Rotor System Design in an Industrial Context

Kristian Dixon – Envision Energy – Global Blade Innovation Centre – Boulder Colorado USA

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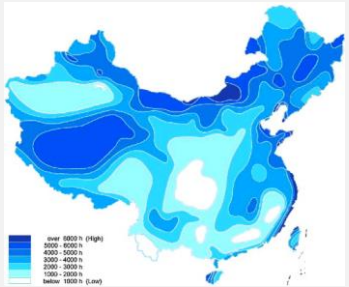
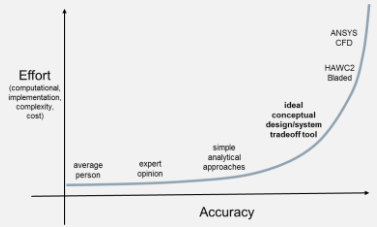
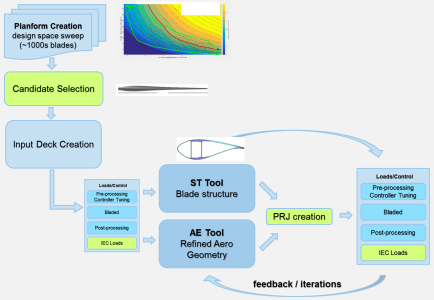
Introduction

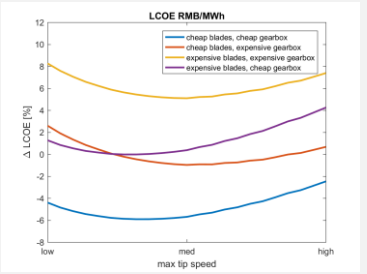
Agenda

- 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
- Conclusions









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

- 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
- Offshore typhoon risk

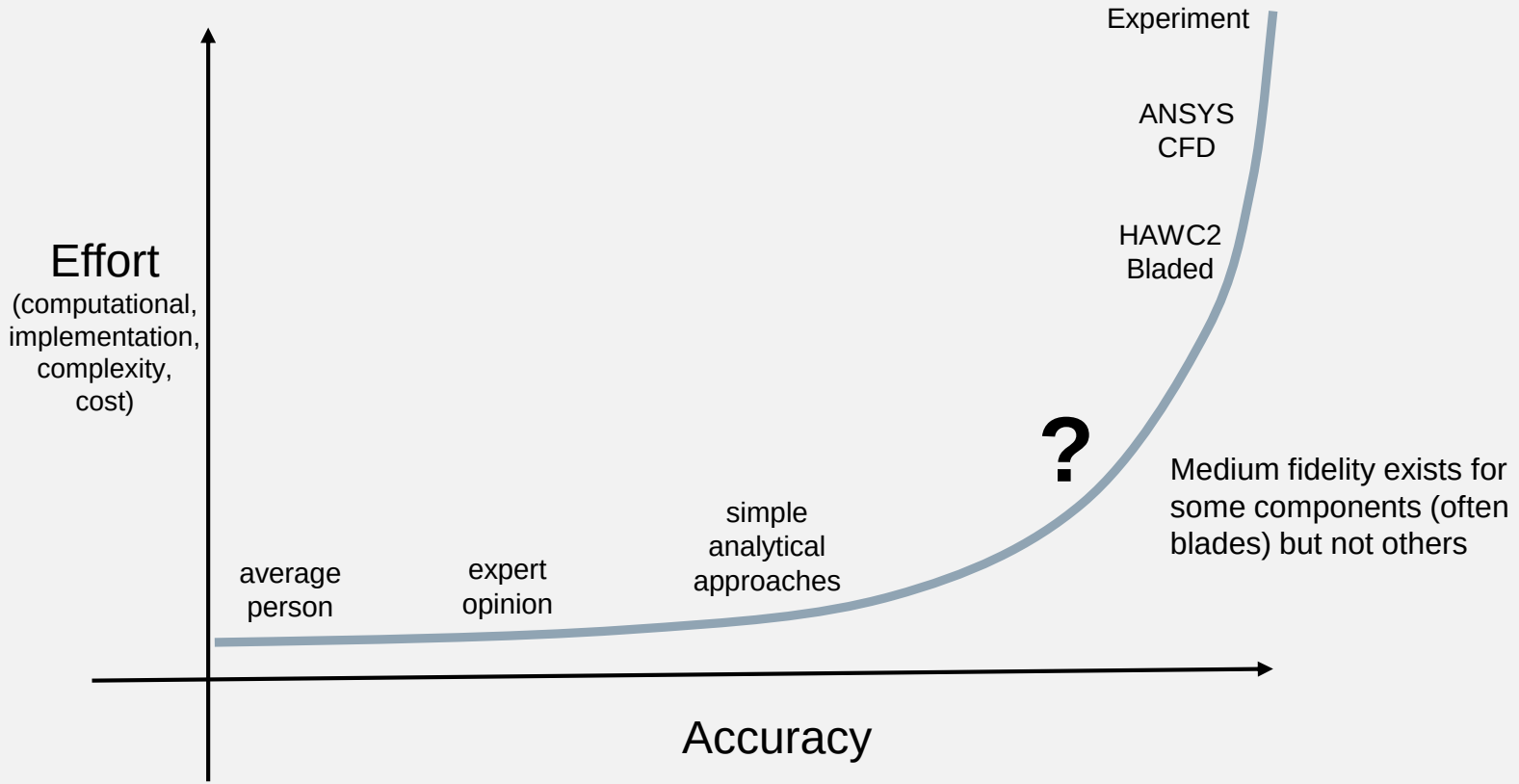
Enable Faster Product Cycles (Decision Making)

