# Gradient Based Optimization of Coupled Multi-fidelity Models with OpenMDAO

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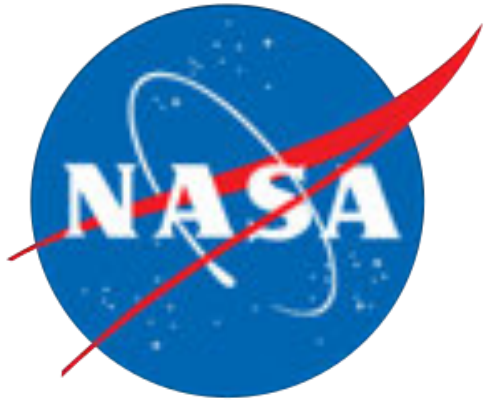
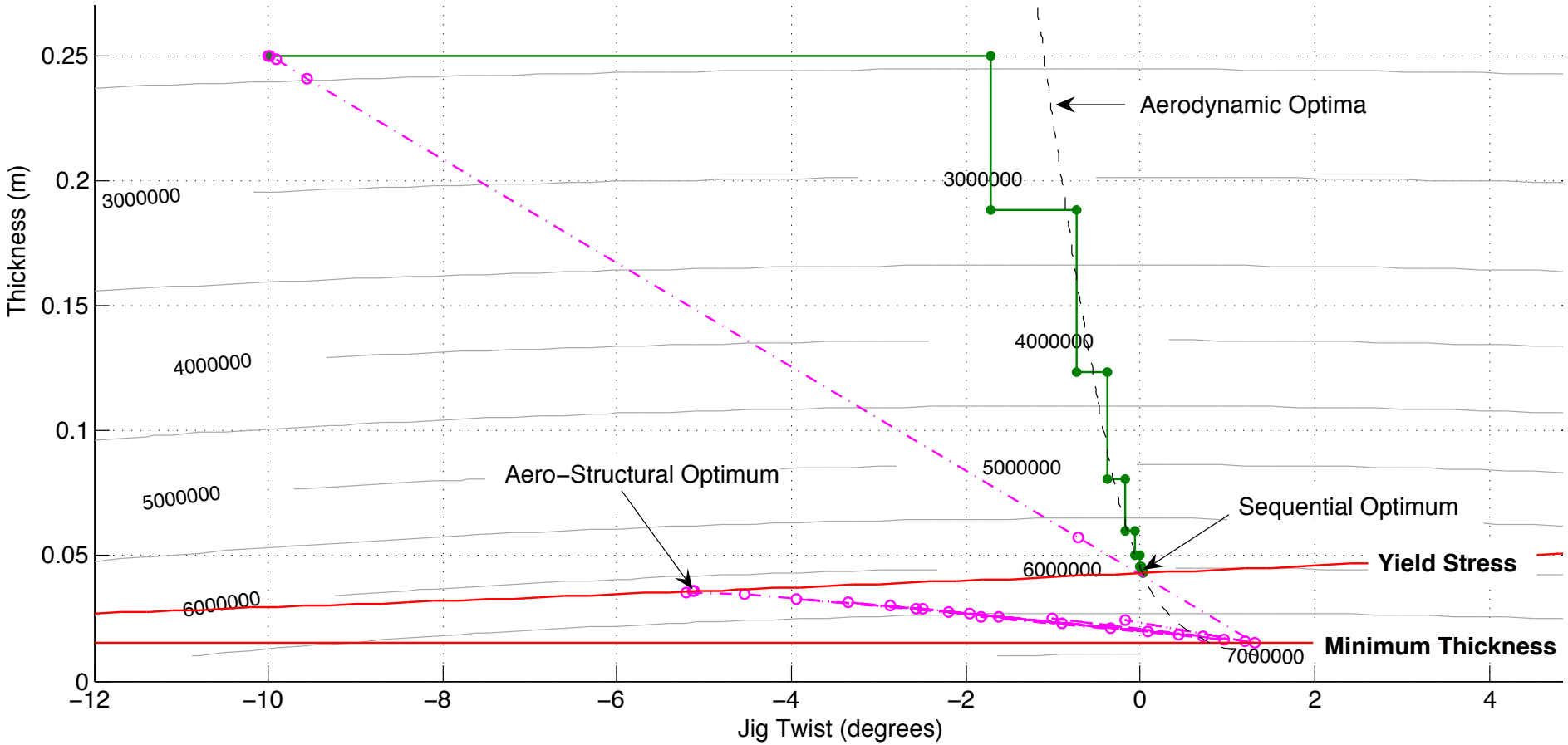


