Informing Blade Design through MDAO Practices

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Agenda

1. Overview of Blade Design at SGRE
2. SGRE's MDAO design tool
3. Example MDAO use cases

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SGRE Boulder Blade Design Office

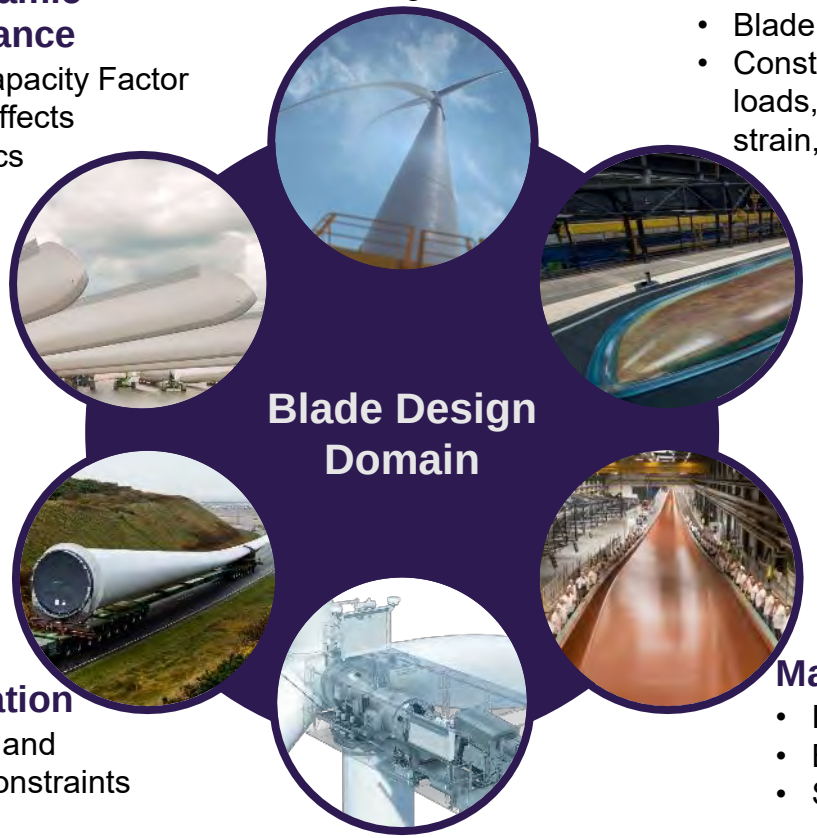
- Established in 2008 as a global competency center
- Responsible for conceptual blade design, from specification to final design
- 50-person office with colocation of Aerodynamics, Loads, Structures, and Controls engineers
- In-house software development of engineering design and analysis tools

Blade Design Problem

Loads and Control
- Extreme and Fatigue loads
- Flutter and frequency analysis
- Component specific impacts
- Peak shaving

Aerodynamic Performance
- AEP, Capacity Factor
- Wake Effects
- Acoustics

Structure Design
- Blade mass, mass moment, cost
- Constraints: Fatigue, extreme loads, tip deflection, buckling, strain, natural frequencies



Transportation
- Rail, road, and shipping constraints
- Handling

Manufacturing
- Factory constraints
- Beam draping
- Supply chain logistics

Rest of System Impacts
- LCOE, Customer Business Case
- Loads on turbine components

