# Rotor System Design – Tradeoffs and Challenges

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**DTU/NREL 4th Wind System Engineering Workshop – Roskilde Denmark, Sept 14th 2017**

# Introduction

## Agenda

- Envision Energy – brief introduction
- The China domestic market
- Effort vs. accuracy tradeoff in design tools and methodologies
- The Envision Blade Design Process
- LCOE example for DFIG machine design decision making

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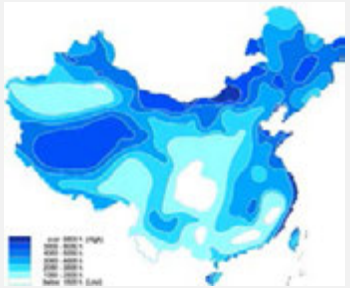
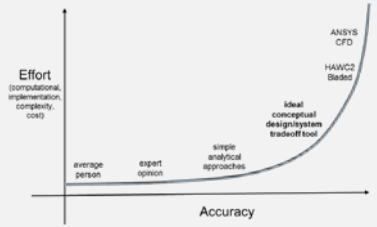
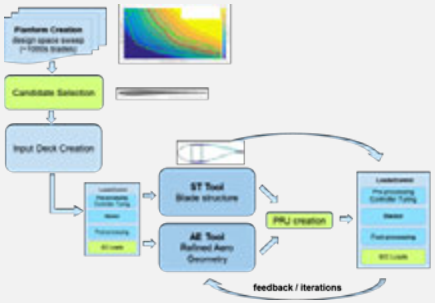
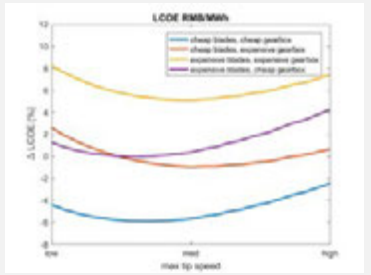




# Envision Energy

## A Brief Introduction

### Summary

- Shanghai based, privately held, founded in 2007
- Business Units:
  - **Turbine OEM**
  - WindOS (park control and SCADA)
  - Wind farm project developer and operator
  - Envision venture capital
- Global Team ~ 1300 employees (growing fast!)
  - **China** – Shanghai HQ
  - **Denmark** – Silkeborg
  - Germany – Hamburg
  - UK – London
  - **USA** – Boulder, Houston, Menlo Park (California)
- Turbine Markets:
  - **China domestic** onshore/offshore
  - Sweden, Mexico and S. America
  - Seeking gradual international growth…
- 2017 installed capacity ~ **4.5 GW**
- 2016 Market share as a turbine OEM:
  - #8-9 globally
  - #3 in China

Source: Global Wind Turbine Trends 2016 - MAKE

# The China Market

## Large Market - Rapid growth

- World 2016 installed capacity: 42% (23 GW) vs. 15% (USA)
- Cumulative installed capacity as of Dec 2016: 34.7% vs. 16.9% (USA)

## Fast Cycle Time

- Fast product cycles
- Portfolio renewed every 2-3 years

## CAPEX Driven

- Cost is threshold for market entry
- Intense domestic competition

## Capacity Constrained

- FPH is primary metric (full power hours) = CF
- AEP is less important (today)
- Transition to position constrained for some local markets with higher MW

## Design Challenges

- Dynamic PRS – design products that are robust to change
- Low wind resources (5.0-6.5 m/s) = low W/m^2
- Increasing pressure for very low noise
- Extreme soiling potential
- LE erosion (rain/fog prone environment)
- Complex terrain sites

## Enable Faster Product Cycles

- Accelerate design cycle time (weeks)
- High 'computational economy' tools and methodologies
- Accurate estimate of CAPEX & LCOE via physics based cost models
- Time to market- focus on long lead time items