# Using uncoupled models (sequential optimization) can prevent you from finding peak performance



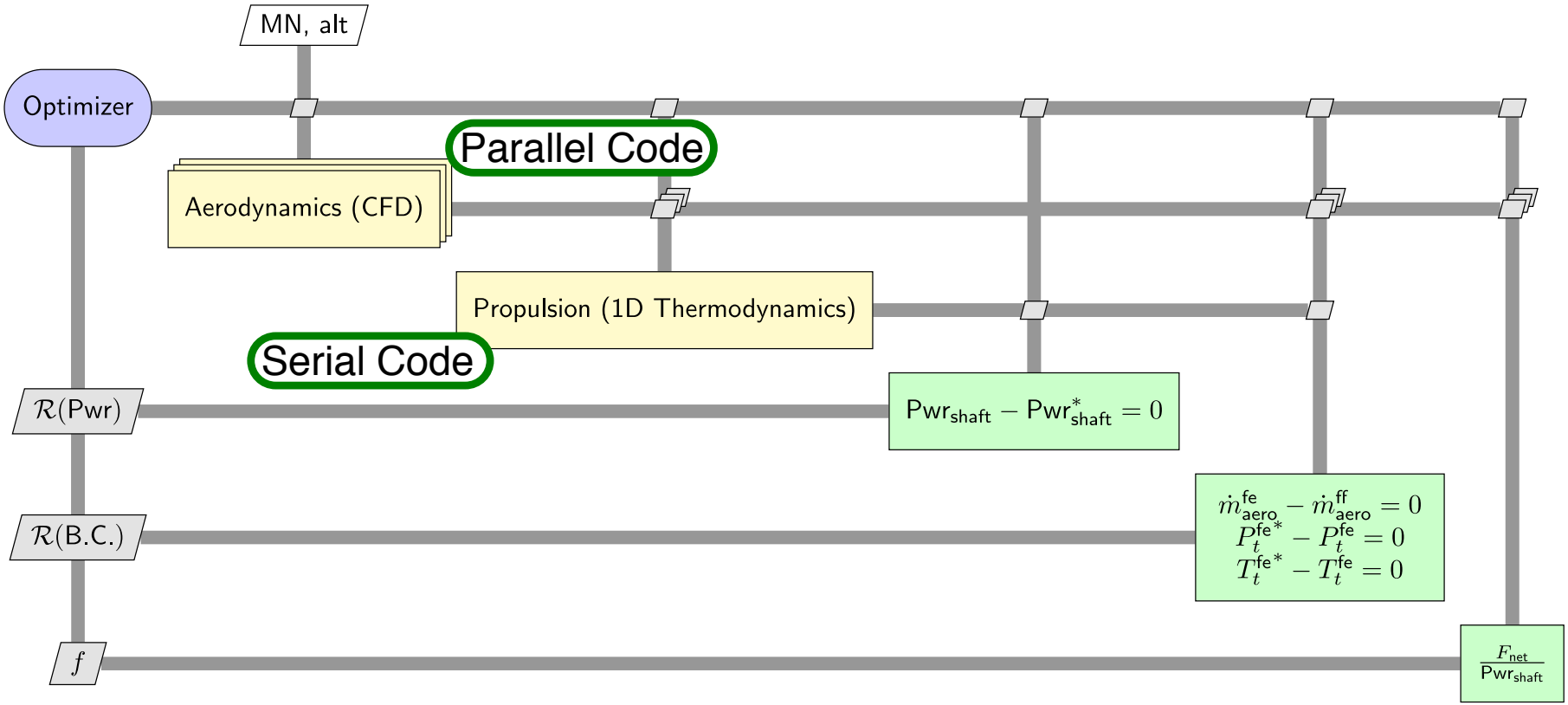

[Chittick and Martins, Struct. Multidiscip. O., 2008]

# Highly synergistic designs require considering of coupling early in the design cycle

- Aerodynamic couplings often require detailed flow-field information — CFD
- Structural couplings can require detailed stress information — FEM
- It is too expensive to analyze everything with high fidelity, so we build multi-fidelity models

