Rotor Design Approaches

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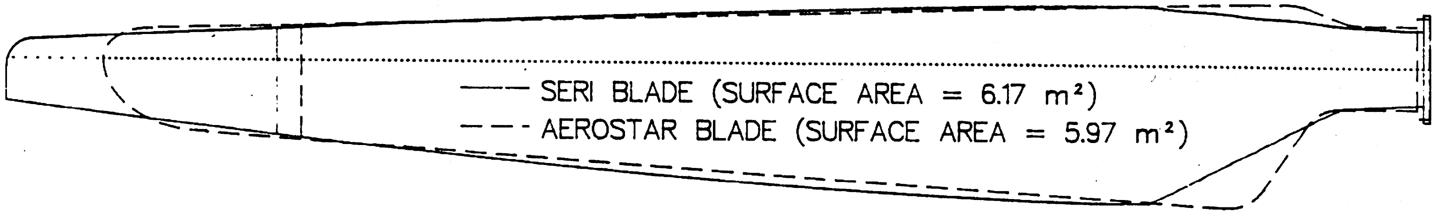
Steady-State Aerodynamics Codes for HAWTs
Selig, Tangler, and Giguère

Outline

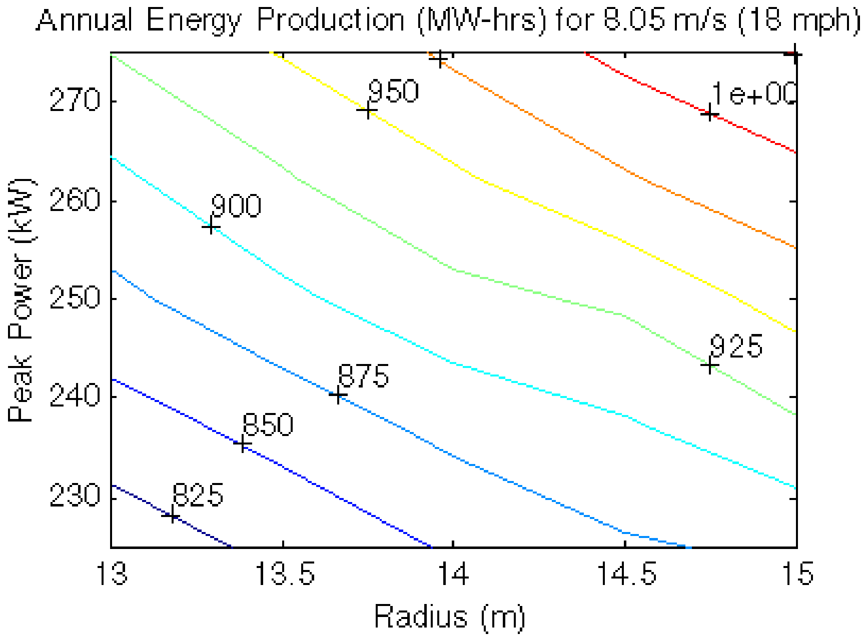
- Design Problems
- Approaches to Design
- Inverse Design