- Accelerate design process (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 (blades, gearbox, large castings)

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

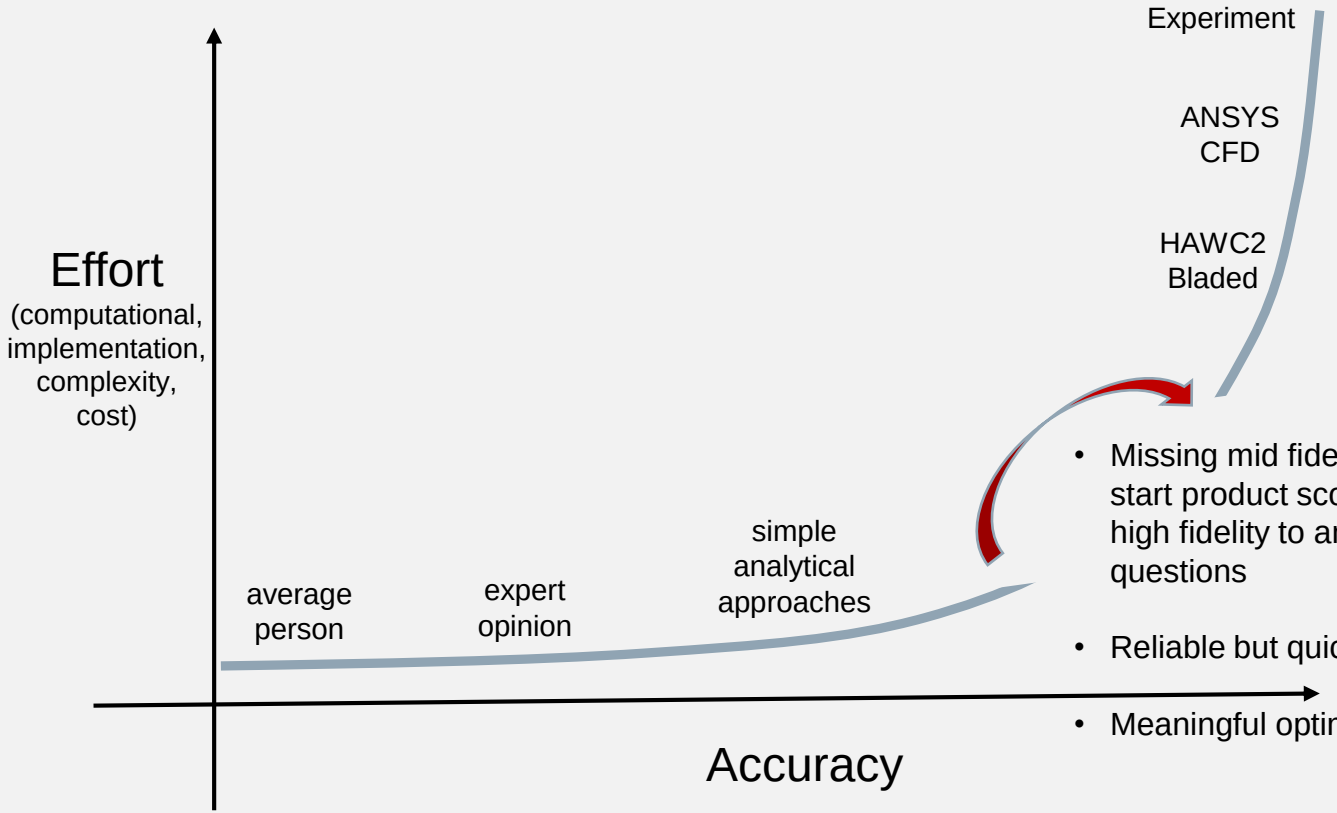
Taking a Step Back: Model/Methodology Effort vs. Accuracy