# **Multi-fidelity**: a single system model that includes analyses at different levels of fidelity

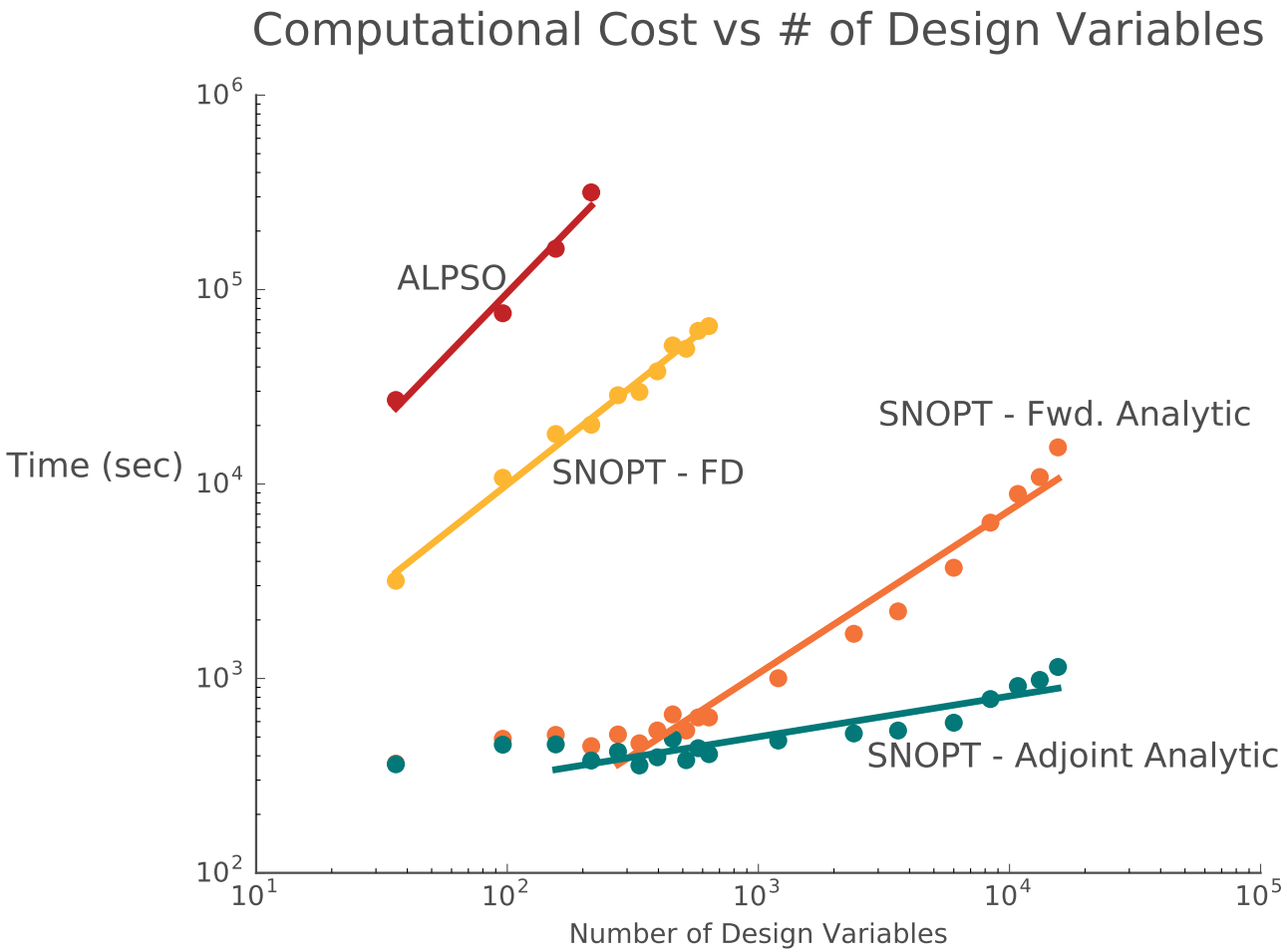
**"Fidelity"** can mean a range of things:
compute cost, number of inputs, mesh size, parallel vs serial ...



# When we use CFD or FEA, the # of design variables and the compute cost grows considerably

- Gradient based optimization effectively navigates large design spaces
- Analytic derivatives are the most efficient way to compute gradients