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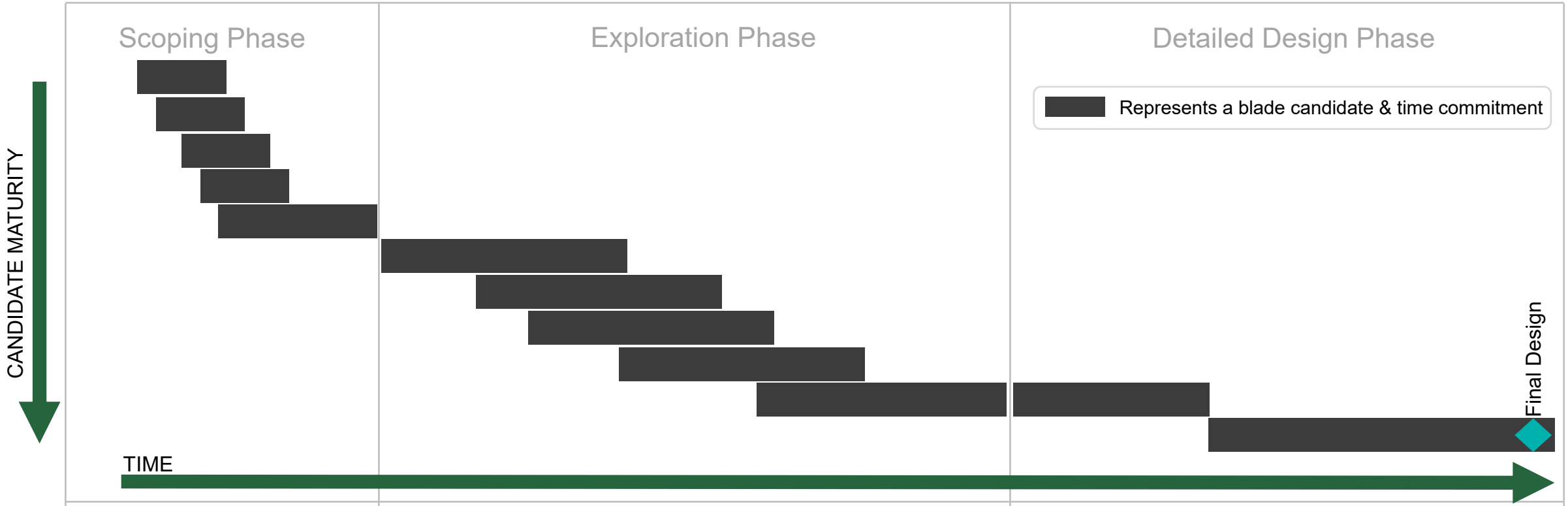
Blade Design Process at SGRE



	Scoping Phase	Exploration Phase	Detailed Design Phase
Desc.	**Feasibility** analysis on many blade candidates and turbine configurations.	**Concept exploration** to find optimal candidate and technologies.	**Execute detailed design** with multiple reviews with stakeholders.
Outcome	Initial reference design point	Mature planform; accurate AEP, mass, and loads estimates	Final design; Sales Power Curve, CAD, Loads Envelope
Tools	Low fidelity	Medium fidelity	High fidelity

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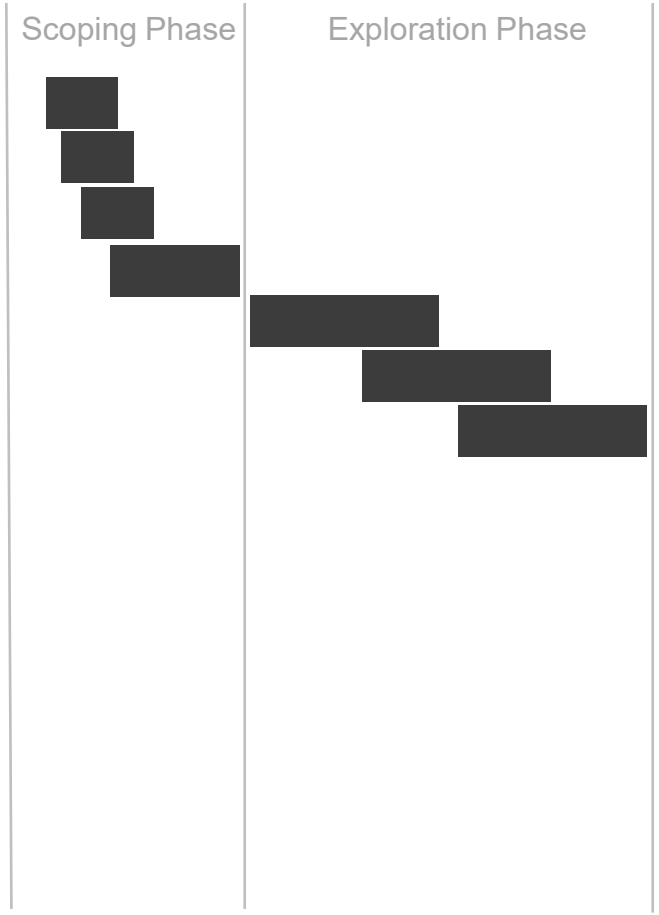
Challenge: Accelerating Conceptual Blade Design