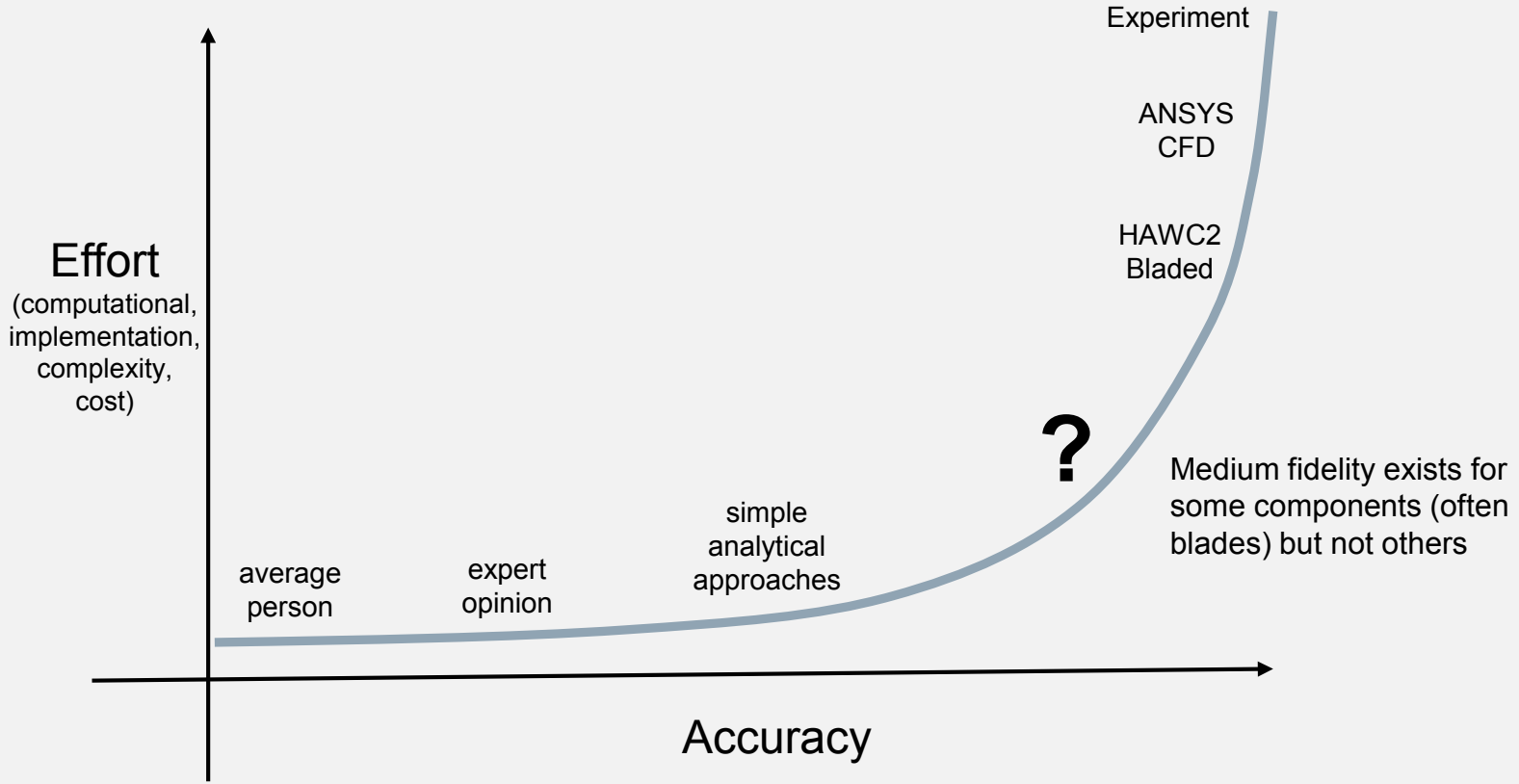
This is where SE can help!



Source: Global Wind Report 2016 Market Update - Global Wind Energy Council – http://gwec.net/publications/global-wind-report-2/global-wind-report-2016/