# Analytic Derivatives lower the compute cost of optimizations



We want to design complex systems
with coupled multi-fidelity models,

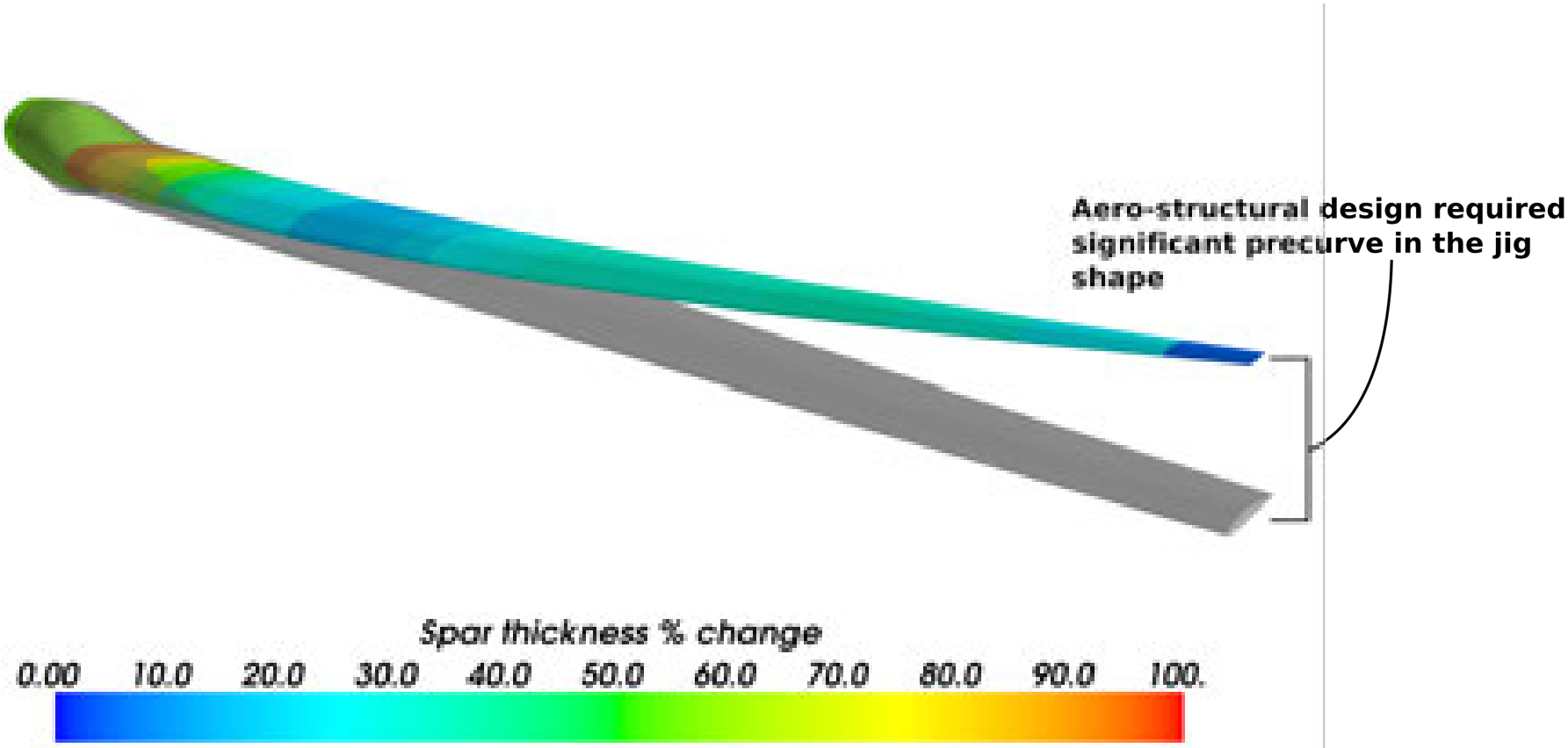
so we use gradient based optimization
with analytic derivatives

(Unfortunately this is easier said than done)