Design Problems

- Retrofit Blades

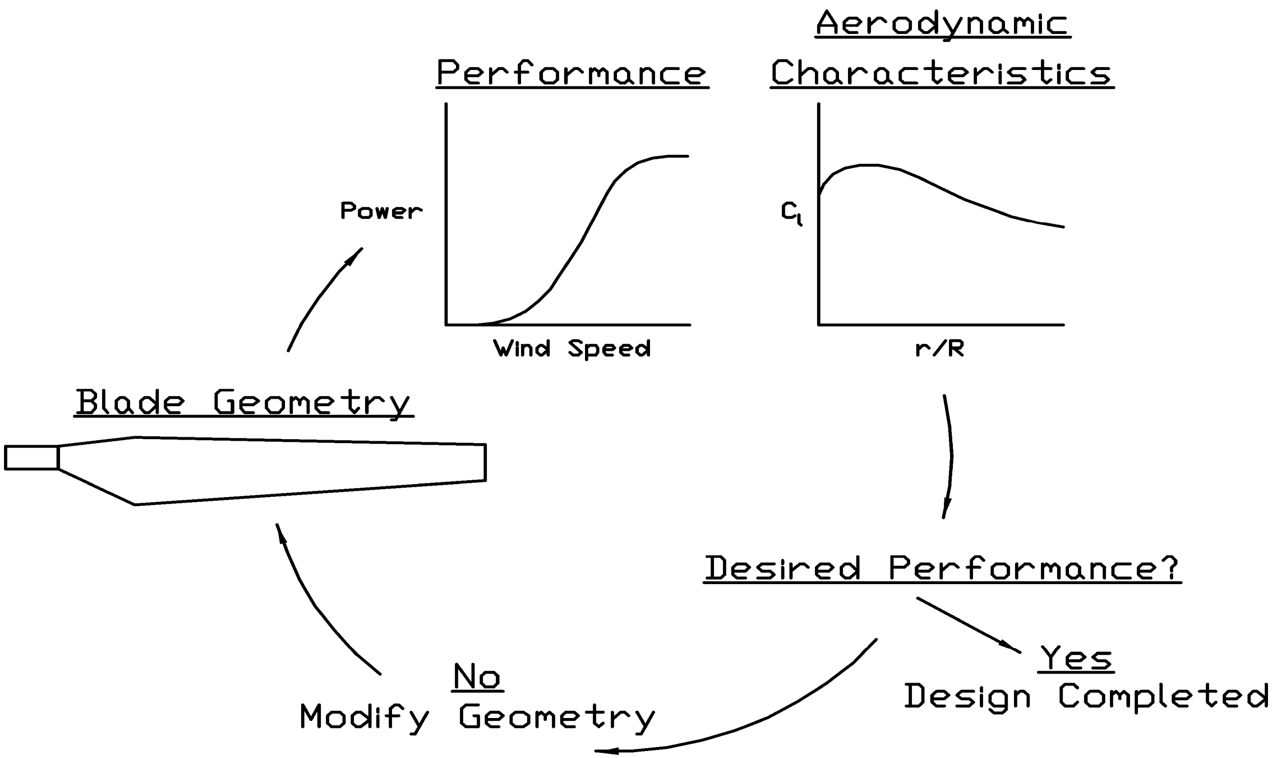


- Trade Studies and Optimization



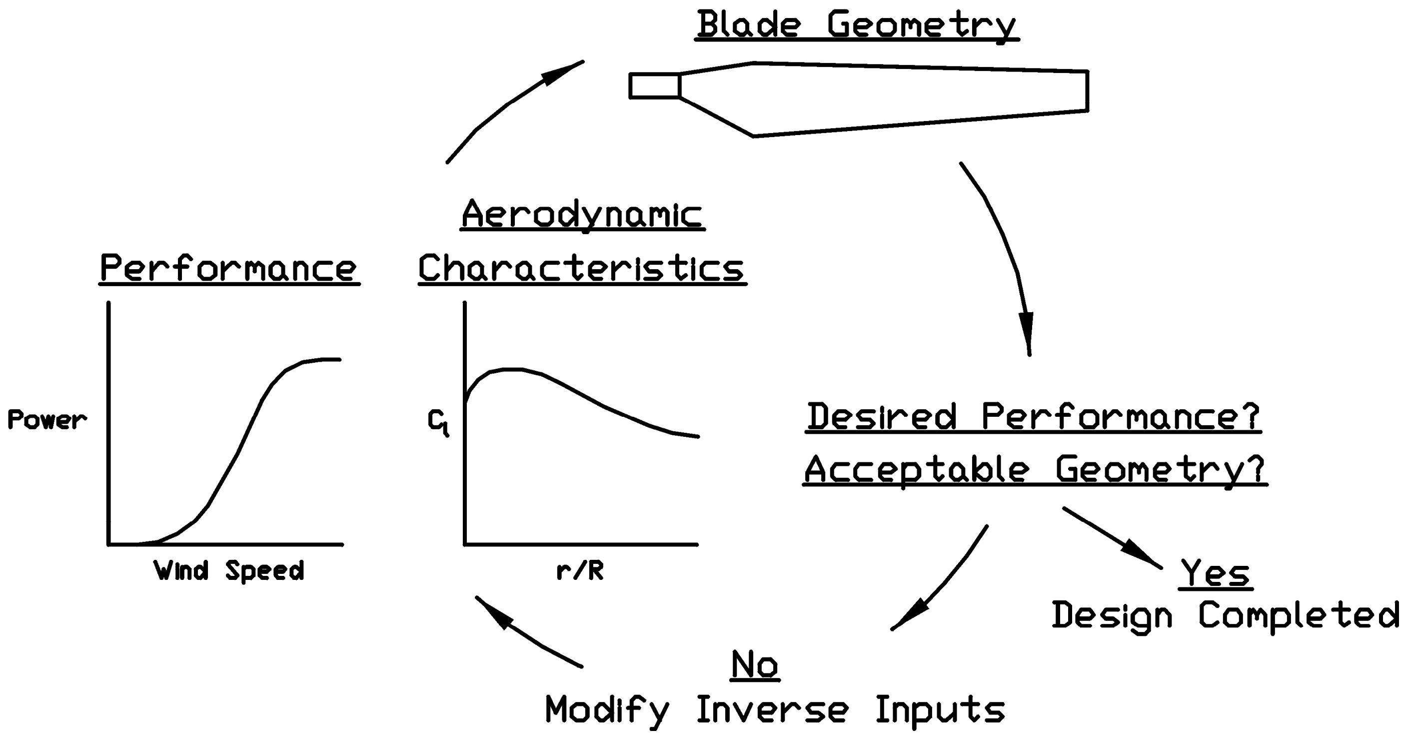
Approaches to Design

- Design by Analysis - Working "Forward"



- Example HAWT Codes: PROP, PROP93, WT_PERF, PROPID

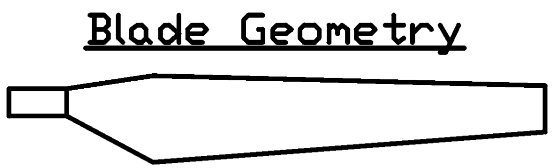
- Inverse Design - Working “Backward”
  - Requires some knowledge of desirable aerodynamic characteristics