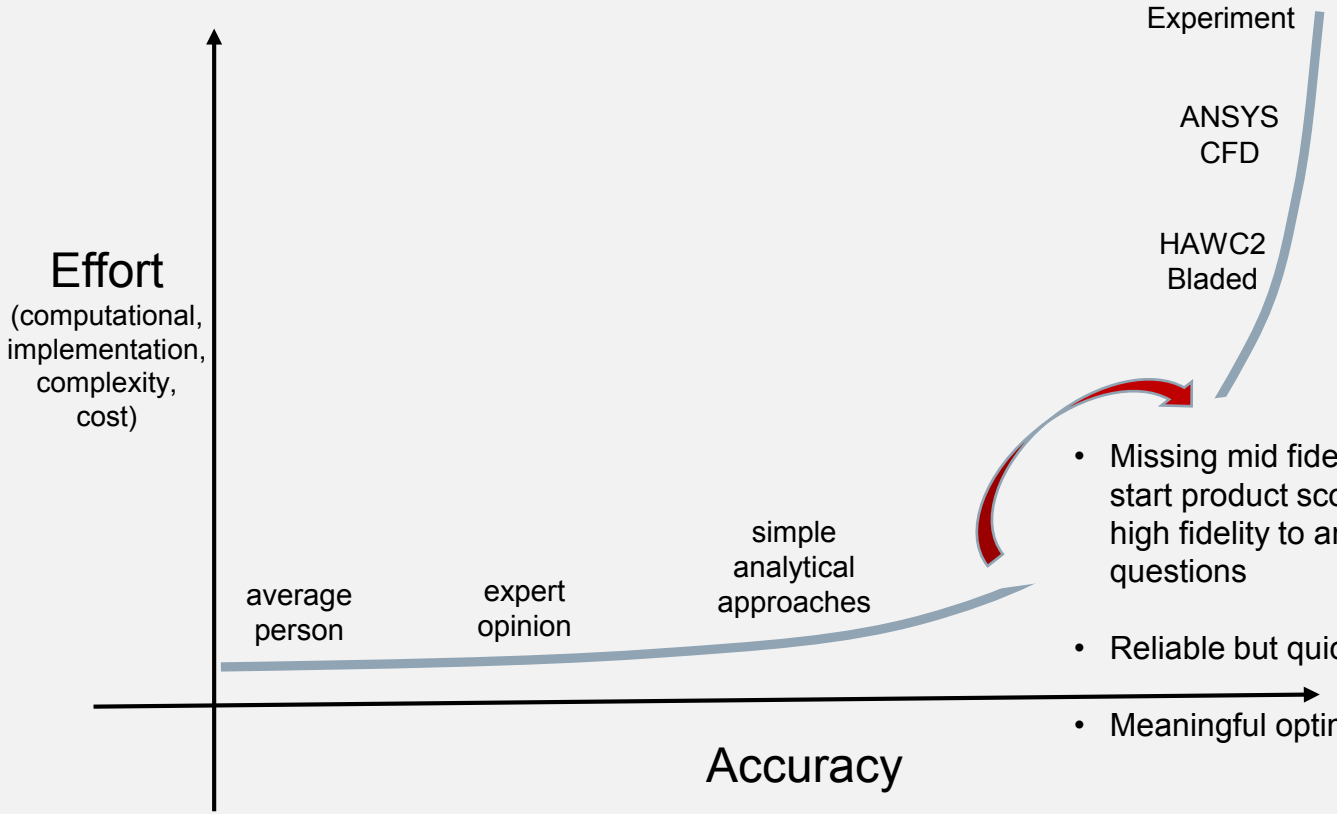
# Taking a Step Back: Model/Methodology Effort vs. Accuracy

"The Pareto Front of Truth"