Reduce Cycle Time for Design Convergence

Multi-disciplinary design analysis

- Aerodynamics, Loads, and Structures in a single tool
- Capture design trade-offs

Multi-fidelity analysis

- Design maturation within the same tool framework
- Include higher fidelity tools earlier in the design process, make more informed decisions / fewer iterations

Optimization

- Parallelized analysis drivers for design space exploration

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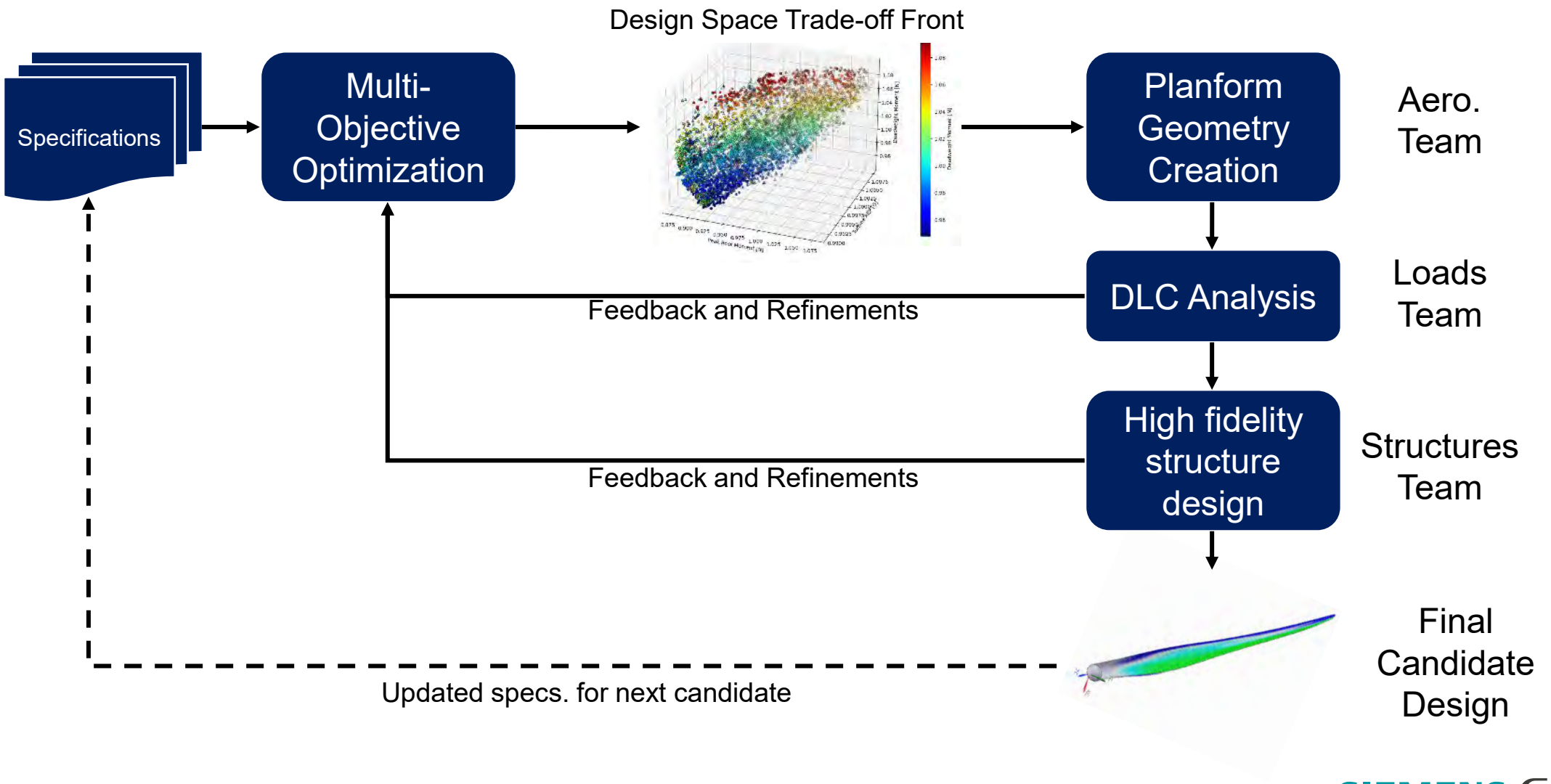
Design Process for a Candidate Blade Design



