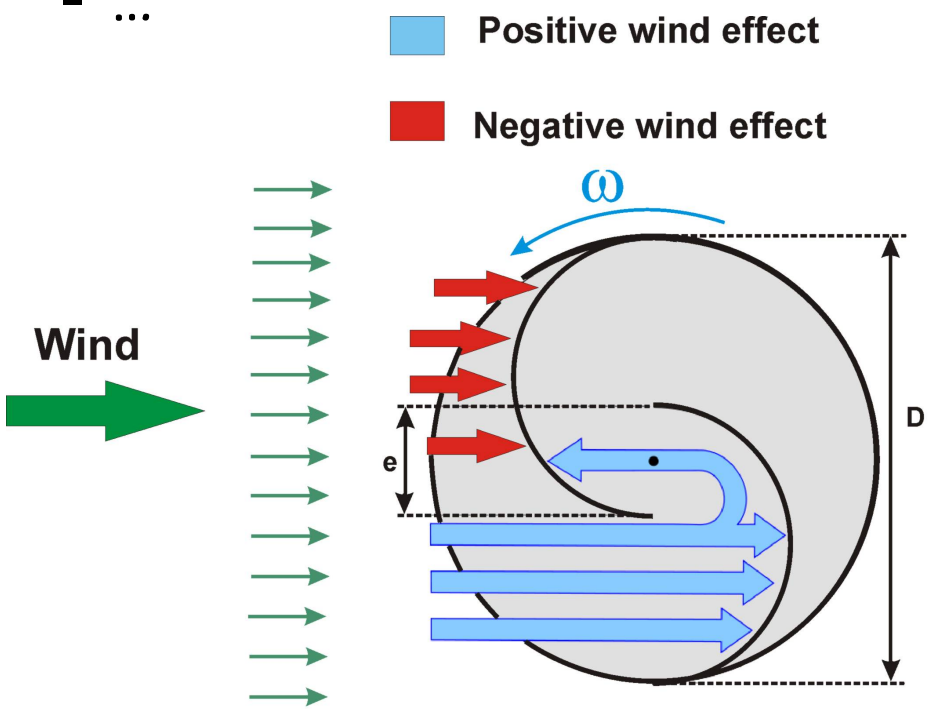
- Until now: increasingly large, three-blade, horizontal-axis turbines dominate the market

- Alternative approaches might be more promising for some conditions (low wind speeds, developing countries, urban environment…): our **target**!

Savonius turbine: a promising alternative?

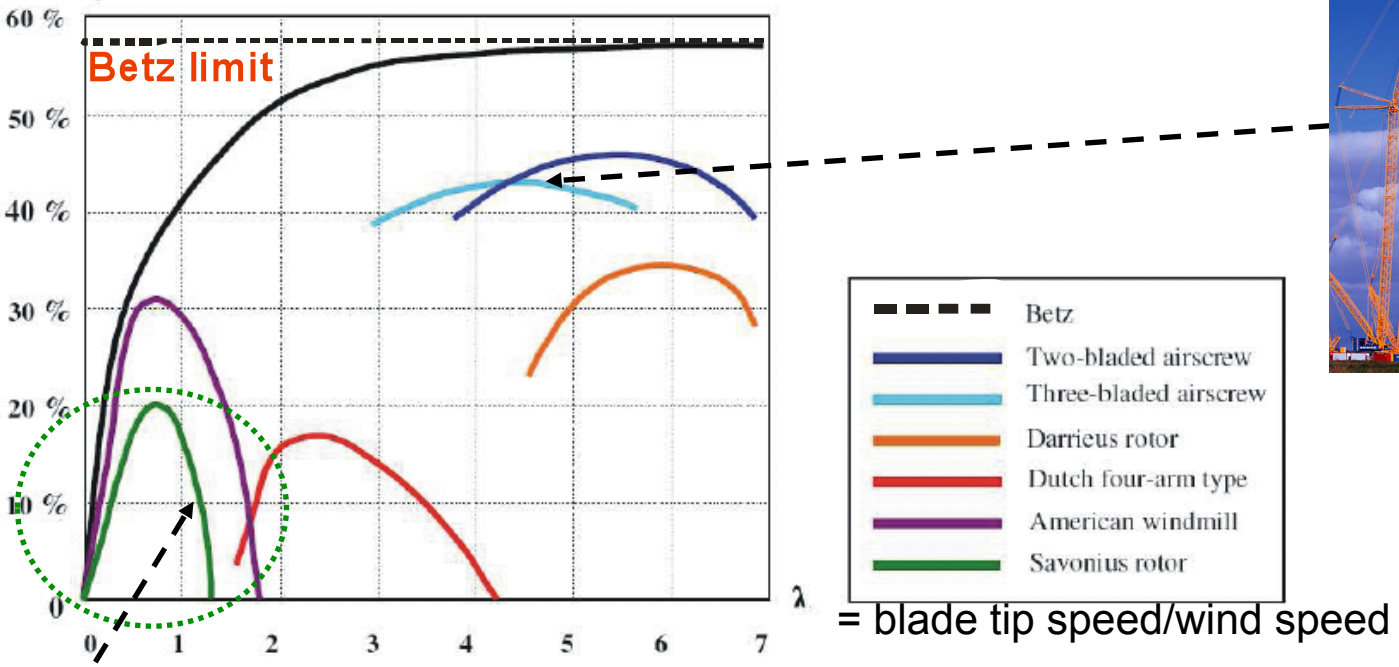
- Vertical-axis wind turbines show a lot of advantages
  - Simplicity
  - Robustness
  - Low cost
  - Less material fatigue
  - Lower noise emissions (low speed)
  - Easy integration
  - …

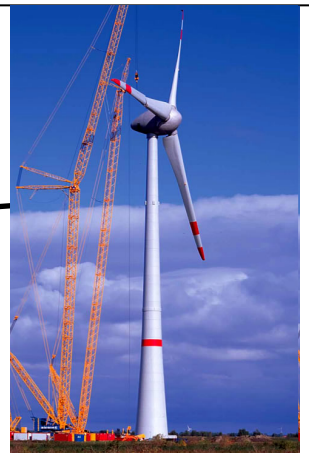




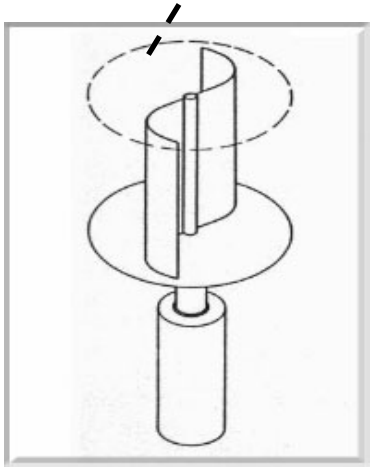
What about efficiency and Cp?

C_p [Menet, *Renewable Energy* 29 (2004)]





= blade tip speed/wind speed



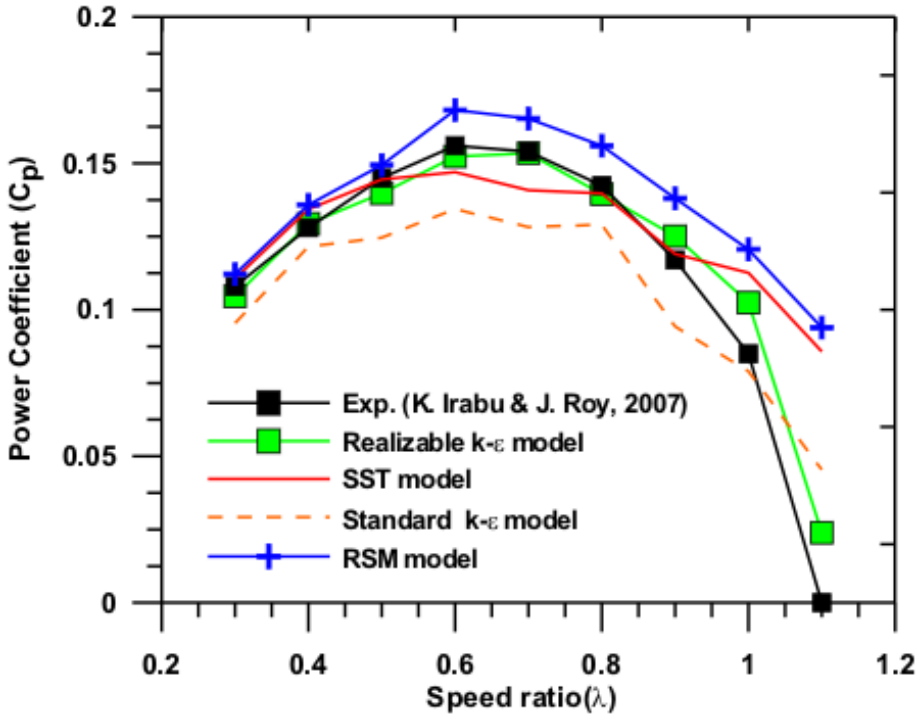
- The standard Savonius turbine is practically useless: the poorest possible system…
- But: can it be improved?
- Savonius proposed it in 1925!

