Part IV: Blade Geometry Optimization

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Steady-State Aerodynamics Codes for HAWTs

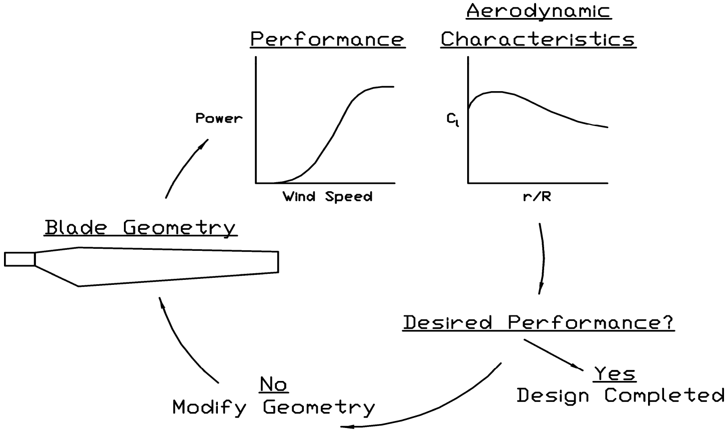
Selig, Tangler, and Giguère

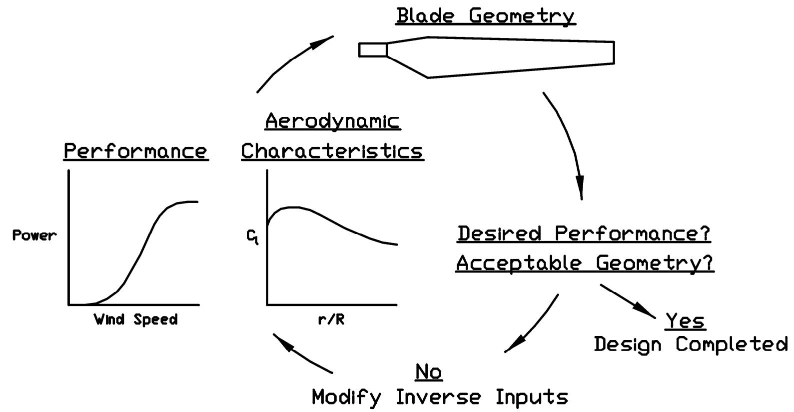
Outline

- Approaches to Optimization
- Blade Geometry Optimization
- Optimization Methods for HAWTs
- PROPGA

Approaches to Optimization

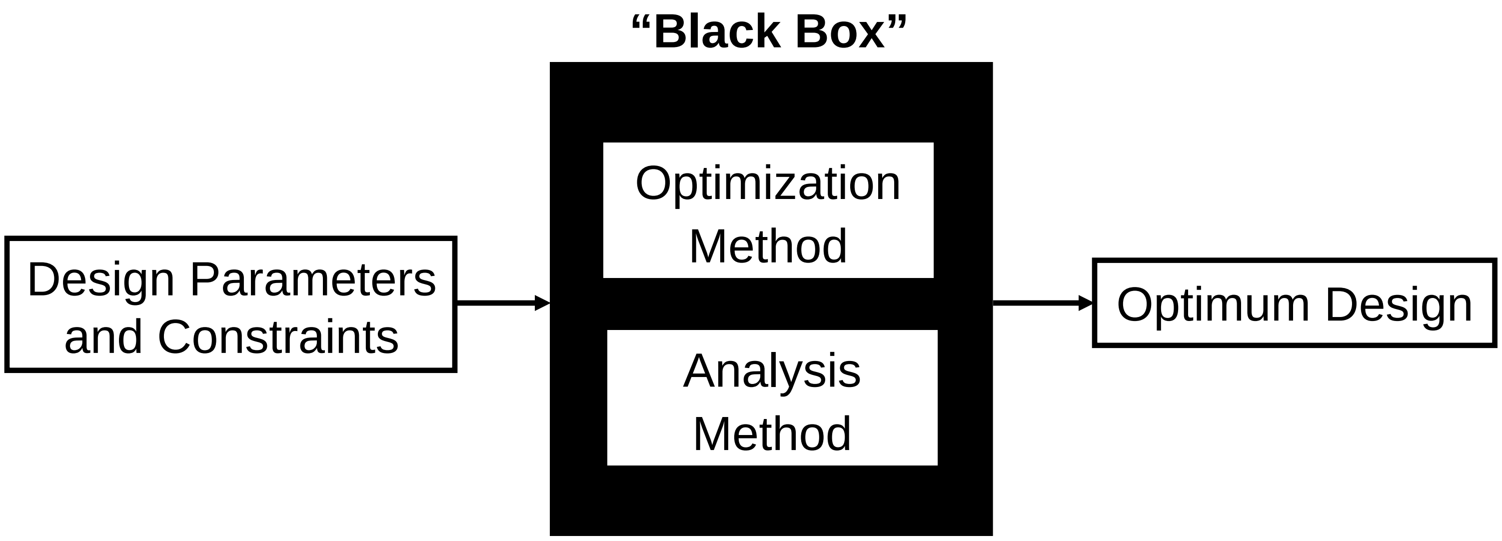
- Iterative Approach
  - Use direct or inverse design method