# Effort vs. Accuracy

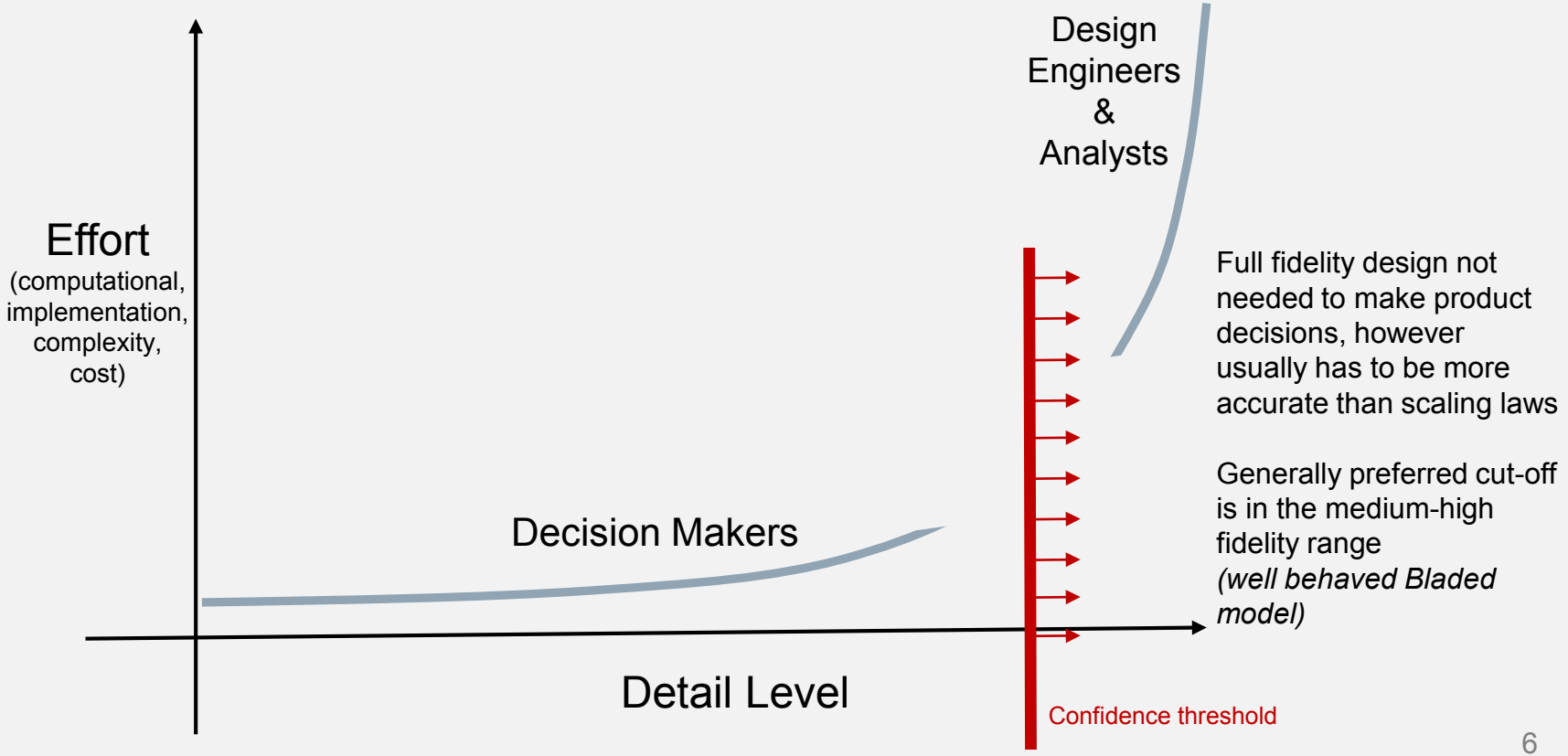
## Medium Fidelity Gap




- Missing mid fidelity makes it harder to start product scoping process = using high fidelity to answer low fidelity questions
- Reliable but quick results is a challenge
- Meaningful optimization difficult

# Effort vs. Accuracy

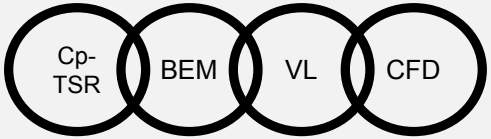
## Gaps in Fidelity Chain Impair Decision Making

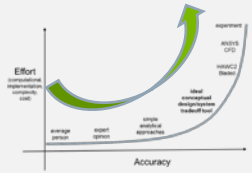


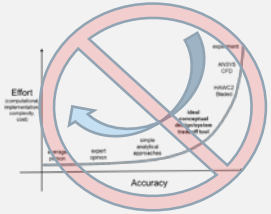
# Enabling Faster Decision Making

## Bridging the Fidelity Gap

- **Get to decision threshold as fast as possible.**
- When creating gap filling models, **do the simplest thing first**. Develop new models from low fidelity to high fidelity.
- Establish a **fidelity chain** for each component/discipline. Validate in sequence of fidelity.
- **Use optimization techniques judiciously**
  - Exploit nesting (reduce DOFs)
  - Optimization is sometimes better at breaking models than producing meaningful results…
- **Challenge need for 'optimality'** given uncertainty and/or timeline



