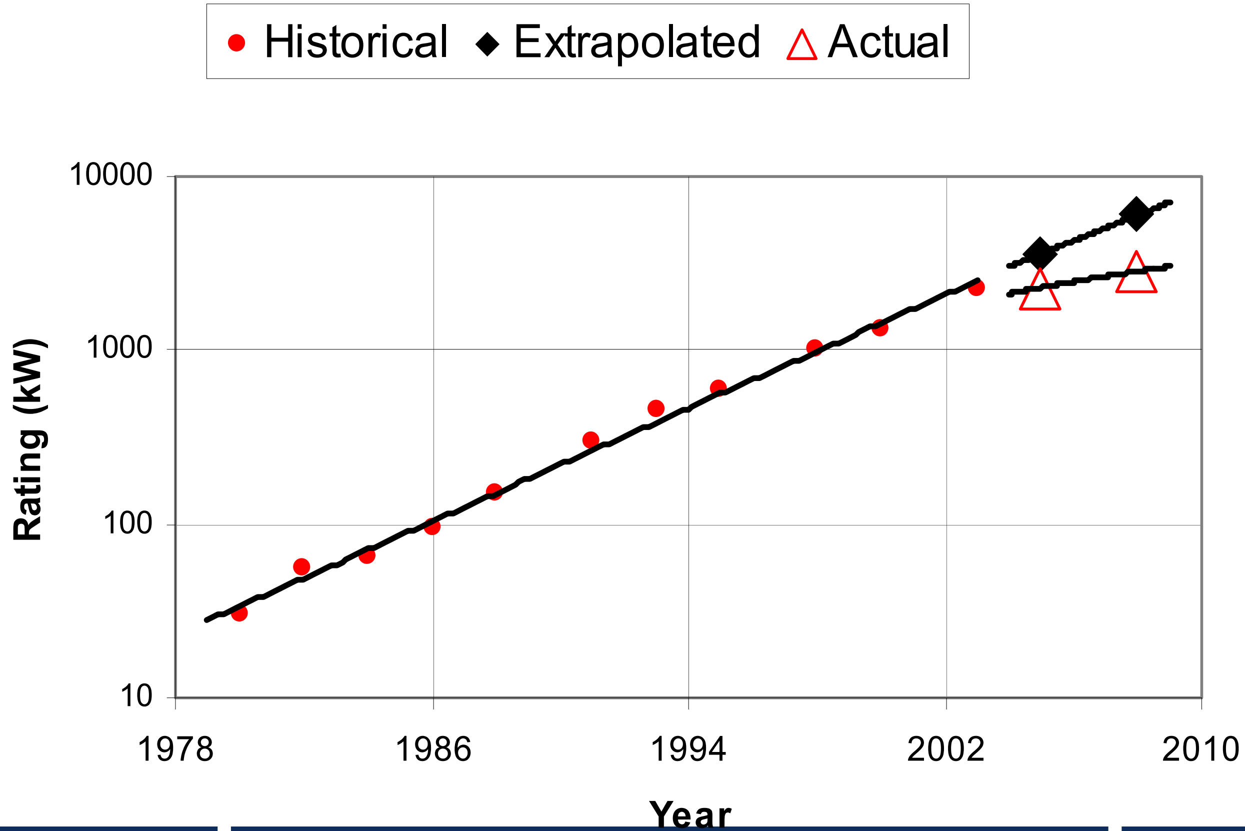
Multidisciplinary Design Optimization of Wind Turbines

Turaj Ashuri, PhD, PEng
Postdoctoral research fellow
Multidisciplinary Design Optimization Laboratory (MDOLAB)
University of Michigan