  - Designer knowledge important
  - Inverse design can lead directly to an optimum blade for maximum energy (variable-speed HAWTs)

- Direct Optimization



  - Many optimization techniques available
  - Nature of problem dictates the optimization method

- "Black Box" Warning!
  - An optimization method will take advantage of the weaknesses of the analysis tool(s) and problem formulation
  - Optimization technique must be implemented with care
  - Know your analysis tool(s)

Blade Geometry Optimization

- Many Design Variables (continuous and discrete)
  - Chord and twist distributions
  - Blade pitch
  - Airfoils
  - Turbine configuration and control systems
- Competing Objectives
  - Maximum energy
  - Minimum cost
- Airfoil data not always smooth ("noisy" problem)
- Complex problem often with many local optima
- Need a robust optimization technique

Optimization Methods for HAWTs

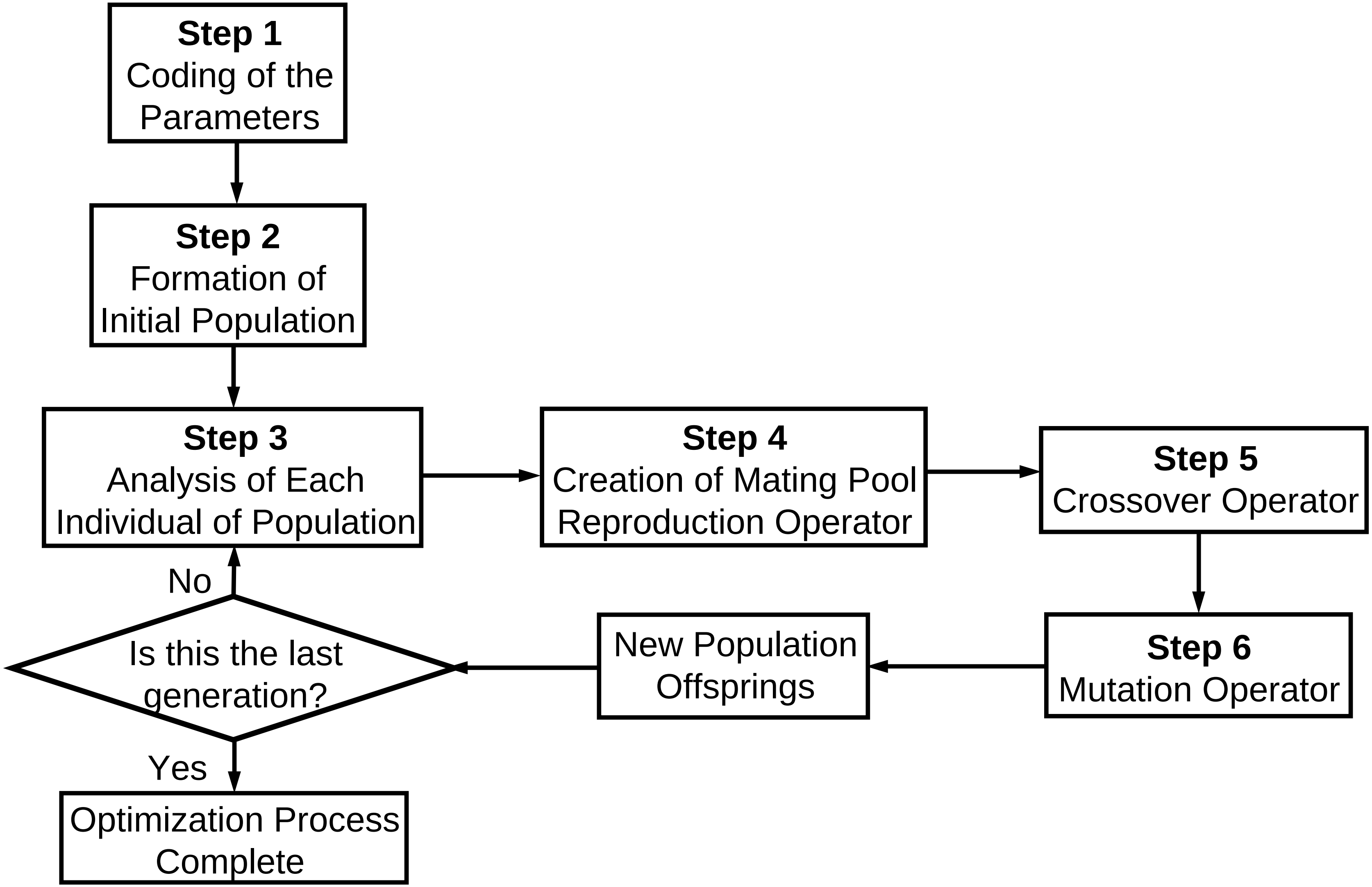
- Garrad Hassan (Jamieson and Brown, 1992)
  - Simplex method for aerodynamic design
  - Optimize chord and twist for maximum energy
- University of Athens (Belessis *et al.*, 1996)
  - Genetic algorithm for aerodynamic design with limited structural constraints
  - Parameterized airfoil data
- Risø (Fuglsang and Madsen, 1996)
  - Sequential linear programming with method of feasible directions for aerodynamic design
  - Structural, fatigue, noise, and cost considerations