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MDAO Design Tool

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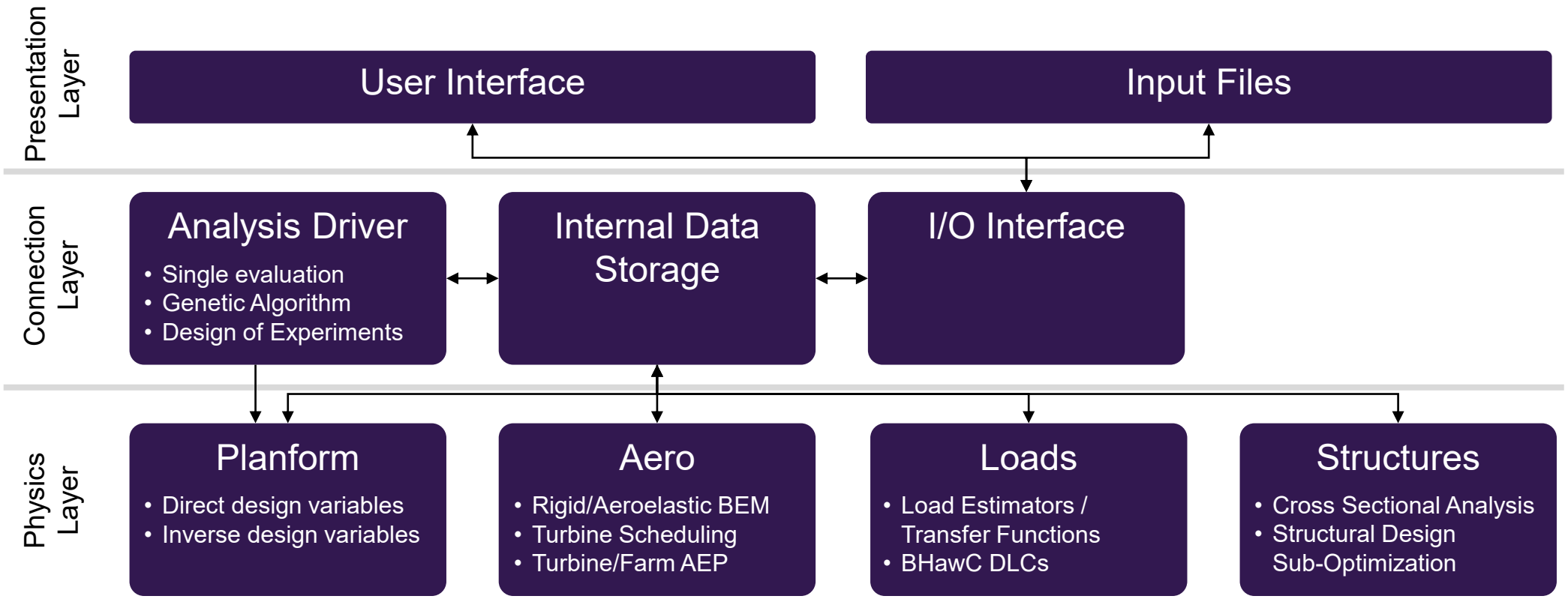
MDAO Tool Framework