# Taking a Step Back: Model/Methodology Effort vs. Accuracy

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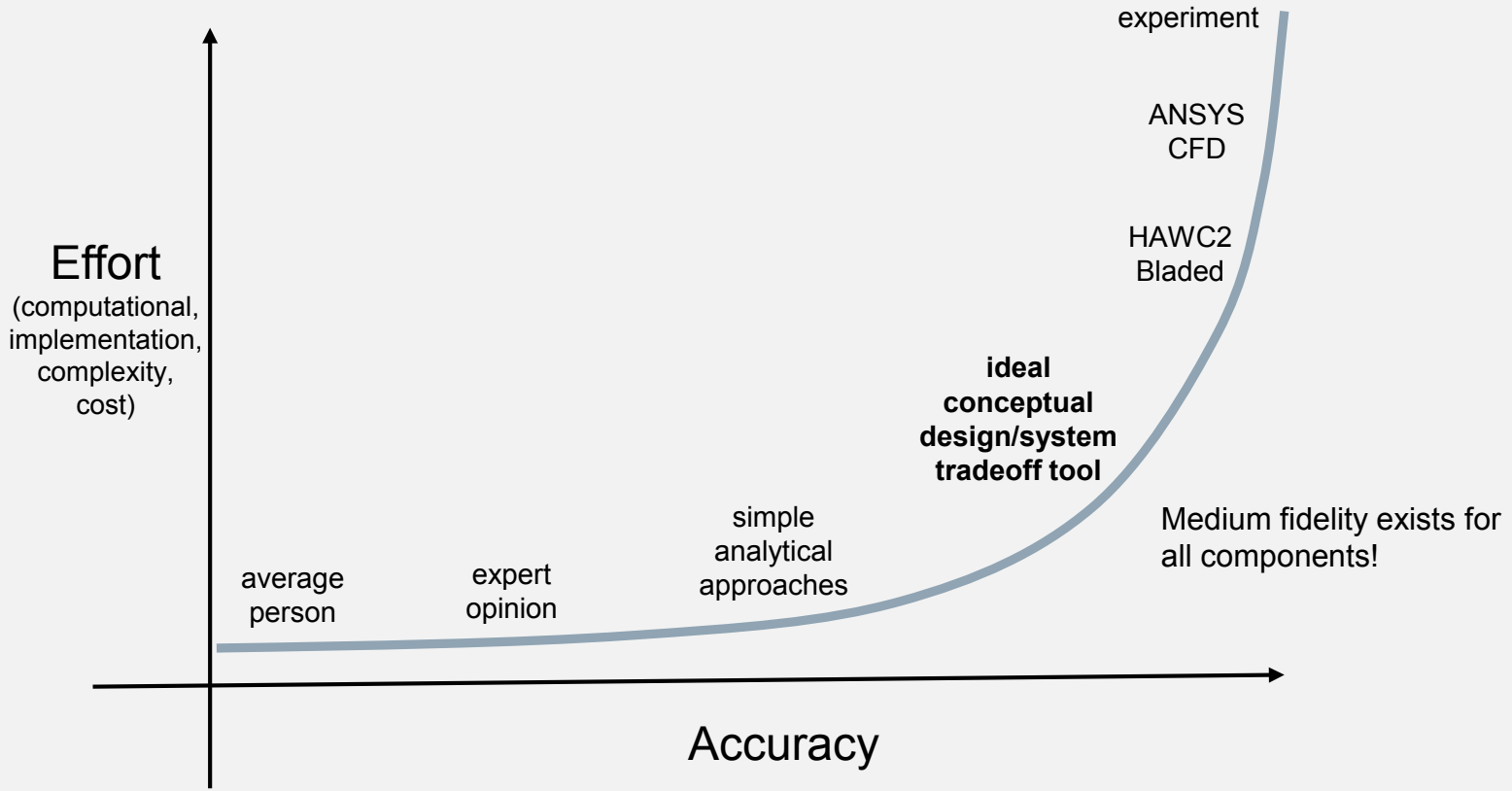
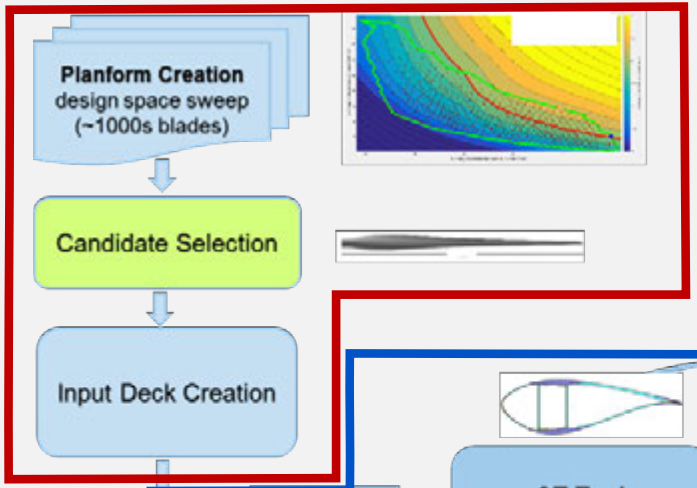