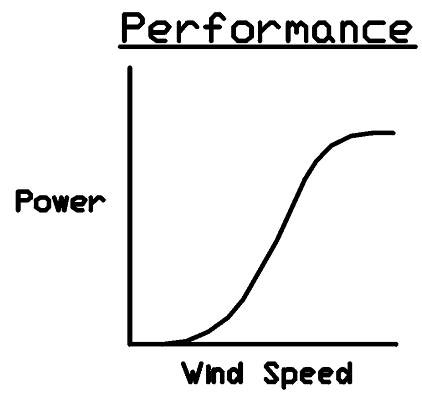


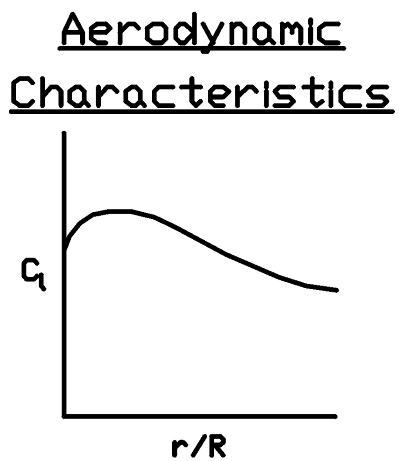
- Example HAWT Code: PROPID

- Optimization
  - Example problem statement: Maximize the annual energy production subject to various constraints given a set of design variables for iteration
- Example Code: PROPGA

Design Variables







- Desire a method that allows for the specification of both independent and dependent variables