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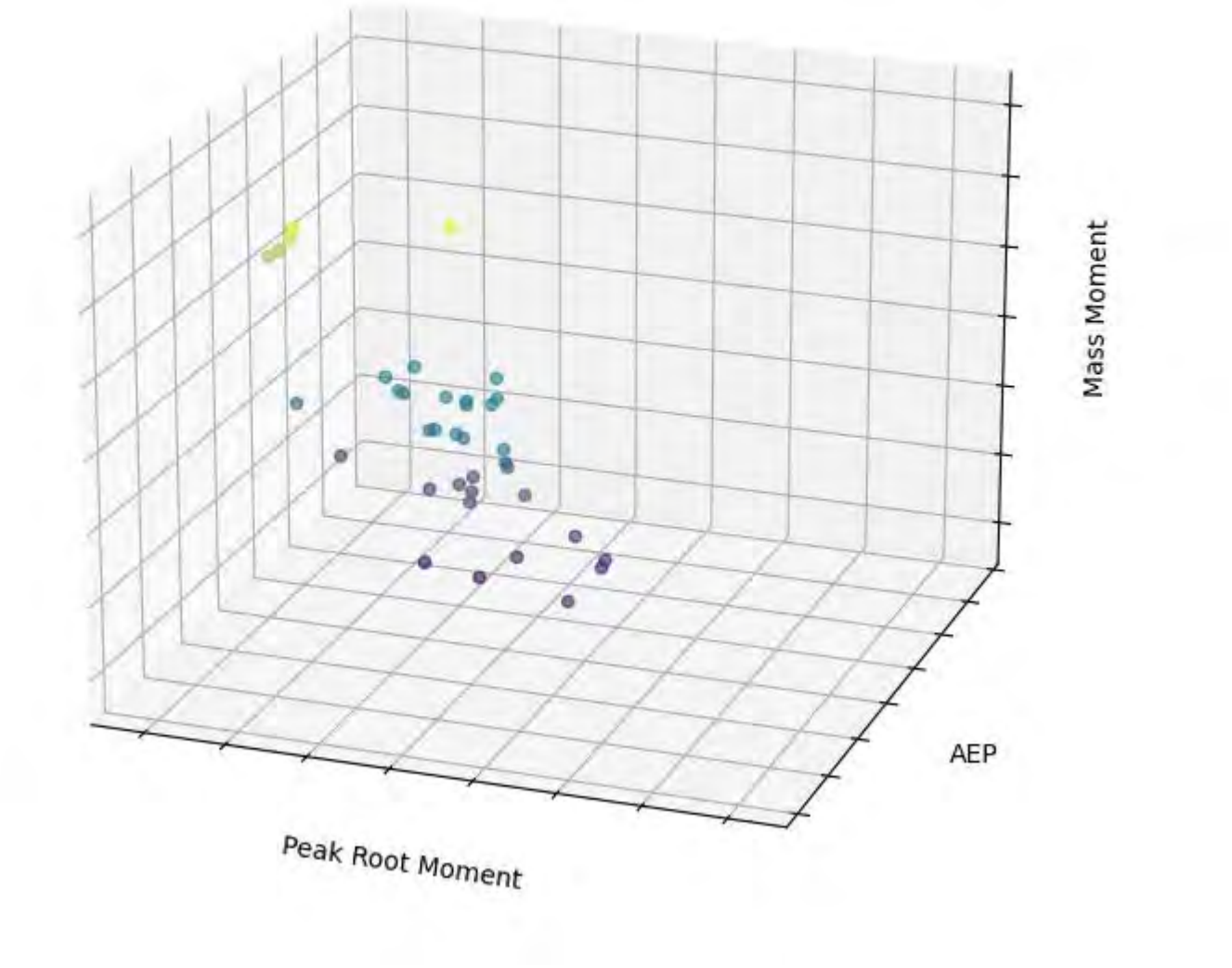
How Is MDAO Used?