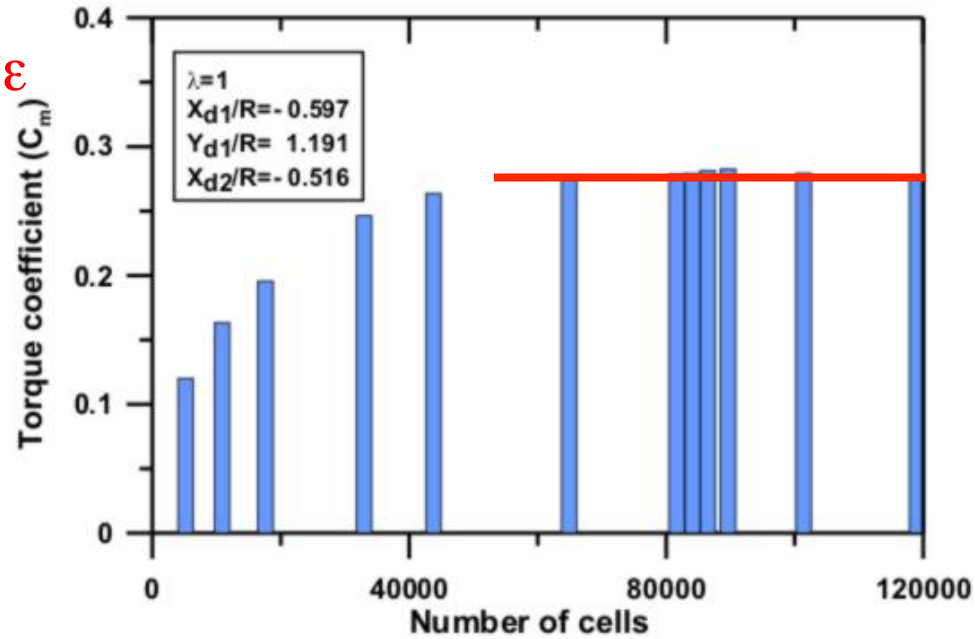
☞ **Optimization using CFD**

Computational Fluid Dynamics: models

- Tool: ANSYS-Fluent
- Second-order discretization
- Fully unsteady description: Sliding Mesh Model and URANS-approach, computing 3 turbine rotations
- 2D computations (horizontal slice) for optimization

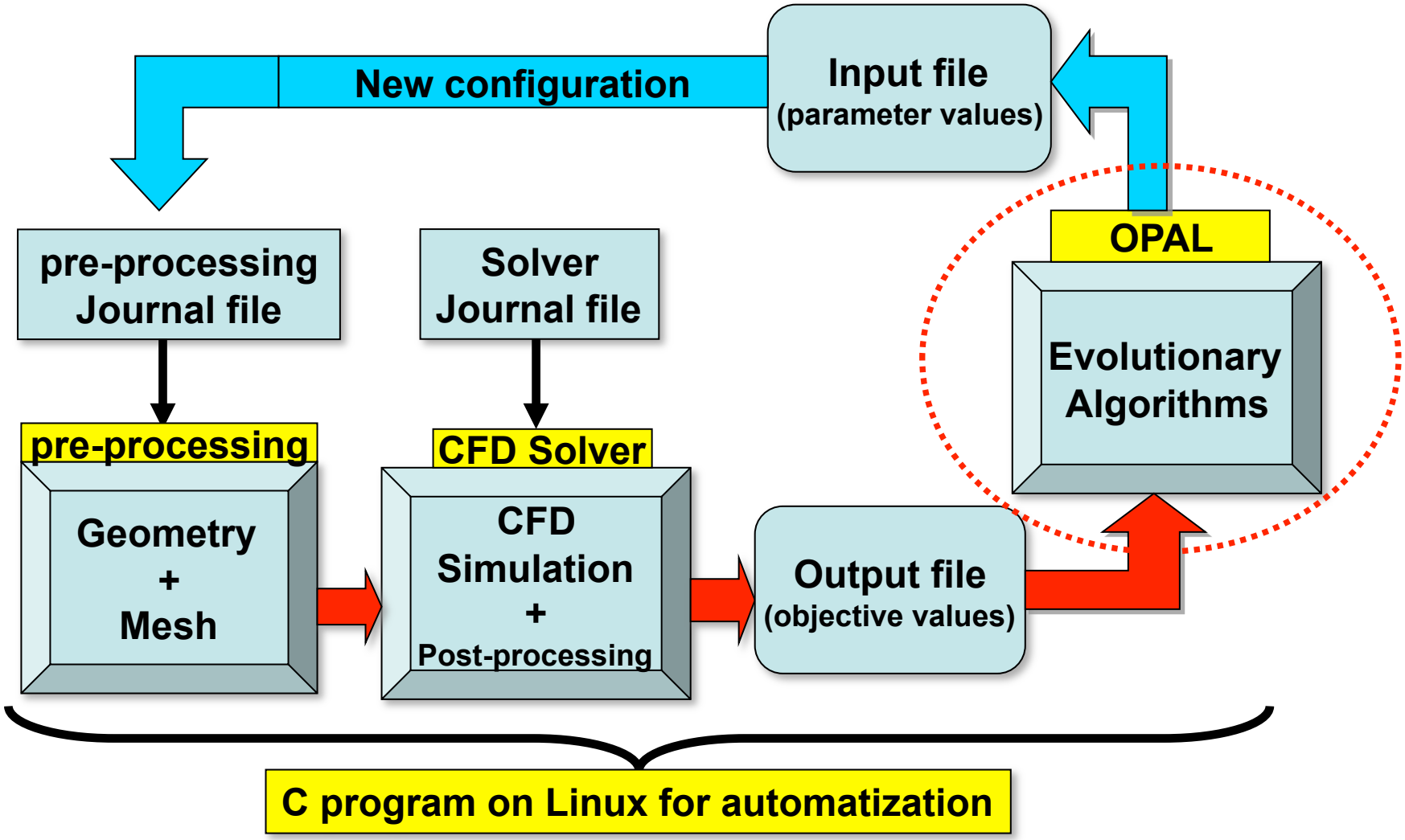
Turbulence model: Realizable k-ε





Grid dependency: 65 000 nodes

Embedding CFD in optimization loop



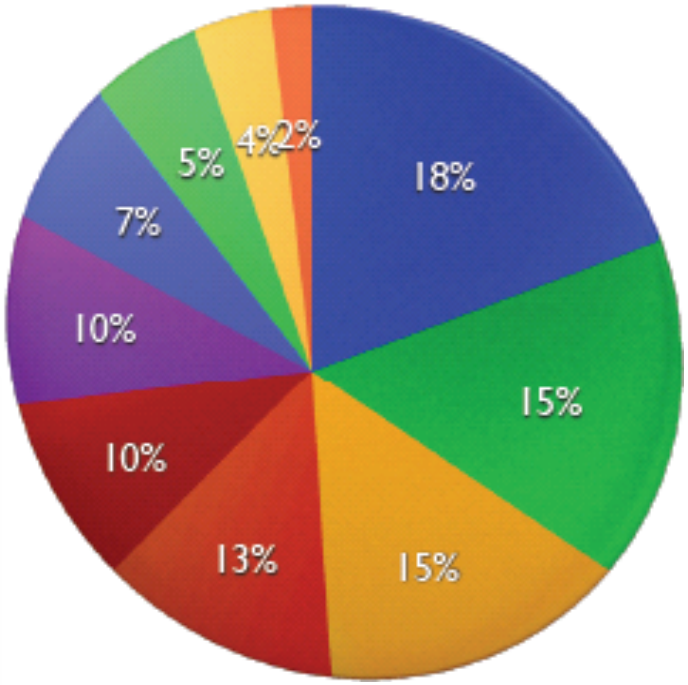
- In-house optimization library OPAL: here using Evolutionary Algorithms (EA)