# Blade Design Process @ Envision Energy

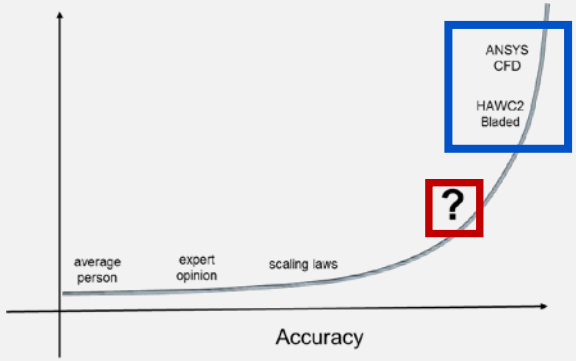
## Bridging the Fidelity Gap

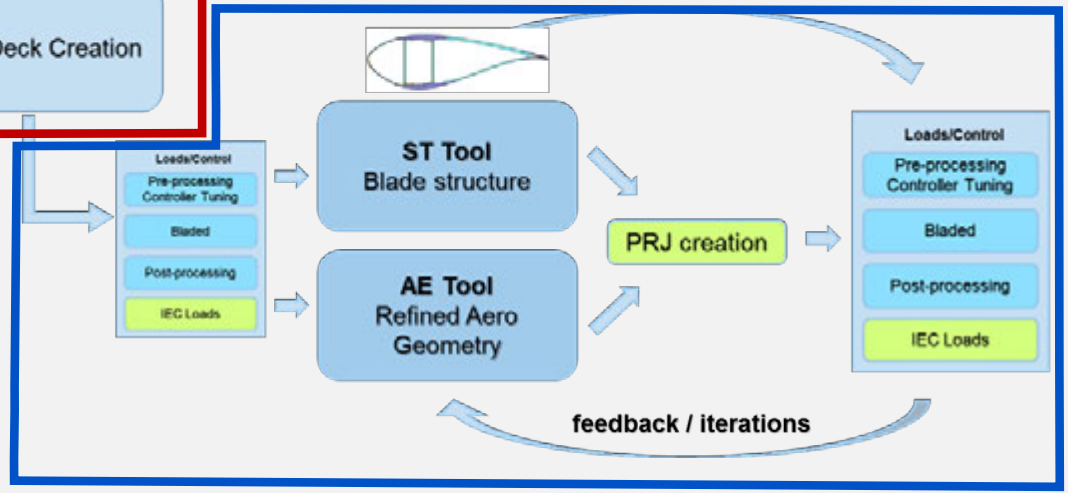



1. Planform creation
2. Aero Performance (BEM)
3. Simplified Controller tuning
4. Load Estimation
5. Structural Design
6. Modal Estimation
7. LCOE