Design Space Exploration



- GA optimization results in information dense trade-off fronts
  (Each dot is a blade design)
- Design engineers compare current/next design iteration to objective trade-off trends on the front
- Design space exploration most useful after changes topology, technology, or large design steps

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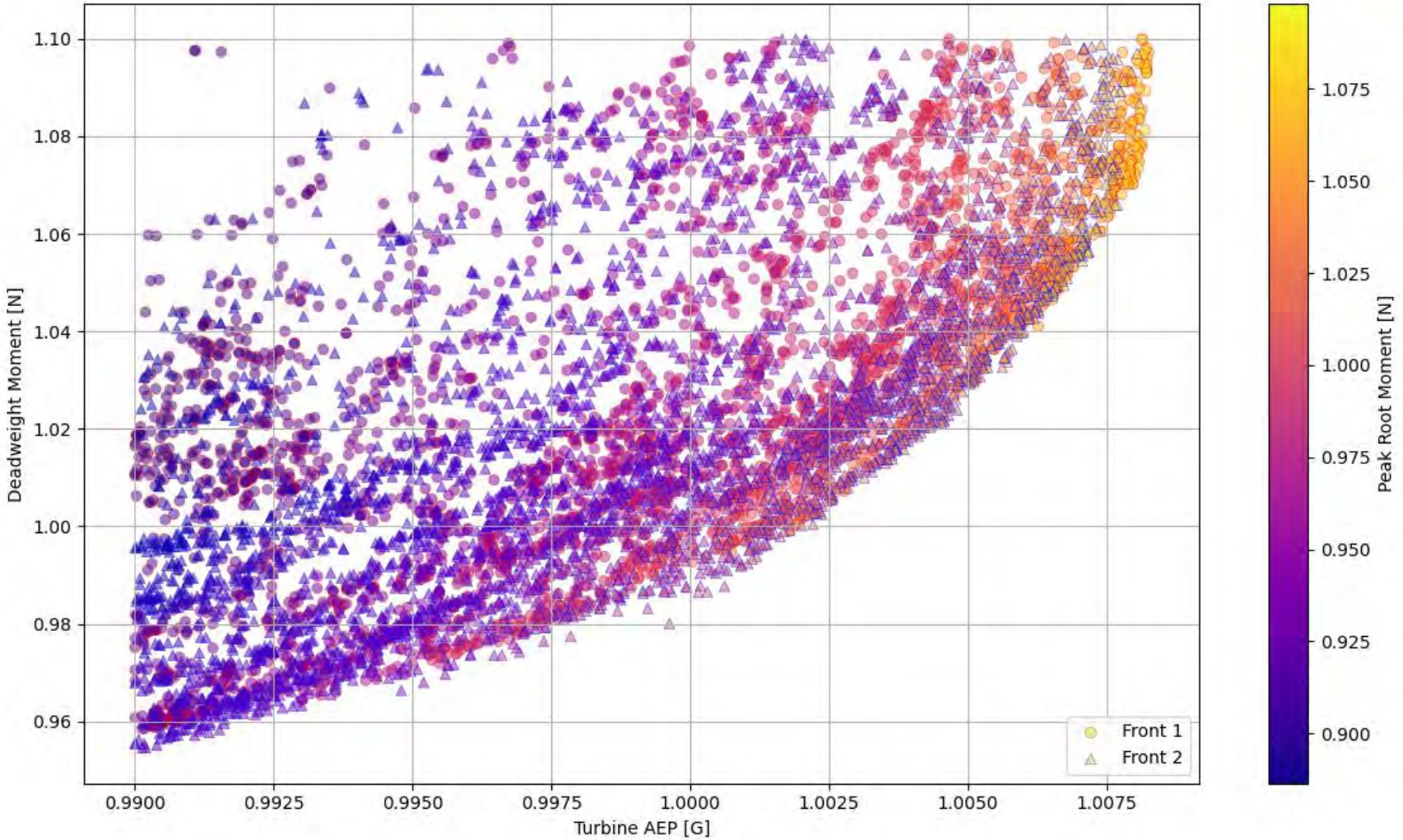