EA: Fitness and ranking

$$\text{Fitness}(i) = \frac{N - \text{rank}(i) + 1}{\sum_j (N - \text{rank}(j) + 1)}$$

G. Orwell: „All animals are equal, but some animals are more equal than others"

Selection process



N **: total number of individuals**

rank : order of the individual according to objective values

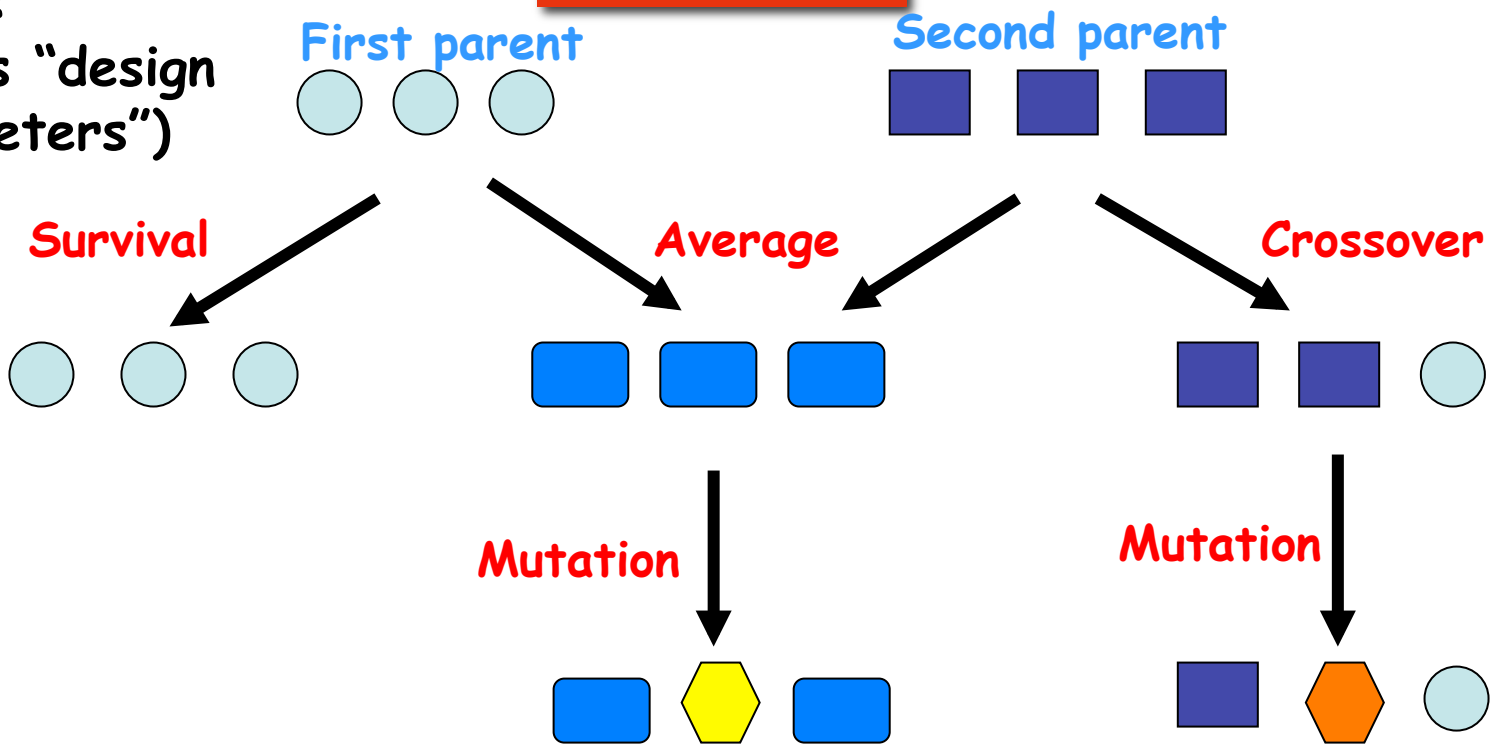
i,j **: index of the individual**

Good rank → Higher chance to survive and reproduce (roulette)

EA: from generation (n) to (n+1)

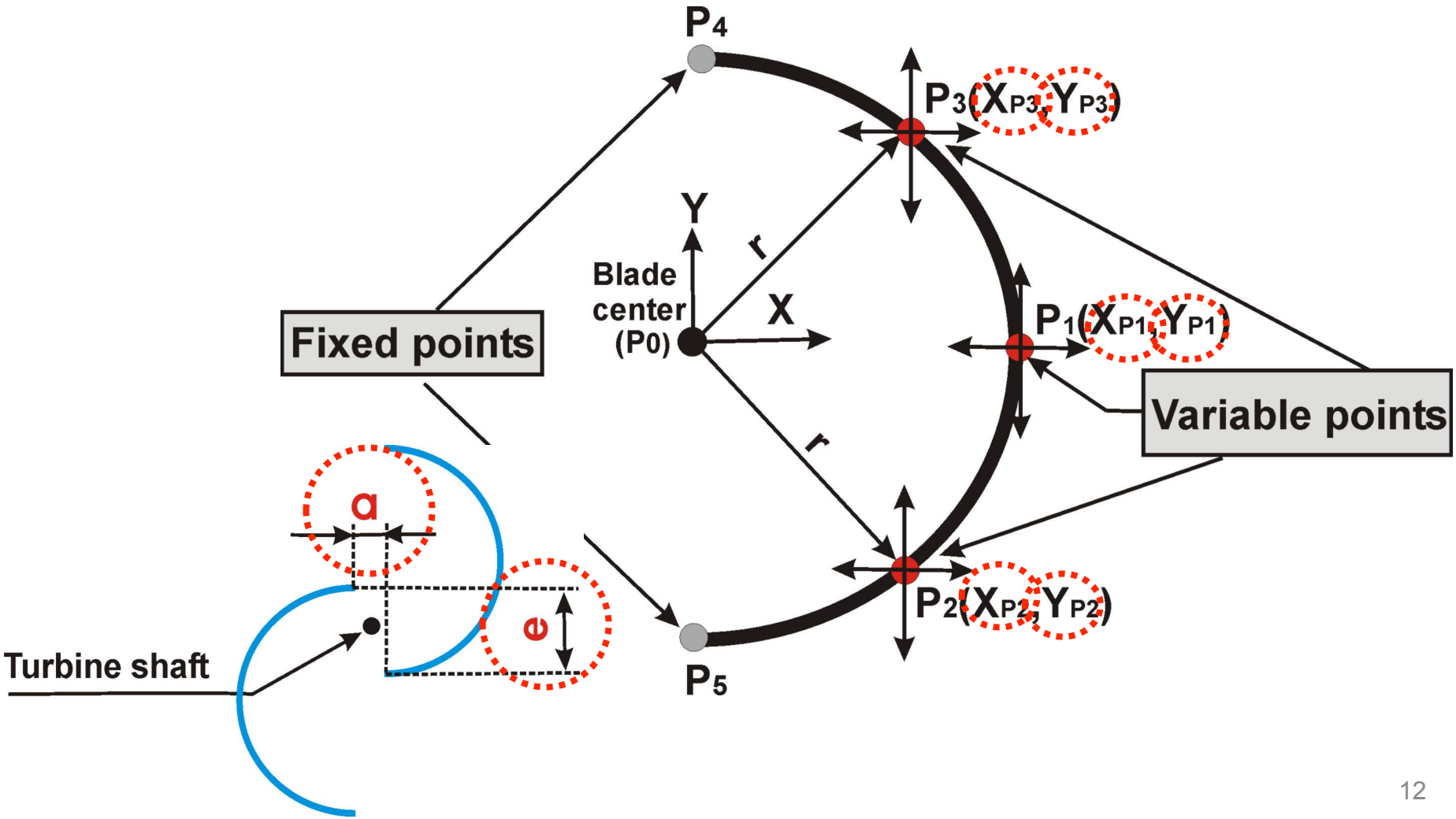
Individuals:
(means "possible designs")