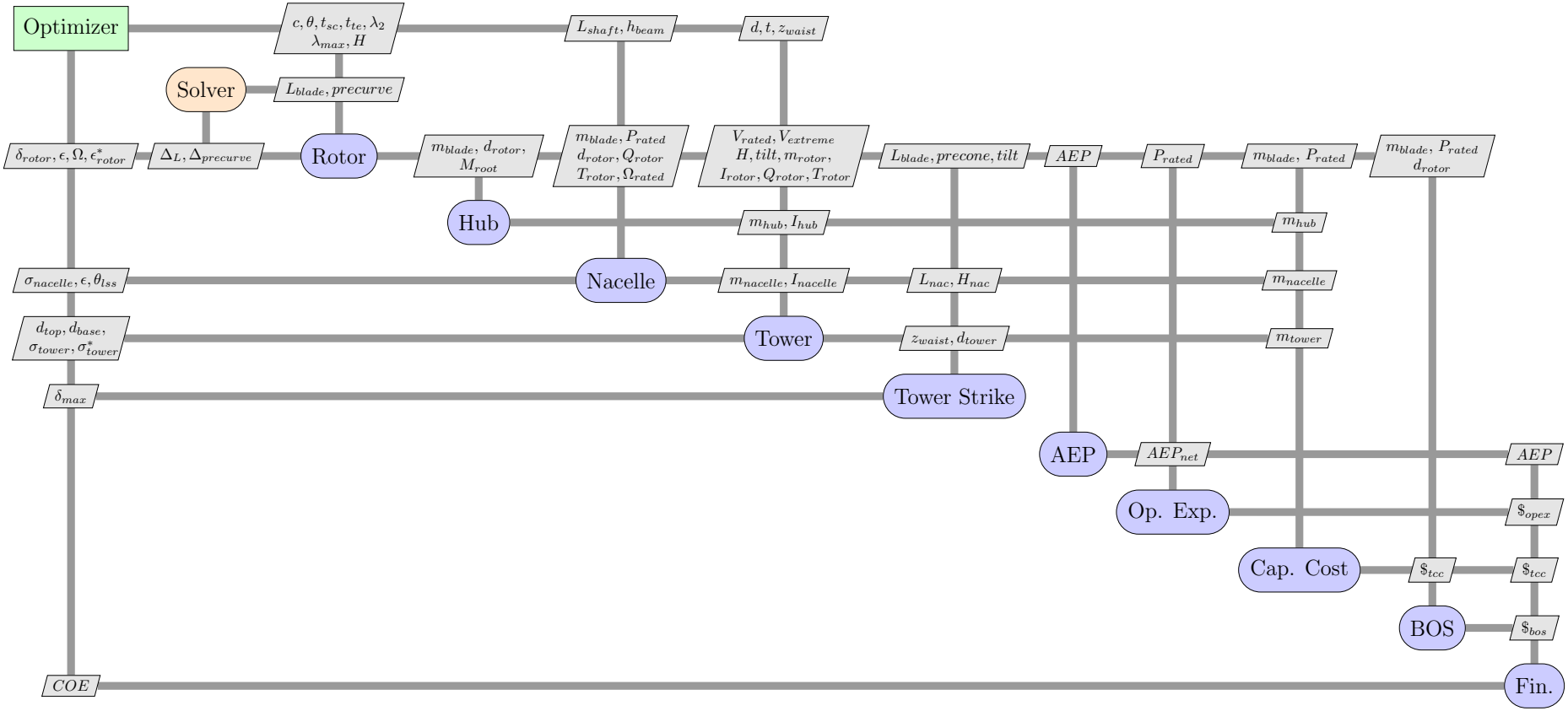
# OpenMDAO can efficiently solve for analytic multi-disciplinary derivatives in parallel on HPC systems

- Runs in parallel with MPI/PETSc on HPC resources
- Uses a distributed memory design to work with sparse distributed data
- Supports matrix-free linear solvers for converging the coupled multidisciplinary derivatives