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MDAO Examples

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High Solidity Example Study: Solidity increased by 10%

Front slices

- Visualize trade-offs along constant planes in the N-D objective space
- Provide “map”: is the current design an optimal trade-off ratio?

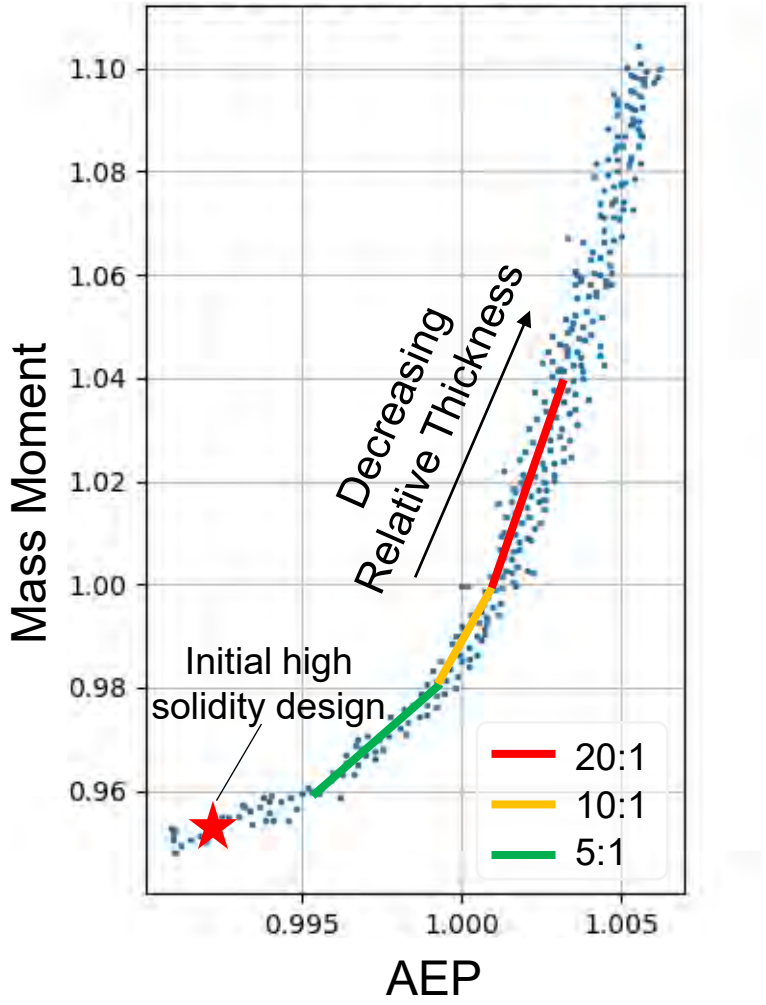
Results

- Initial design has a poor trade-off ratio between AEP and Mass Moment
- Typically aim for the “knee” of the curve;
  In this case 5:1 – 10:1 region is more desirable
- Cost models determine the optimal trade-off ratios

Conclusions

- After topology changes, we are often far from optimal
- Design changes are needed in multiple dimensions, not always intuitive, which optimization is very good at solving
- Expert designers are needed to formulate the right optimization problems and interpret the results