Genes:
(means "design parameters")

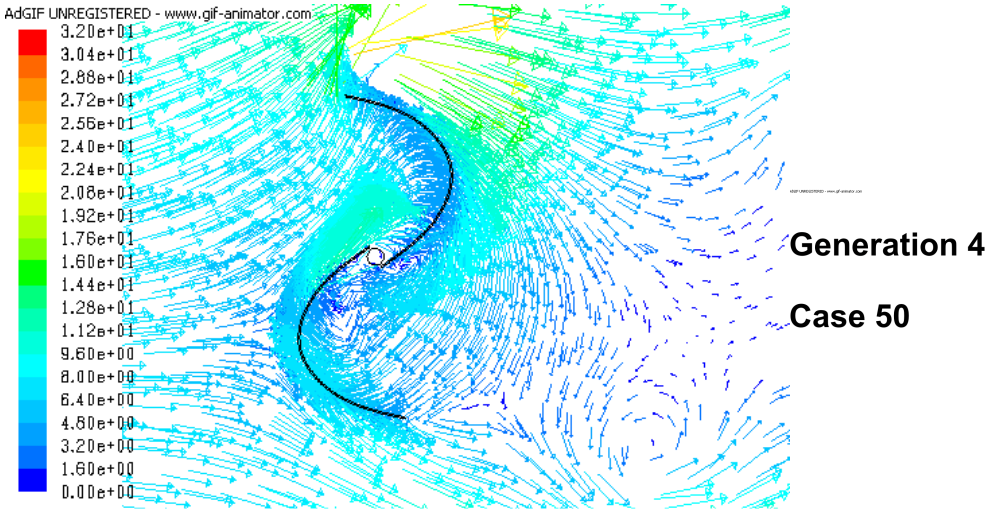


First try: optimize blade shape and shaft

- Fixed: external diameter of turbine, wind speed, speed ratio
- Free parameters: **8** (a, e; X and Y for 3 points)
- Maximize **1** target function: Cp

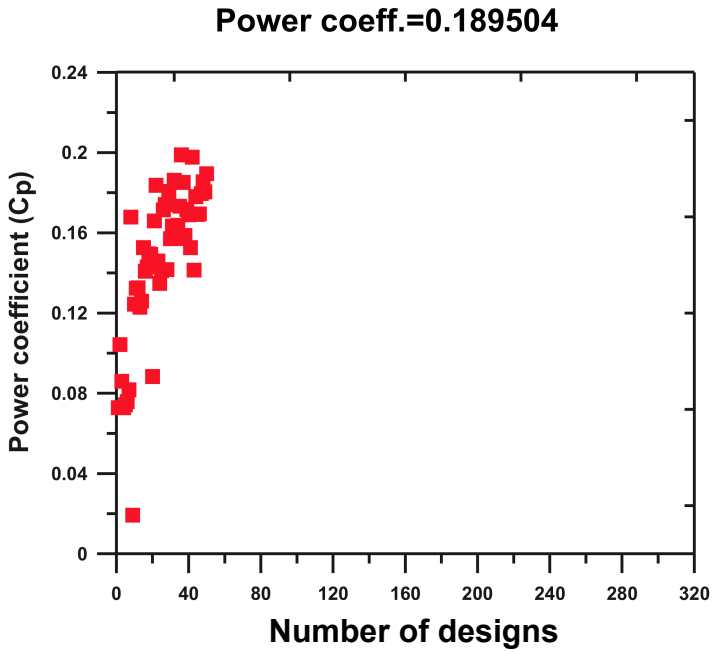


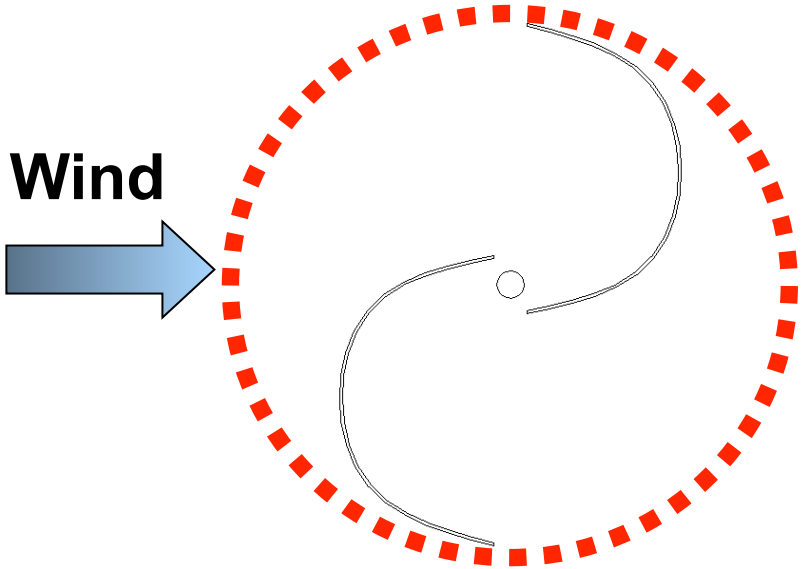
Let's start it!