Medium fidelity

Get higher fidelity running sooner with reduced iterations

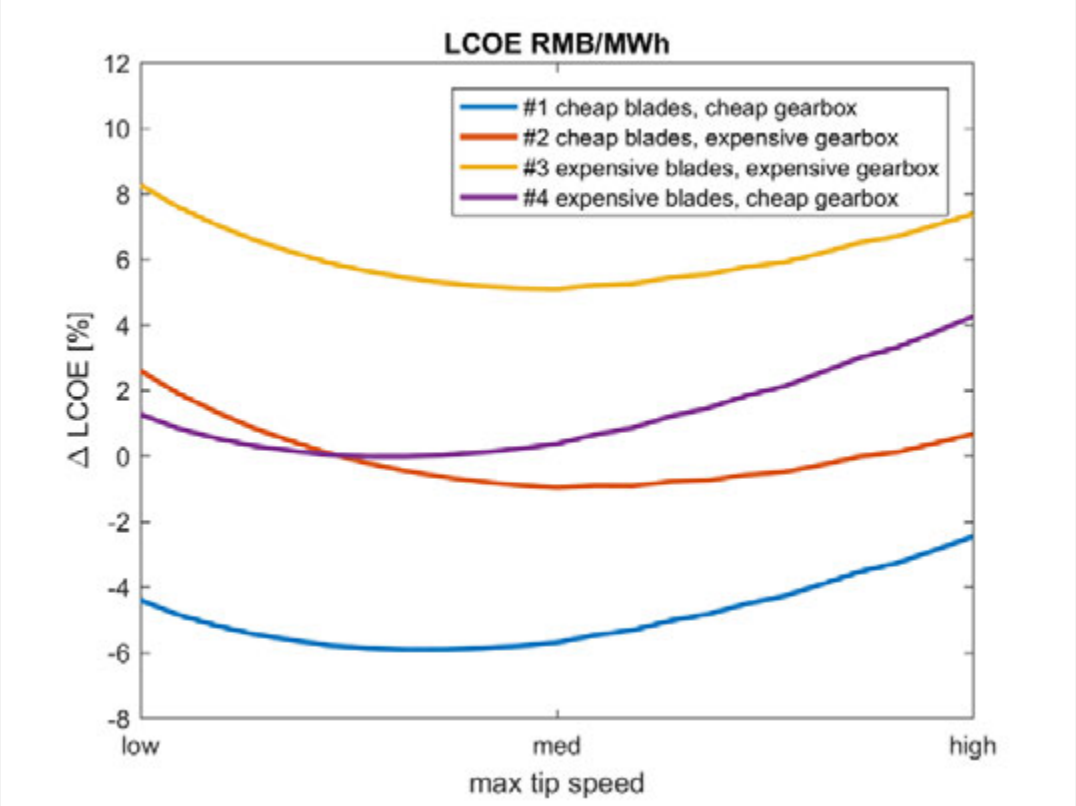


# LCOE vs. Tip Speed Example

## Summary

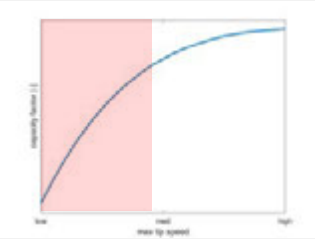
- Fixed rotor diameter and rated power (market acceptance)
- Fixed aero geometry, optimized structure
- LCOE assumed project size (MW)
- Physics/load driven mass and cost models for blade, tower, gearbox, generator and converter
- All other components are estimated by ratio
- Uncertain cost scenarios can be compared ‘apples to apples’
- **Optimal tip speed for LCOE is strongly dependent on cost scenario**

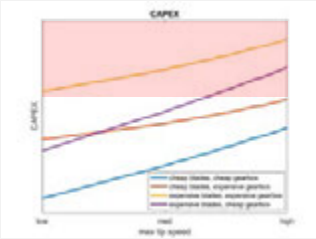


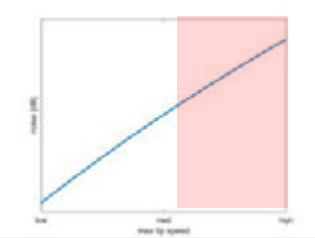
# LCOE vs. Tip Speed Example

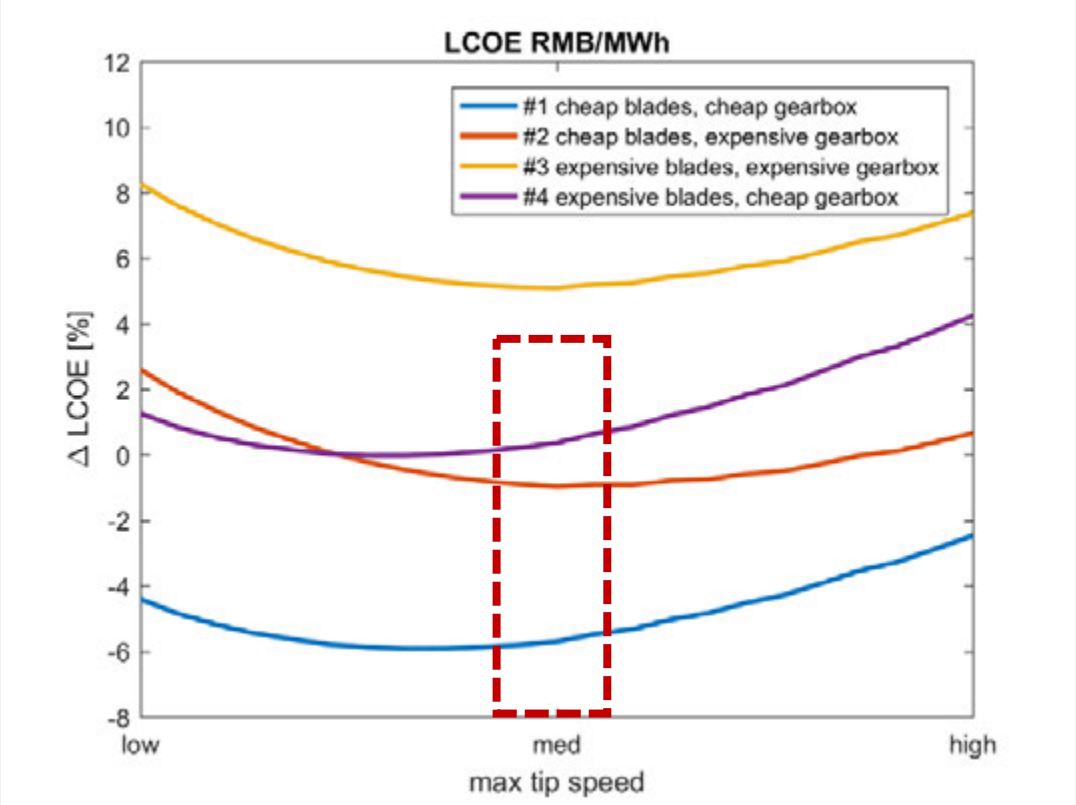
- CAPEX and CF (FPH) constraints are common in Chinese market
- Noise is also increasingly important