Front Slice along Constant Loads



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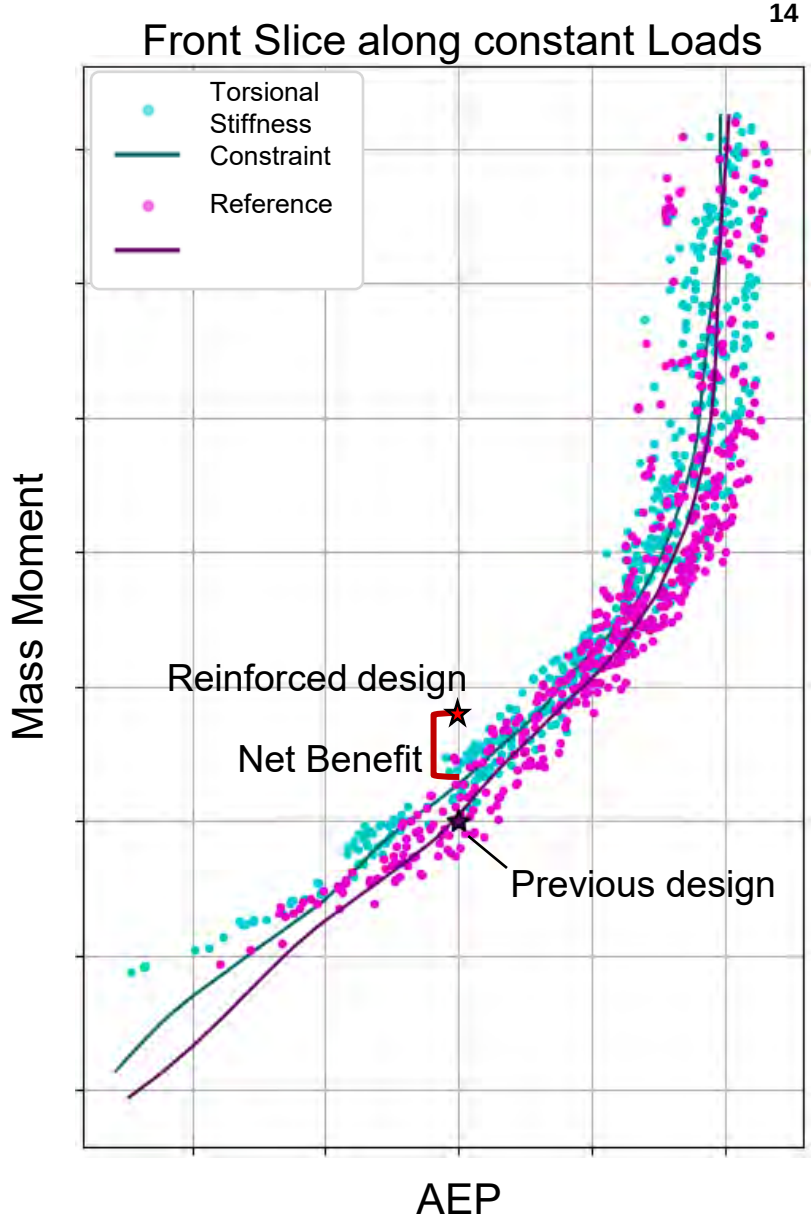
Flutter Requirements Example Case

Scenario

- Blade stiffness can come from blade structure or the planform design
- **Goal:** Remove reinforcement (high mass moment penalty) using planform design while satisfying the same flutter constraint

Result

- Significant net benefit to mass moment



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Conclusions

- MDAO is invaluable for accelerating blade design projects
  - Improves the quality of candidate designs, reducing the number of design iterations needed
  - Optimization results are not always intuitive solutions
- Optimization is not push button
  - Findings from optimization are a design direction, rather than a final design
  - Experienced design engineers needed to correctly formulate problems and interpret results
  - High fidelity analysis is needed after low/mid fidelity MDAO
- Modern software engineering best practices: moving beyond “research codes”
  - Investing in software development leads to better:
    - Code maintainability
    - Development agility
    - Improved user outcomes
  - Focus on extensibility
  - Detailed project planning
  - High unit test coverage with automated testing → maintain accuracy and reliability
    (Over 2,500 CI pipeline tests to date)

Questions?

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