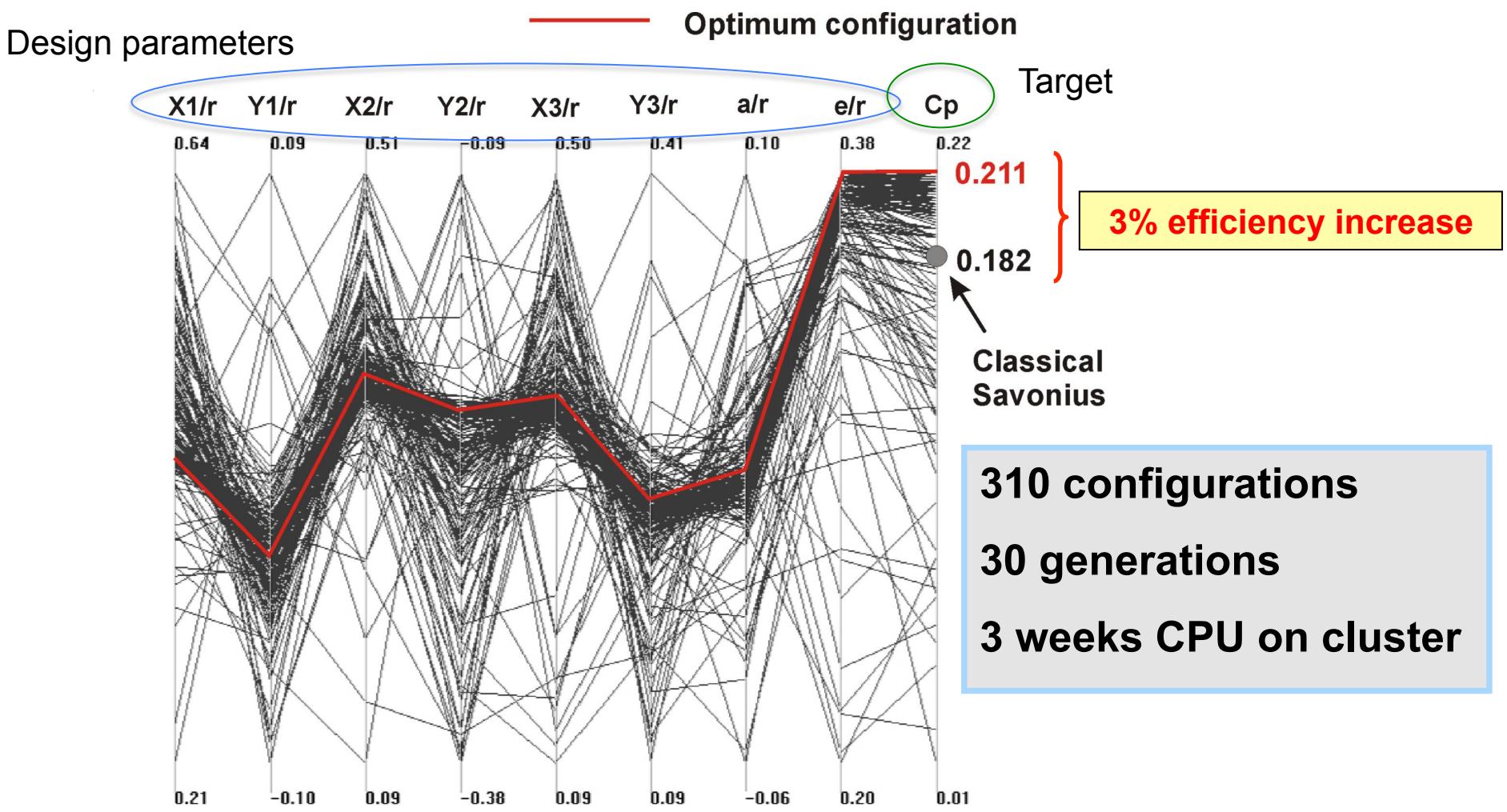
Generation 4

Case 50





Analysis of results: parallel coordinates



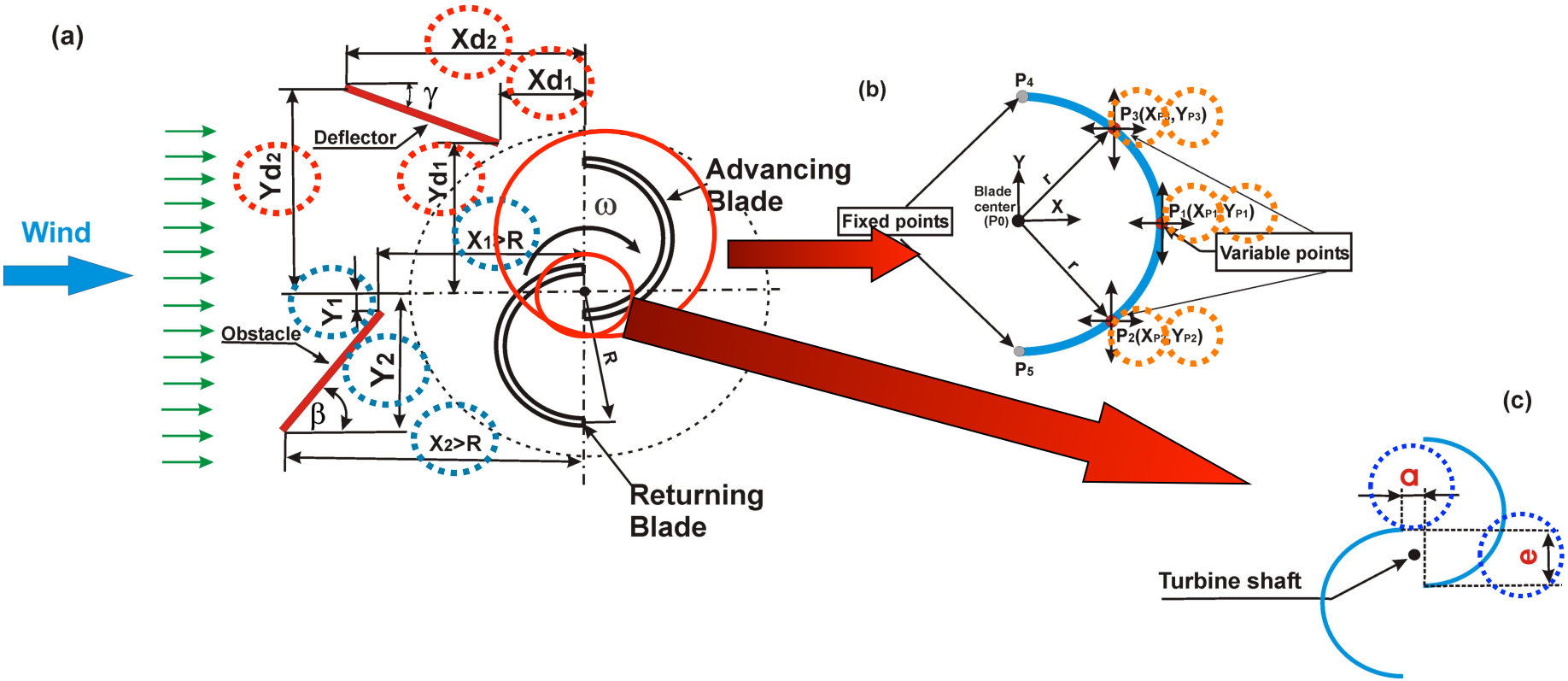
310 configurations

30 generations

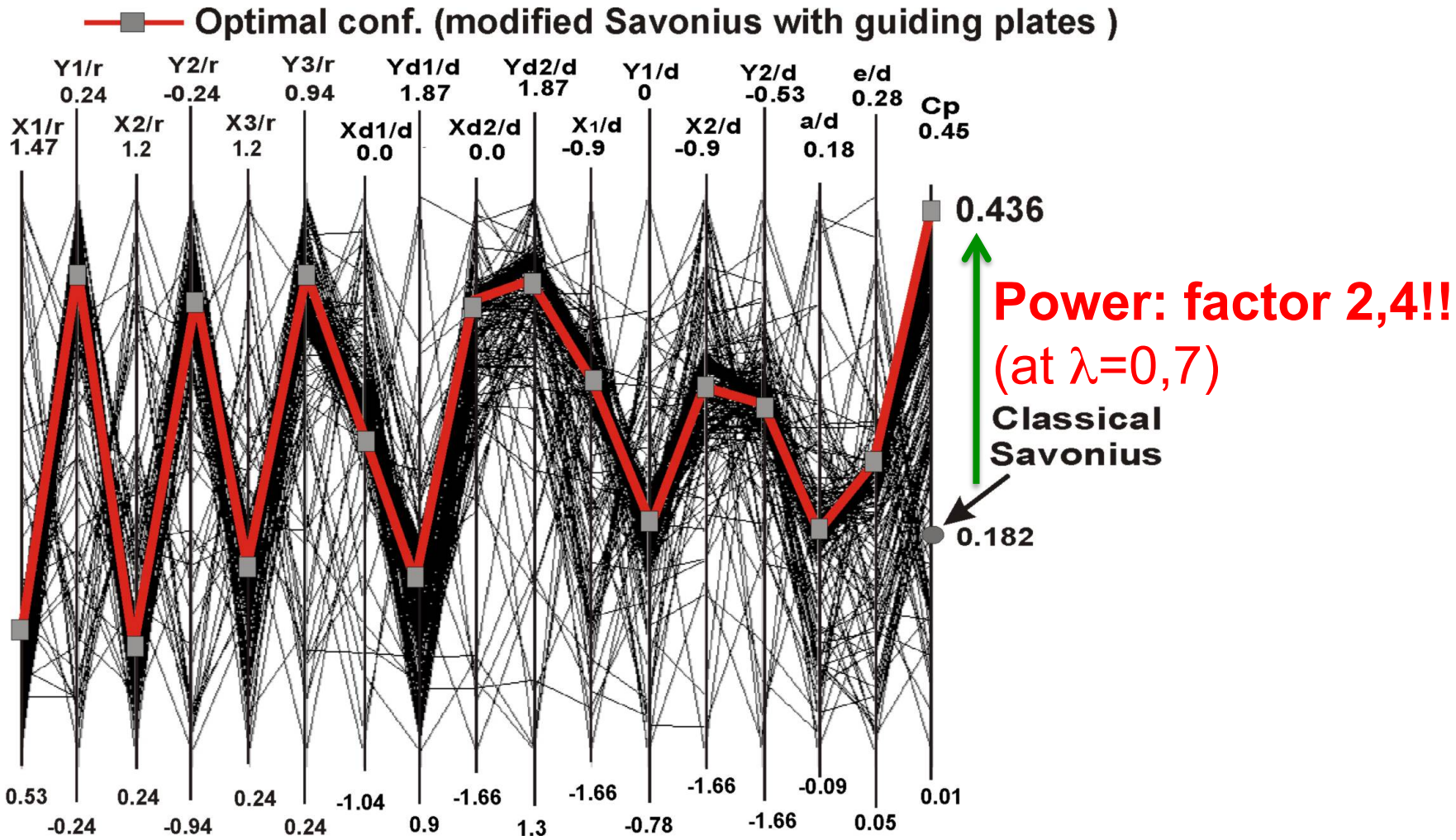
3 weeks CPU on cluster

Can we do even better?