PROPGA

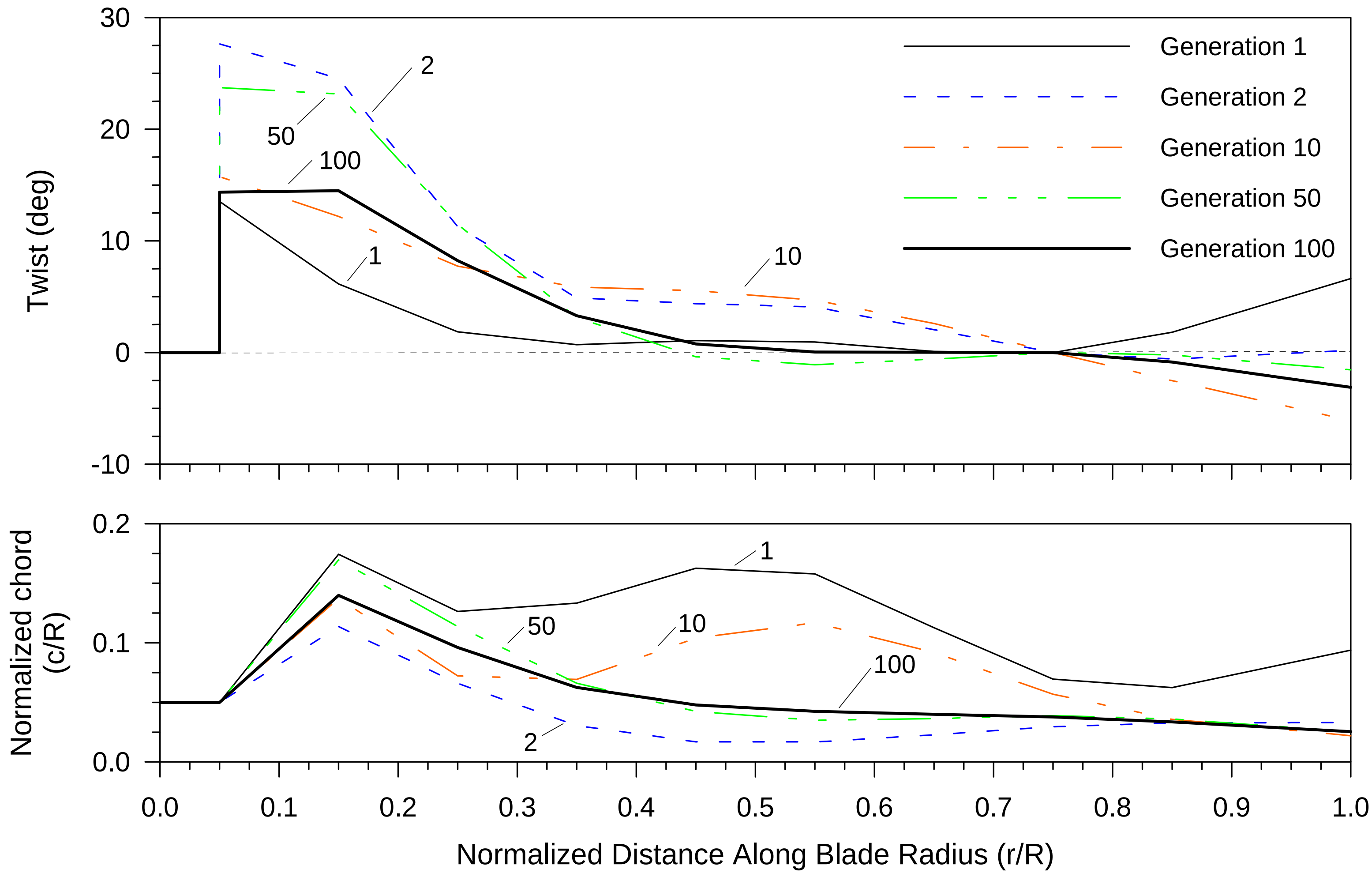
- Description
  - Genetic-algorithm based optimization method
  - Optimize blade geometry given set of constraints
    - Possible design variables
      - chord and twist distributions, blade pitch, rotor diameter, number of blades, etc.
    - Typical constraints
      - Operating conditions, rated power, airfoil distribution, steady-blade loads, and all fixed design variables
  - Uses PROPID to evaluate the blade designs and achieve inverse design specifications
  - Initially developed to optimize blades for max. energy

- What are Genetic Algorithms (GAs)?
  - Robust search technique based on the principle of the survival of the fittest
  - Work with a coding of the parameters
    - Simplified example: blade chord & pitch is 101001
  - Search from sub-set (population) of possible solutions over a number of generations
  - Use objective function information (selection)
  - Use probabilistic transition rules based on and genetic operations
    - crossover: 111|1 & 000|0 gives 1110 & 0001
    - mutation: 1 to 0 or 0 to 1 (small probability)
    - etc.