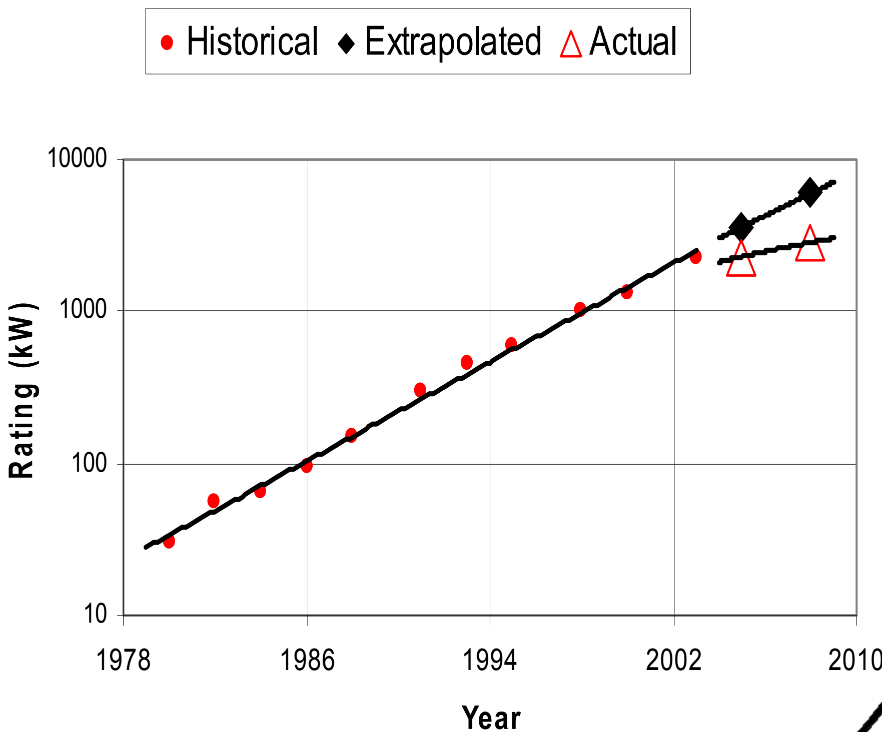
2nd NREL System Engineering workshop, Golden, CO., USA
01/29/2013