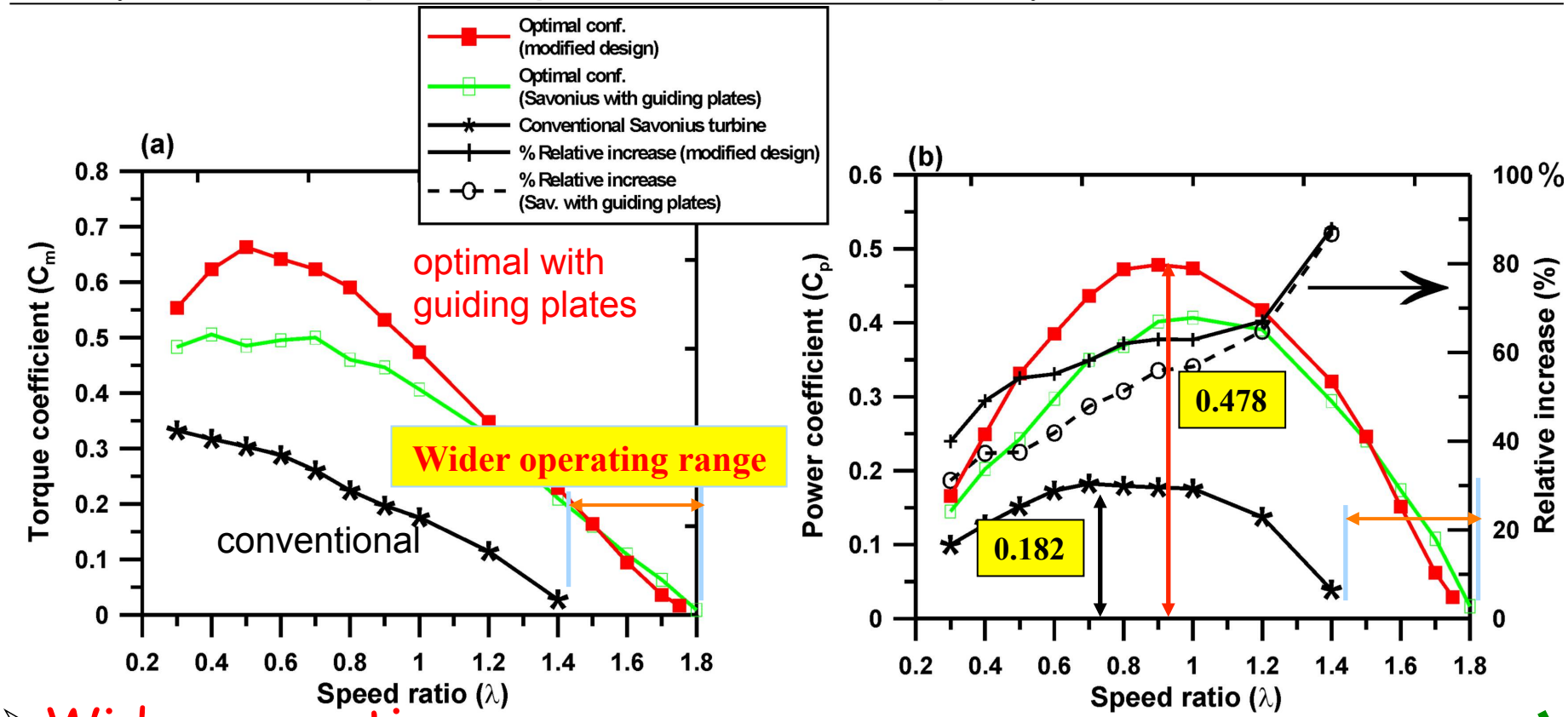
- Involving simultaneously guiding plates (deflector & obstacle)
- Free parameters: now **16** (very challenging)
- Maximize **1** target function: Cp



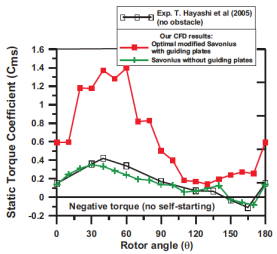
Optimal result



Operating range, off-design performance



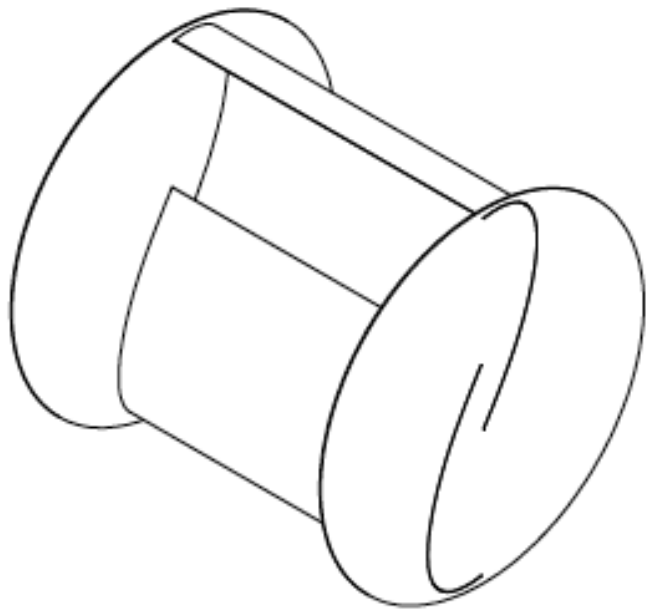
- Wider operating range
- Systematically considerably higher Cp
- Peak Cp increased by factor 2,62!
- Always self-starting



A dream come true!

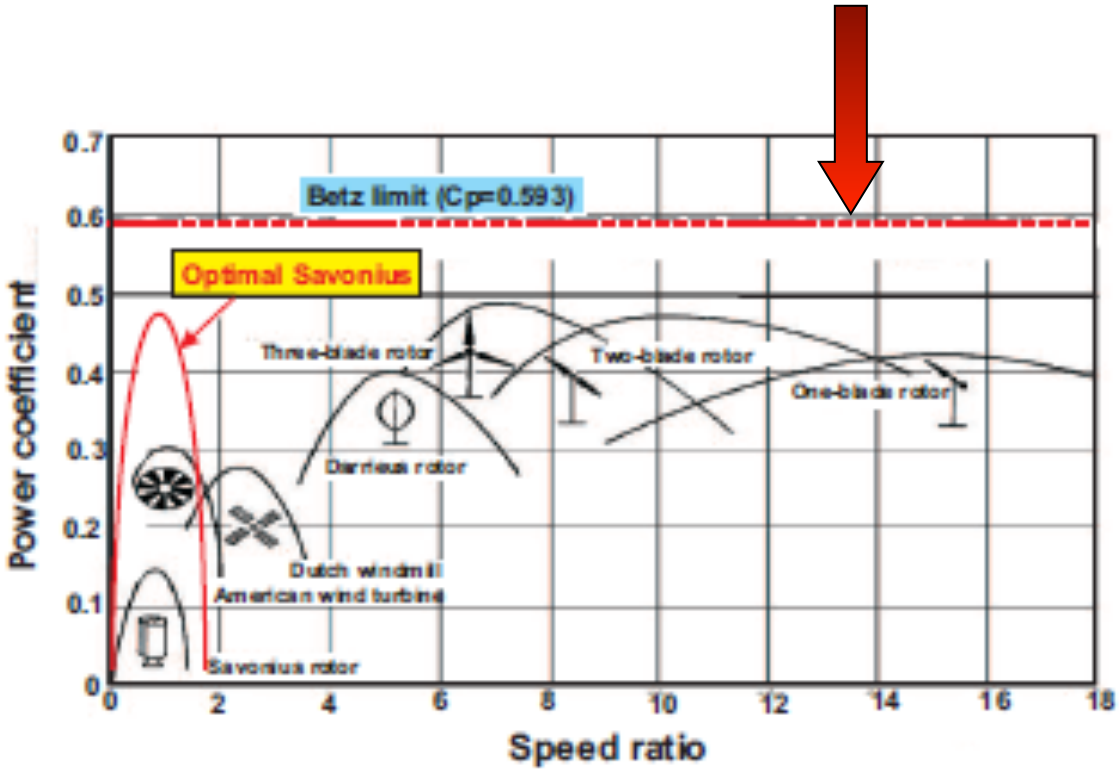
A dream come true??