From an Inverse Design Perspective

- Through an inverse design approach (e.g., PROPID), blade performance characteristics can be prescribed so long as associated input variables are given up for iteration.
- Examples:

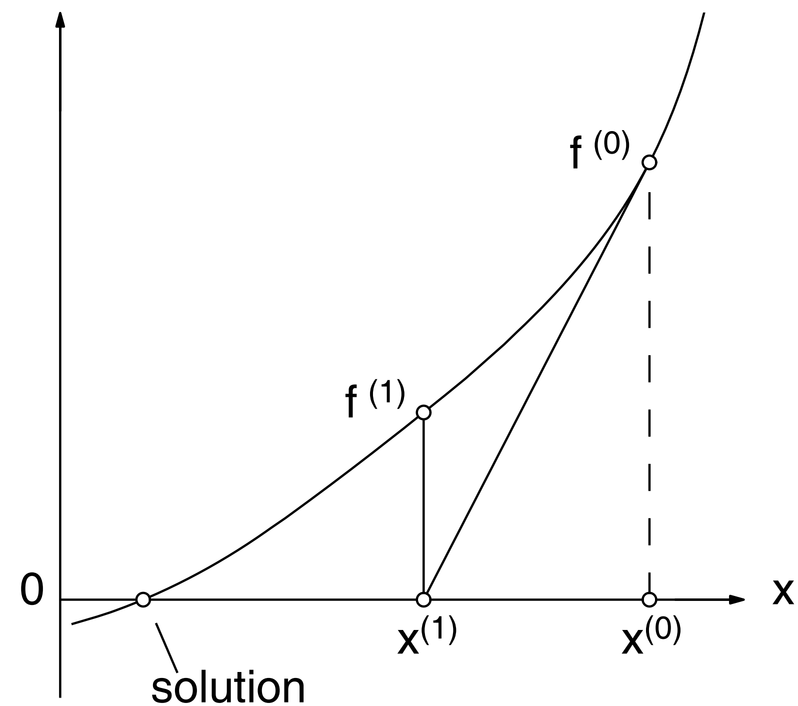
– Iterate on:	To achieve prescribed:
Rotor radius	=> Rotor peak power
Twist distribution	=> Lift coef distribution
Chord distribution	=> Axial inflow distribution

- Caveats
  - Some knowledge of the interdependence between the variables is required, e.g. the connection between the twist distribution and lift coefficient distribution.
  - Not all inverse specifications are physically realizable. For example, a specified peak power of 1 MW is not consistent with a rotor having a 3-ft radius.

Iteration Scheme

- Multidimensional Newton iteration is used to achieve the prescribed rotor performance
- Special "Tricks"
  - Step limits can be set to avoid divergence
  - Iteration can be performed in stages
  - Parameterization of the input allows for better convergence

$$f = P_{current} - P_{desired}$$



PROPID for Analysis

- Traditional Independent Variables (Input)
  - Number of Blades
  - Radius
  - Hub Cutout
  - Chord Distribution
  - Twist Distribution
  - Blade Pitch
  - Rotor Rotation Speed (rpm) or Tip-Speed Ratio
  - Wind Speed
  - Airfoils

- Traditional Dependent Variables - Sample (Output)
  - Power Curve
  - Power Coefficient Cp Curve
  - Rated Power
  - Maximum Power Coefficient
  - Maximum Torque
  - Lift Coefficient Distribution
  - Axial Inflow Distribution
  - Blade L/D Distribution
  - Annual Energy Production
  - Etc
- Each of these dependent variables can also be prescribed using the inverse capabilities of PROPID

Aerodynamic Design Considerations

- Clean vs. Rough Blade Performance
- Stall Regulated vs. Variable Speed
- Fixed Pitch vs. Variable Pitch
- Site Conditions, e.g. Avg. Wind Speed and Turbulence
- Generator Characteristics, e.g., Small Turbines, Two Speed

Common Design Drivers

- Generator => Peak Power
- Gearbox => Max Torque
- Noise => Tip Speed
- Structures => Airfoil Thickness
- Materials => Geometric Constraints
- Cost