"The Pareto Front of Truth"



Effort vs. Accuracy

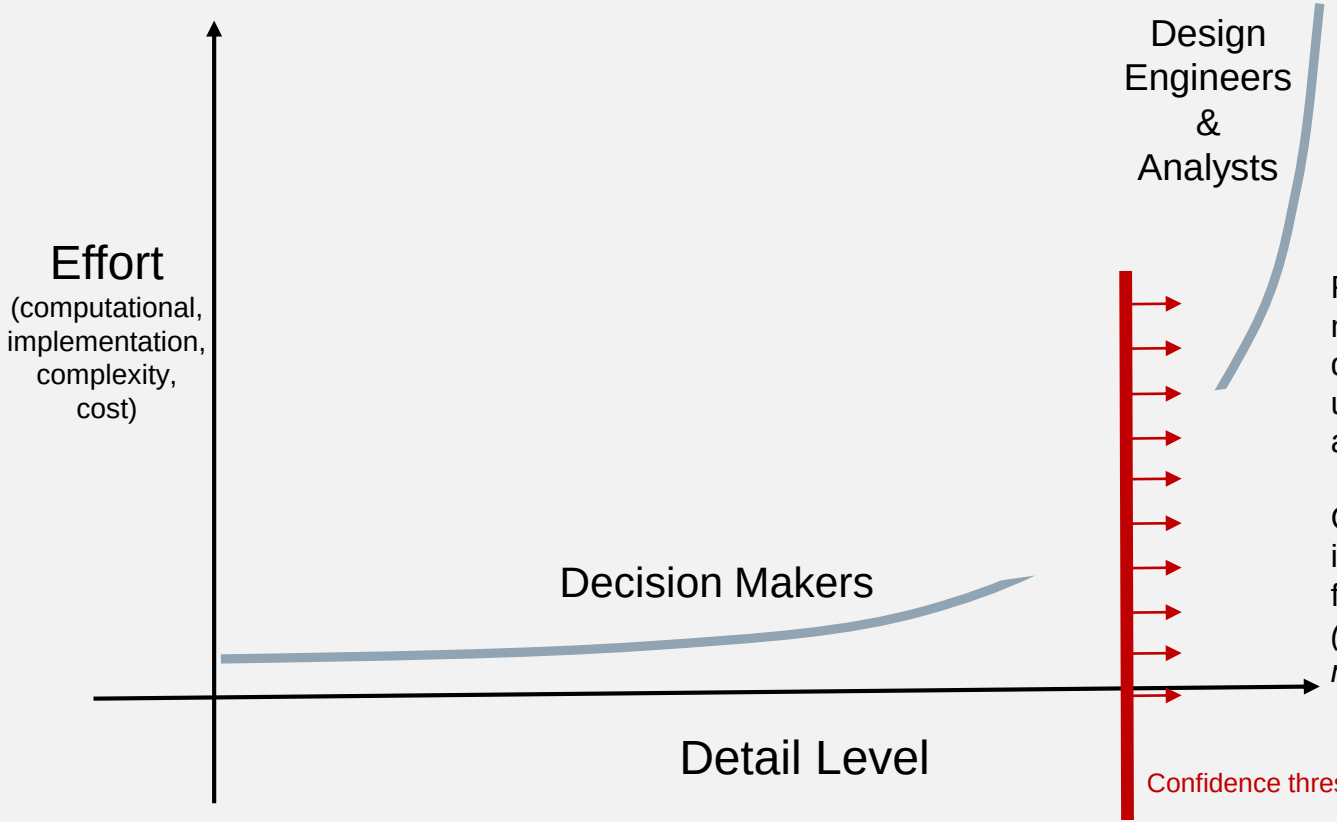
Medium Fidelity Gap



- 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



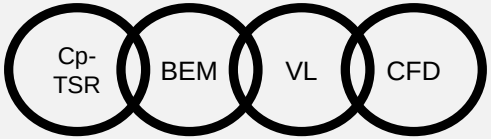
Full fidelity design not needed to make product decisions, however usually has to be more accurate than scaling laws

Generally preferred cut-off is in the medium-high fidelity range *(well behaved Bladed model)*

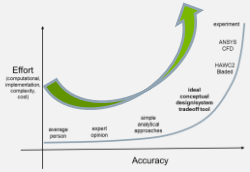
Enabling Faster Decision Making

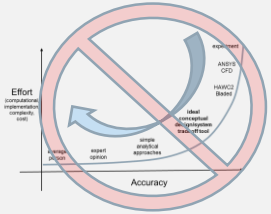
Bridging the Fidelity Gap

Objective: 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.
- Automate parts of design problem with simplified methods/models
- 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
- Challenge need for high fidelity - move the threshold