- Or: "Should we believe CFD?"
- Certainly NOT without checking twice…
- And remembering many approximations (URANS, k-ε, 2D…)
- It is worth comparing dream and reality!
- First for a small-scale prototype
- Looks promising so far: wait and see!



Conclusions

- CFD-based optimization relying on EA was able to deliver a tremendously improved design
- Its properties are extremely good: extended operation range, still working up to λ=1,7, excellent self-starting, peak power coefficient of 0.48 at λ=0,9, approaching Betz' limit



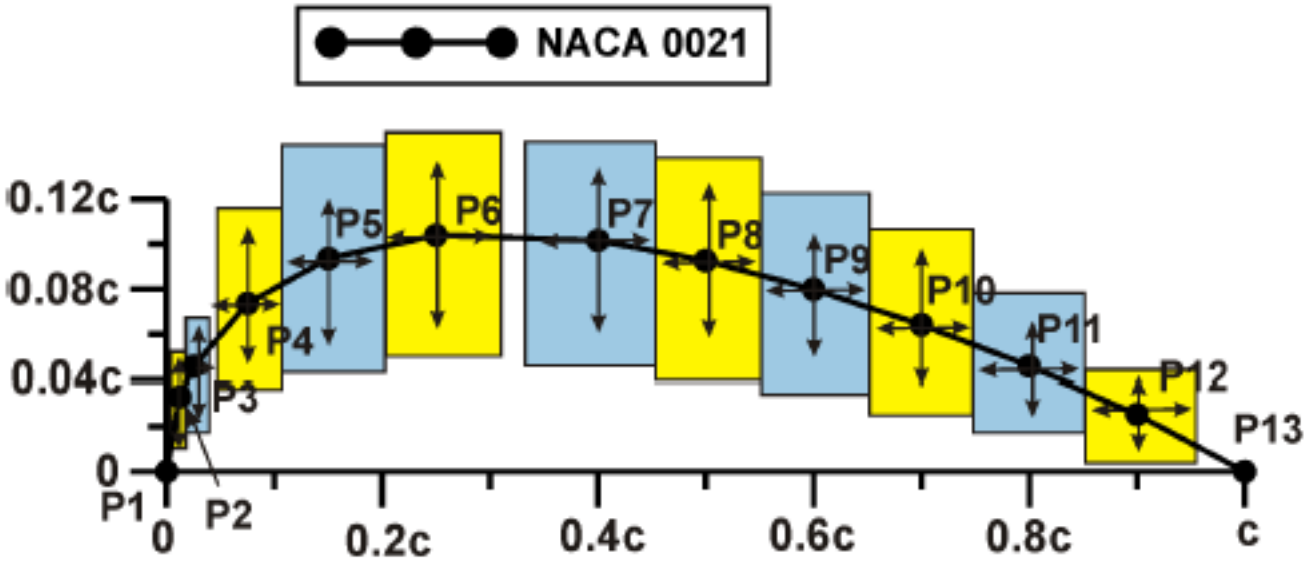
- Design patented

Aber: Wo bleibt der Fluss?

- Das ist vielleicht schön und gut…
- aber was hat das alles mit Fluss-Strom zu tun??

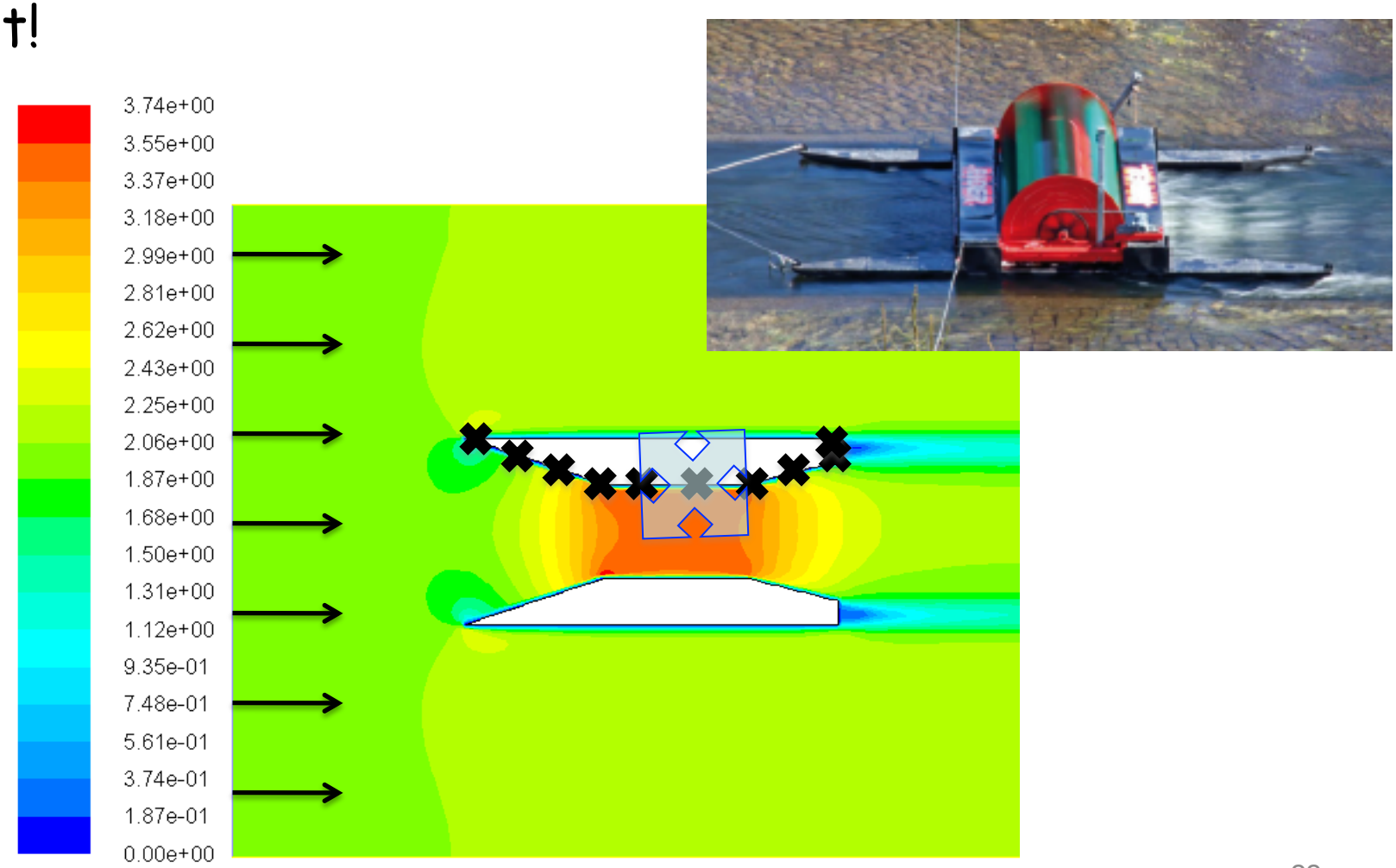
Die Methodik!