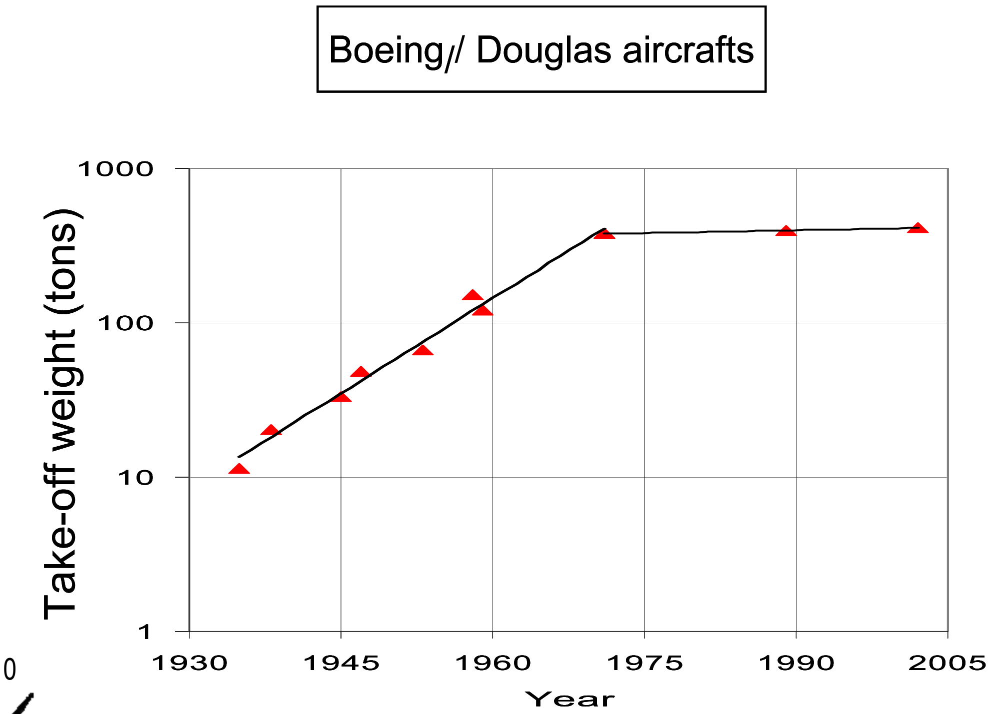
Size => Index of technology development

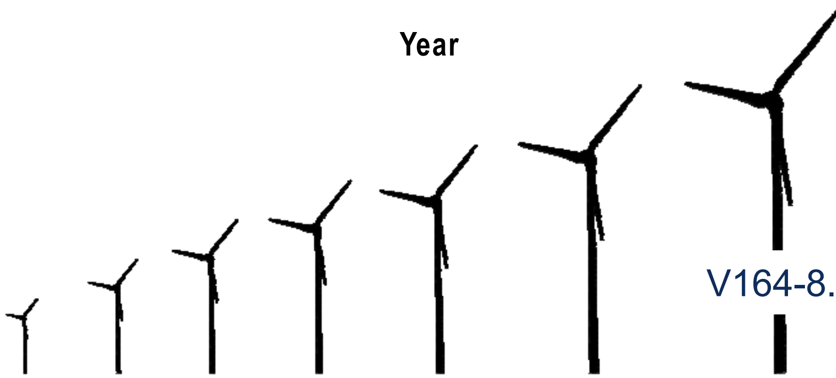
- Continuous growth in size (and power output) of wind turbines over the last decades
- Retarded growth in the last years



Comparison with aircraft industry







A380

Wind turbines have not yet reached their economical and technical limit

Wind turbine size considerations

Why Bigger

- Enabling bulk generation of electricity
- Lower operational expenses per installed capacity
- Higher energy capture per area land use
- More potentials for cost reduction

Why Not Bigger

- Manufacturing, transportation and installation problems
- Risk and uncertainty in design process
- Visual impact (onshore)
- Upscaling of current concepts seems to be not beneficial

Conclusion based on size

- Wind turbine industry not yet as mature as aerospace industry
- Many innovation yet to be made and justified in multidisciplinary context
- Knowledge transfer from aerospace (and offshore oil and gas) required

- Multidisciplinary Design Optimization (MDO) is vital to further decrease the cost
- MDO is needed to study new concepts and design alternatives

- Most of the MDO experience can be learned, transferred and adapted from aerospace industry

State of the art in wind turbine MDO

- Majority of the design optimization studies with isolated disciplines
- Low-fidelity simulation for those few multidisciplinary studies
- Optimization at the component level (not wind turbine level)
- Simplified or not realistic objective function
- Design constraints often not complete or well representative
- Limited number of design variables
- The use of optimization techniques in the design process not at professional level (algorithms and sensitivity analysis)
- …

Status in aerospace MDO:

- High-fidelity simulations, MDO with realistic objectives and constraints, several thousand of design variables and sophisticated optimization techniques

Wind turbine MDO is lagging behind aerospace severely!

MDO of this research (1/2)

- 5 MW NREL wind turbine as the initial design
- 3D wind field simulation using TurbSim
- Time domain aeroelastic simulation using AeroDyn+FAST
- Postprocessing using Crunch
- Levelized cost of energy as the objective function
  - WindPact cost models to estimate all the system costs
  - Annual energy production calculation based on site-specific data
- Rotor and tower design at the same time
  - Blade aerodynamic: Chord and twist distribution (6 design variables)
  - Blade structure: Spar-cap, shear-web and shell thickness distribution (12 design variables)
  - Rotor RPM (1 design variable)
  - Tower structure: Diameter and thickness at the bottom and top (4 design variables)
  - Tower height (1 design variables)

MDO of this research (2/2)

- Design constraints
  - Fatigue damage at 5 stations along the blade and tower
  - Natural frequencies of the blade and tower
  - Stresses at 5 stations along the blade and tower
  - Blade-tower and tower-interface clearance
- DLC6.2 to calculate ULS
- DLC1.2-00 to calculate FLS
- Time domain simulation with multi-seeds for ETM and NTM
- Gradient based optimization with multi-search algorithms
- Finite difference sensitivity analysis
- Computations implemented on a cluster of computers (40 nodes)
- 25 days (wall time) optimization

Overall results

- Objective function
  - 2.1% reduction of the LCOE

- Design changes
  - 3.1% longer blade
  - 1.8% heavier blade
  - 1.1% increase in blade-tip-speed
  - 3.2% higher hub height
  - 1.7% heavier tower
  - 1.1% shift in first flap frequency (blade)
  - Different chord, twist angle, stiffness and mass distribution

Future work

- Addition of the controller as a new discipline
- High-fidelity simulation of aerodynamic loads
- High-fidelity simulation of structural response
- Inclusion of soil dynamics (P-Y curves)
- More design load cases than DLC1.2-00 and 6.2
- More design variables than 24 used in this research
- Inclusion of local and global buckling as design constraints
- Replacement of the finite difference sensitivity analysis with more advanced techniques
- More accurate cost models than the WindPact
- …

End

Thank you for your attention

Question and discussion