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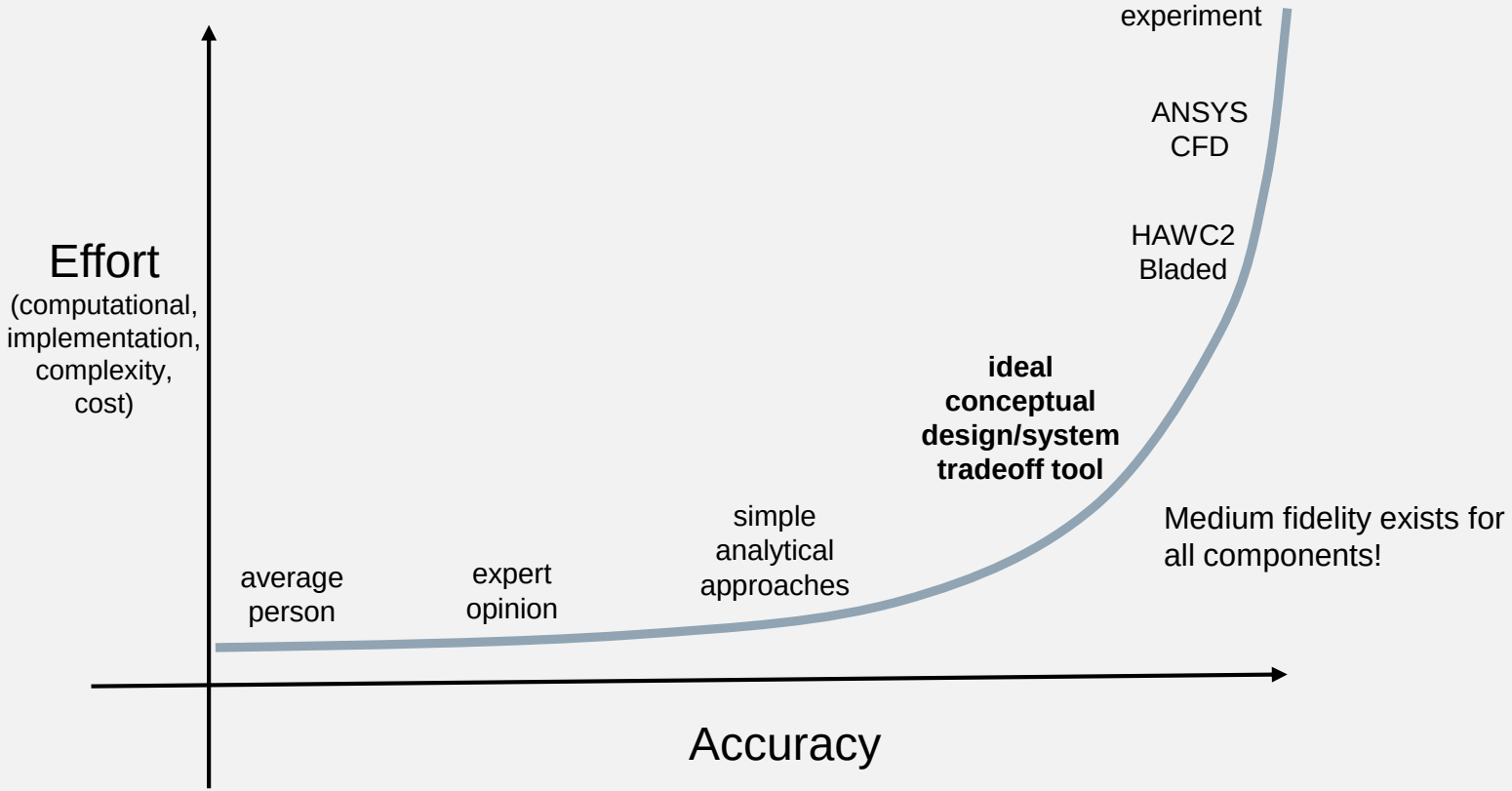