- Strömungssimulation/CFD funktioniert gleich gut für Luft- und für Wasserströmungen...
- Die Optimierung der Schaufel, der Betriebsparameter, der Strömungsführung kann in identischer Weise erfolgen.
- Also ist die Simulationskette direkt übertragbar!



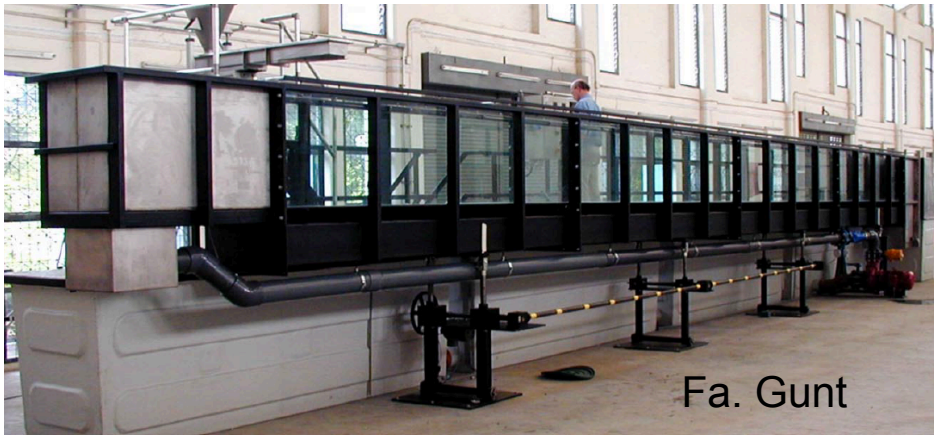
Vorberechnungen

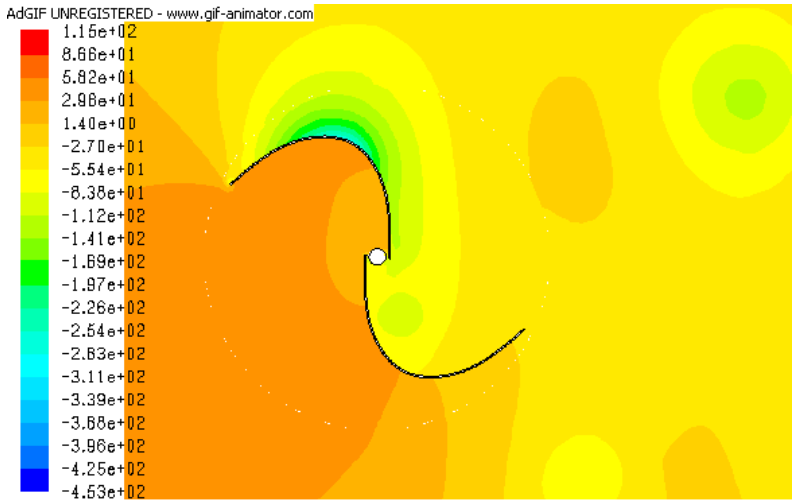
- Die numerische Simulation der Strömungsführung wurde bereits gestartet...
- und deutet darauf hin, dass viel Optimierungspotential noch existiert!



Zusammenfassung

- Eine Simulationskette wurde entwickelt, die es ermöglicht, die Eigenschaften einer Fluidenergiemaschine zu optimieren (Schaufelform, Strömungsführung, Betriebsparameter…)
- Diese konnte bereits erfolgreich für eine vertikale Windturbine eingesetzt werden
- Die Methode ist direkt auf andere Systeme (z.B. moderne Wasserräder) übertragbar
- Experimentelle Vergleiche (Validierung des numerischen Modells am Anfang, Überprüfung der Ergebnisse am Ende) bleiben unabdingbar:
  - ➡Bedarf für einen entsprechenden Wasserkanal!





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-G. Janiga
-P. Berg
-B. Wunderlich
-J. Meyer
-P. Fischer
-D. Meinecke
-C. Kisow
Many thanks to all of them!

Thank you for your attention!

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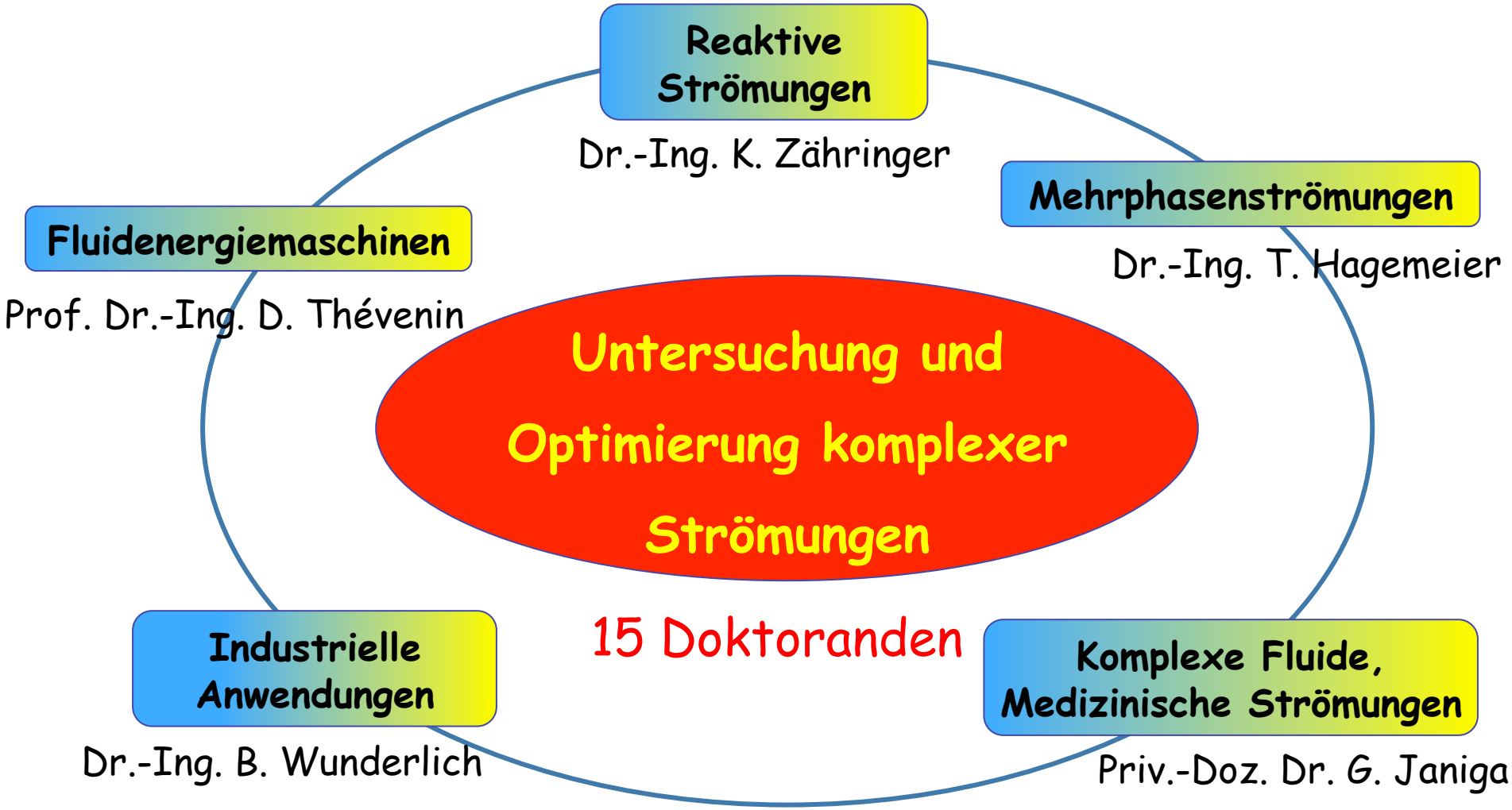
Struktur des Lehrstuhls



7 Technik- und Verwaltungspersonal

Numerisch: Priv.-Doz. Dr. G. Janiga Experimentell: Dr. K. Zähringer