- PROPGA Flowchart

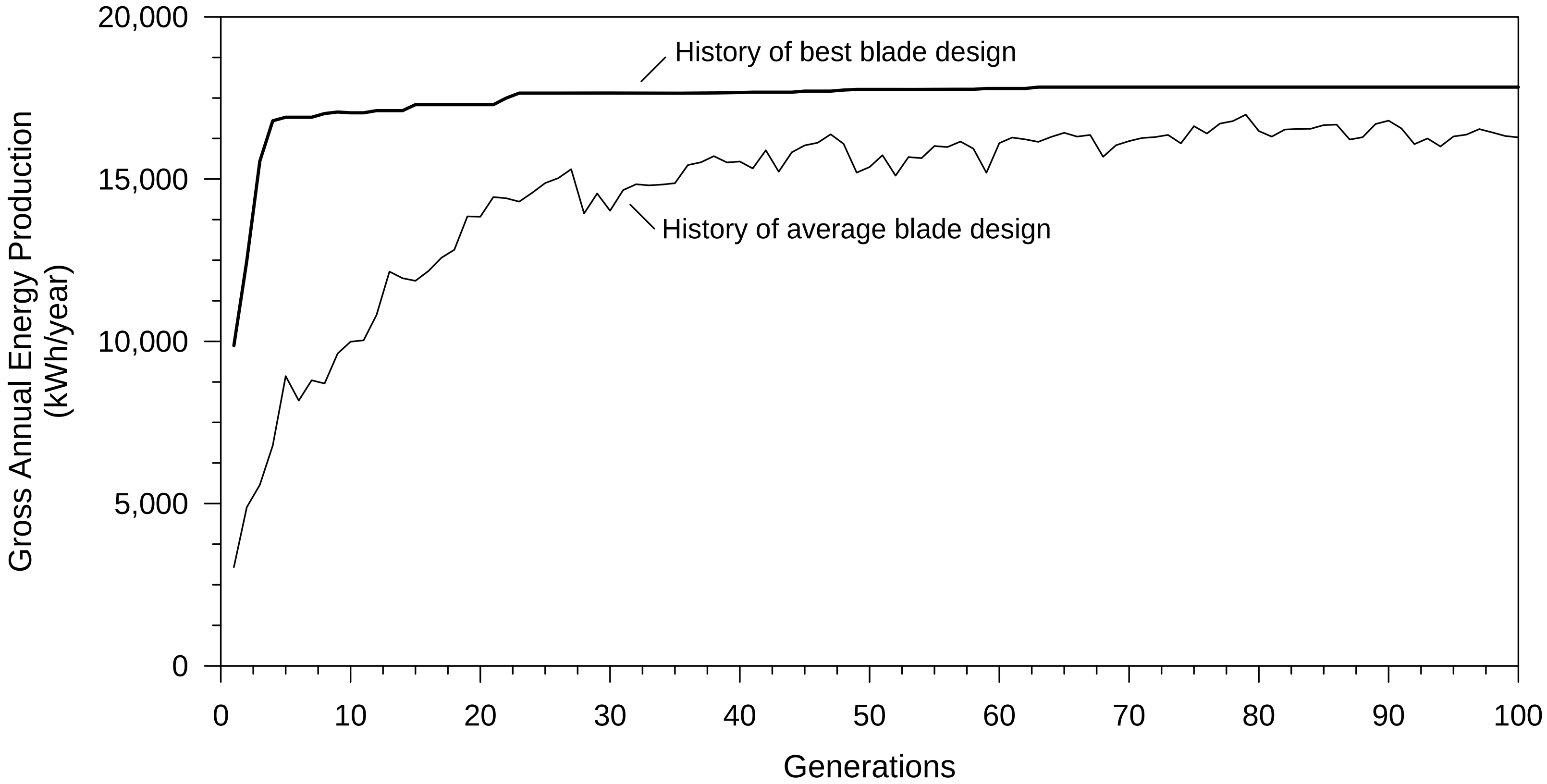


- Blade Design Example (Maximize Energy Capture)
  - Evolution of the chord and twist distributions



– History of the energy production

- Population of 100 blades over 100 generations



- Blades Designed with PROPGA/PROPID
  - Tapered/twisted blade for the NREL Combined Experiment Rotor
  - WindLite 8-kW wind turbine
  - Replacement blade for the Jacob’s 20-kW HAWT
  - Twist distribution of the replacement blade for the US Windpower 100-kW turbines