# Aerostructural wind turbine blade design with 10 engineering disciplines

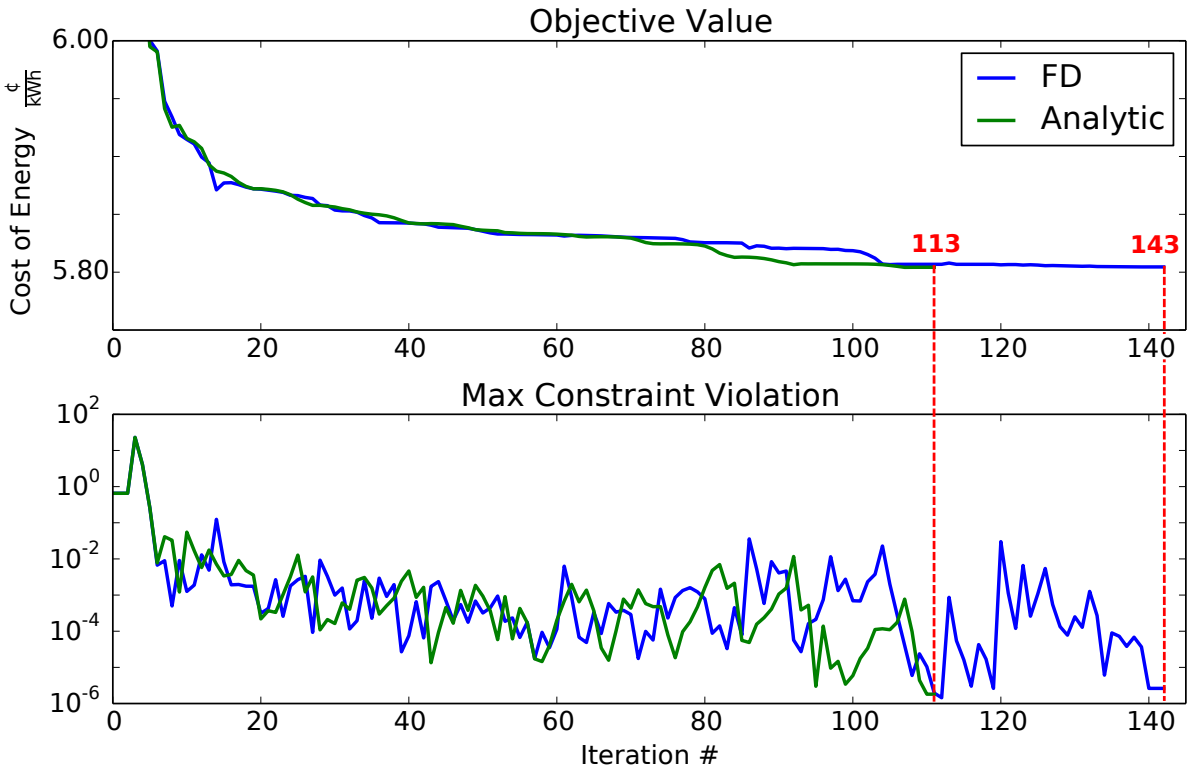


# 10 engineering disciplines with multi-fidelity aerostructural coupling in the rotor design

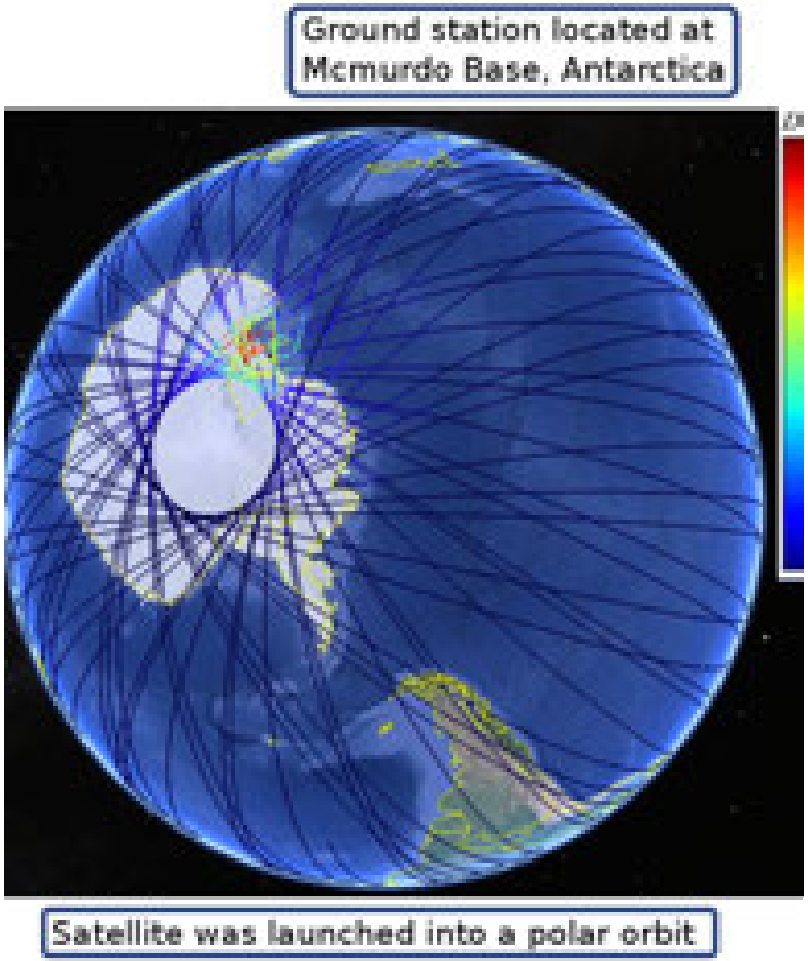


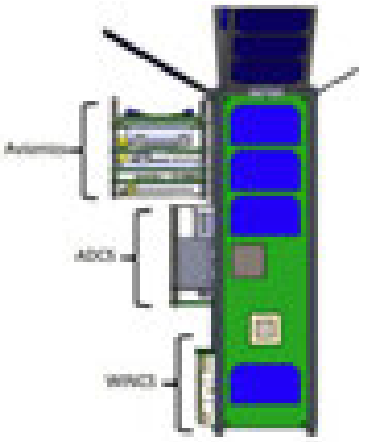
# Optimization was 5x faster with analytic derivatives