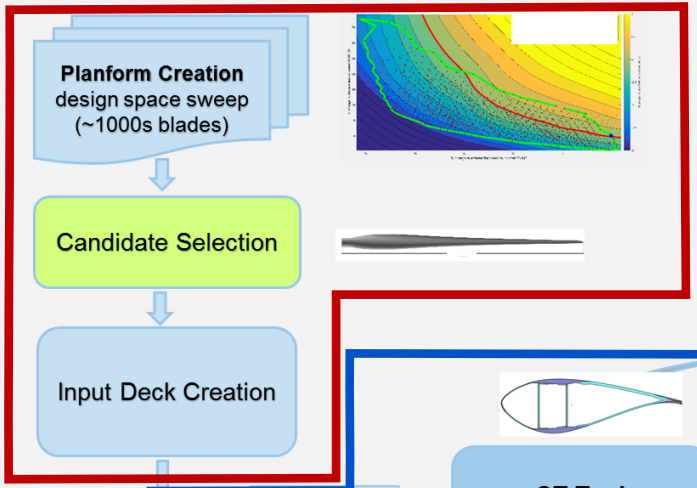
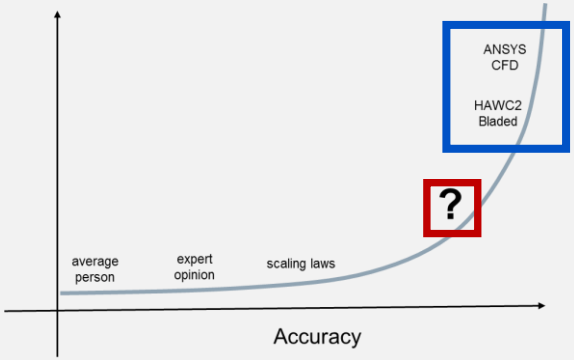