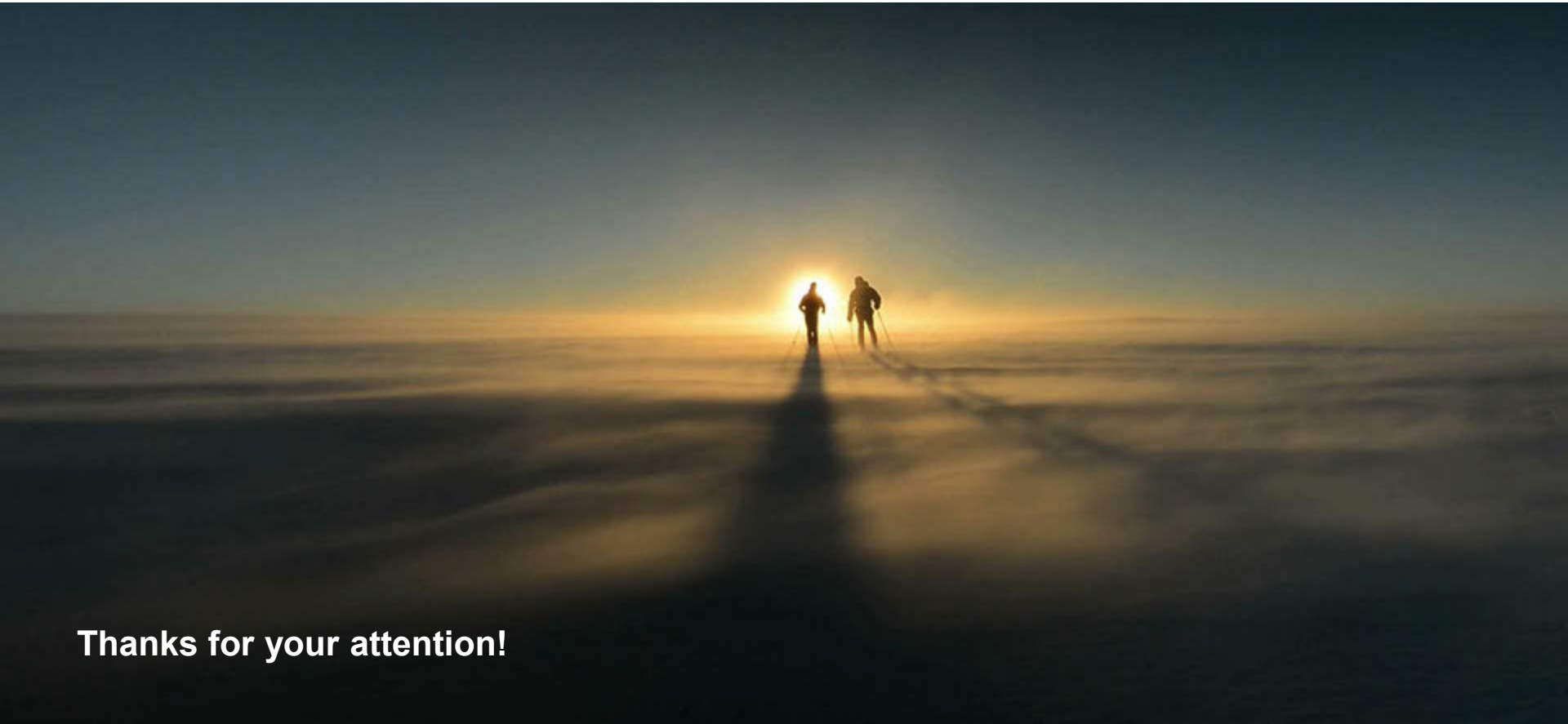
- **Overlaying constraints can provide further guidance** – optimal tip speed is in fact dictated by CF and noise…








Thanks for your attention!