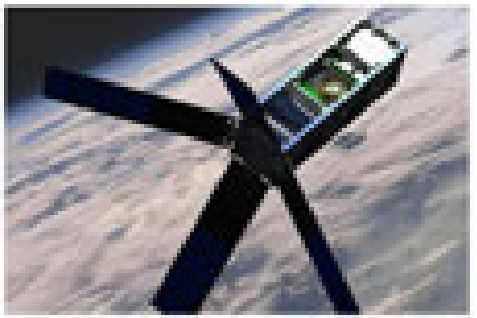
| | Finite-Difference | Analytic |
|---|---|---|
| Objective (COE in ¢/kWh) | 5.8045 | 5.8042 |
| Max Constraint Violation | $2.62 \times 10^{-6}$ | $1.81 \times 10^{-6}$ |
| # Major Iterations | 143 | 113 |
| Time Per Major Iteration (minutes) | 2.27 | 0.59 |
| **Total Run Time (hours)** | **5.43** | **1.11** |



# An optimal control problem for a satellite design with 25000 variables was solved in 8 hours on 6 CPUs



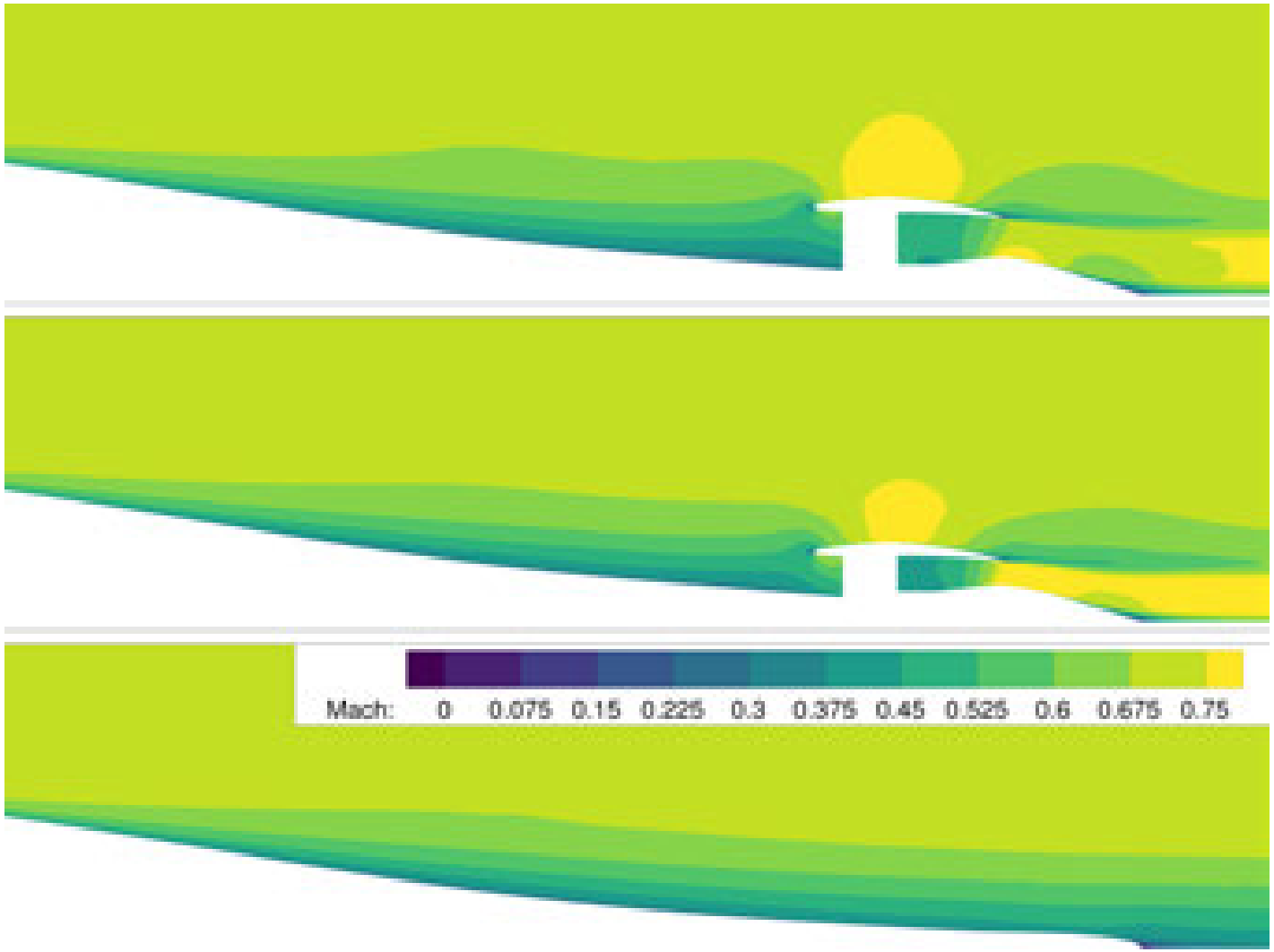





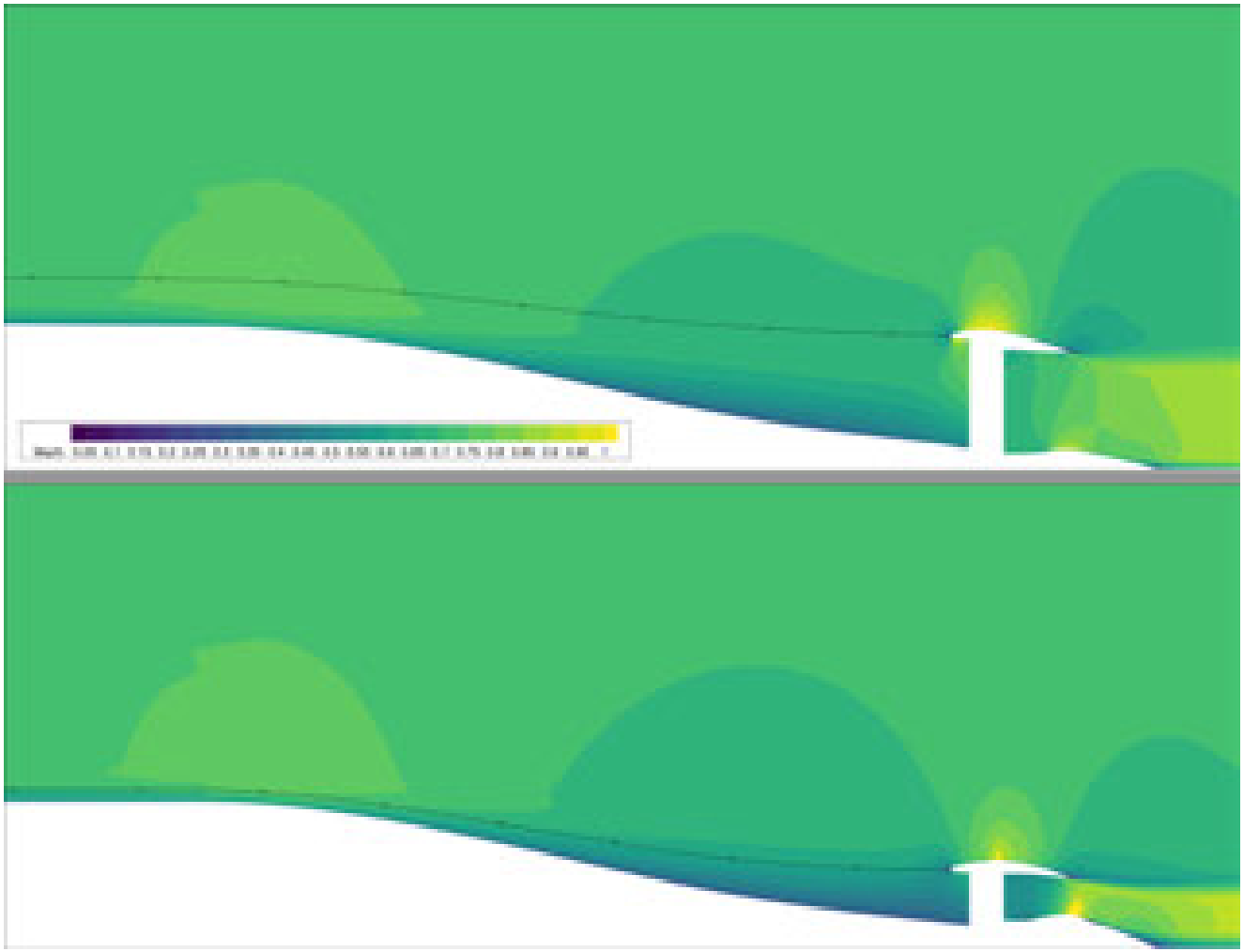
# Turboelectric aircraft concept used boundary layer ingestion (BLI) get 12% mission fuel burn reduction


Turboelectric propulsion system has an electric BLI propulsor powered by generators mounted on the under-wing turbofans

# A fully coupled model is crucial for capturing the correct system performance



# The optimized configuration produced a significantly different nacelle geometry than the baseline



Optimized design

Initial design

# Summary

- We increasingly need to built coupled multi-fidelity models to accurately model coupled systems
- Gradient based optimization with analytic derivatives provides a tool to navigate the resulting larger design spaces, but posses implementation challenges
- OpenMDAO simplifies the implementation and lets you solve big multi-fidelity problems efficiently