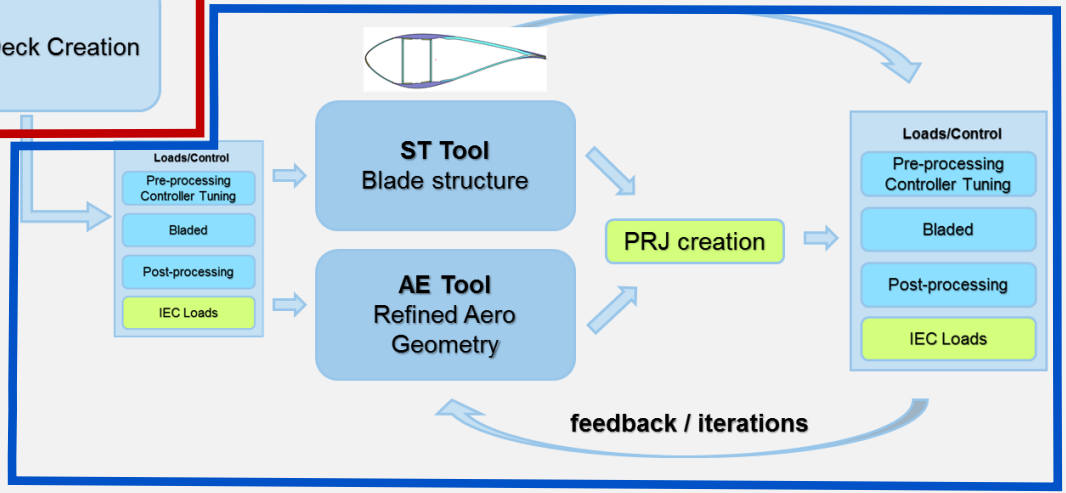
Blade Design Process @ Envision Energy

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



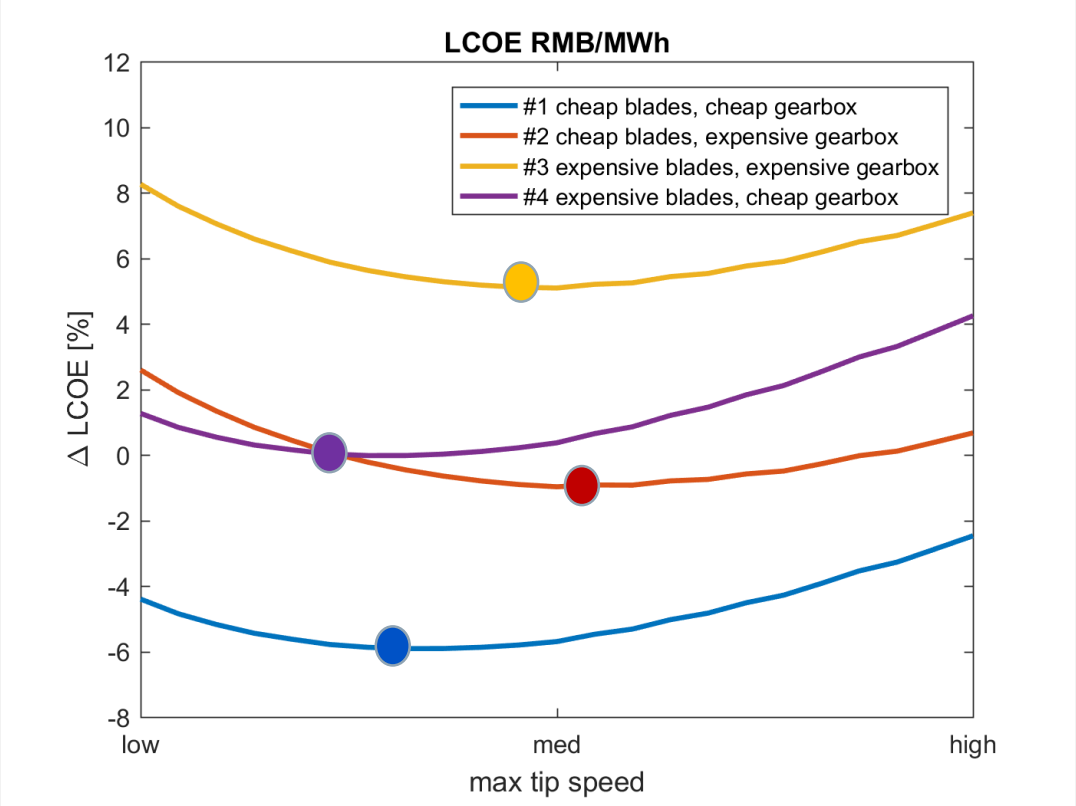


LCOE vs. Tip Speed Example

Blade vs. Gearbox Cost

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**

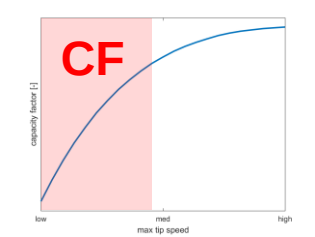


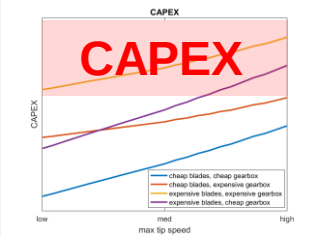
LCOE vs. Tip Speed Example

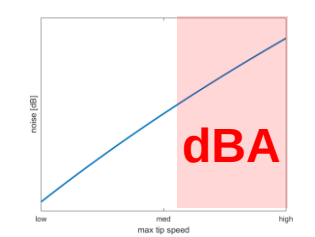
Constraints

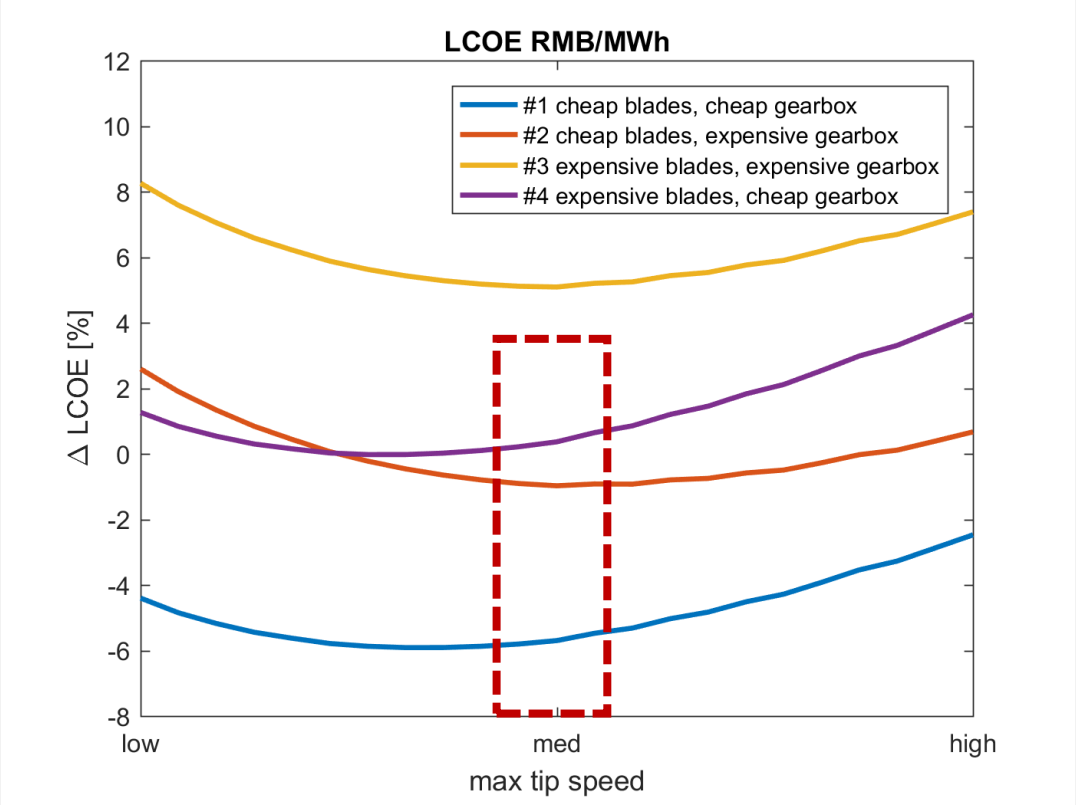
- CAPEX and CF (FPH) constraints are common in Chinese market
- Noise is also increasingly important

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









Industrial Input for Research Community

Solve Representative Problems

- Use representative turbine models
  - Use IEA Task 37 models
  - NREL 5MW is useful but outdated
- Global trend is towards lower W/m^2
  - Turbines increasingly ultimate load dimensioned *not* fatigue
  - Blade design overwhelming driven by tip deflection
  - DLC 1.X is design driving – shutdown, fault and parked cases can be very OEM specific with limited generality
- Global trend is towards shorter product cycles, lower CAPEX
  - When developing new tools/methods consider cycle time ~hours/days.
  - If possible consider cost impact
- Use system thinking
  - Novel concepts are great – considering more than one component increases value to industry
  - Consider need for certification (failsafe)
  - Field O&M, 20 year life etc.
- All OEM problems are multi objective
  - Pure performance (AEP) problems don't exist
  - Quantify tradeoffs if possible – assume "no free lunch"
- Use a multi-fidelity approach
  - Move from simple to complex
  - Establish a inter-fidelity verification chain
  - Enables deeper understanding of the problem / faster debugging of complex models

Source: Global Wind Turbine Trends 2016 - MAKE


Thanks for your attention! Questions?