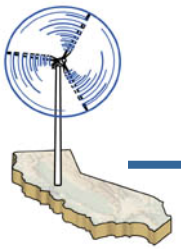
Permitting Setbacks for Wind Turbines and the Blade Throw Hazard

Scott Larwood

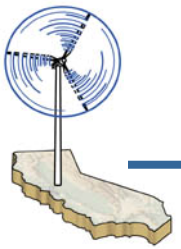
California Wind Energy Collaborative

UC Davis Doctoral Student



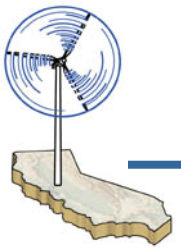
Organization

- Purpose of Investigation
- Setbacks for California Counties
- Blade Failure Probabilities
- Blade Throw Analyses
- Conclusions

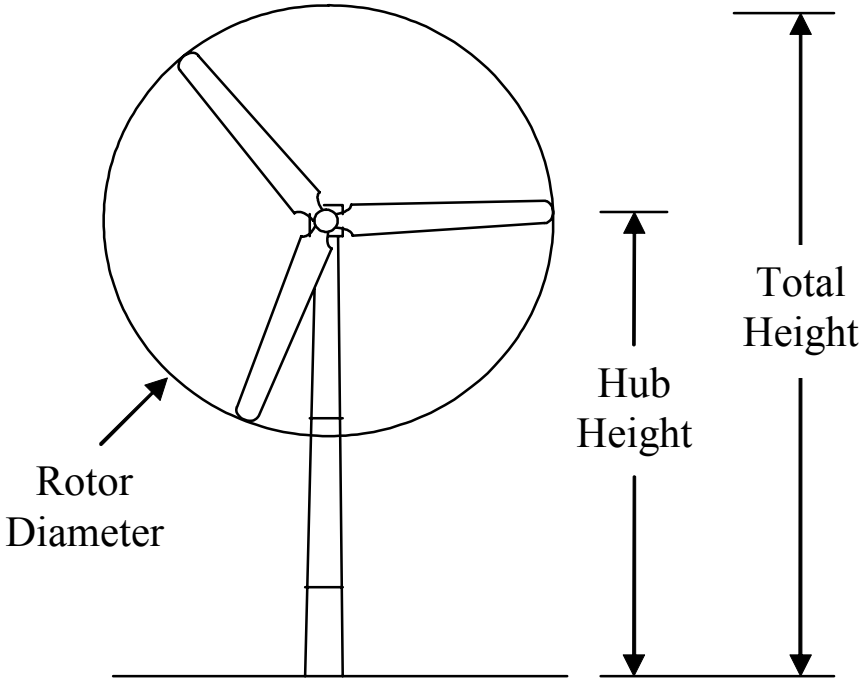


Purpose

- Part of “Wind Plant Optimization” task for California Wind Energy Collaborative
- Study and Report on permitting issues with regards to the blade throw hazard
  - Seemed to be based on maximum range and a function of turbine size
  - Setbacks vary county to county
  - Setbacks can limit revenue with modern turbine heights

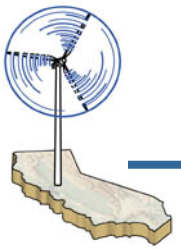


Turbine Geometry

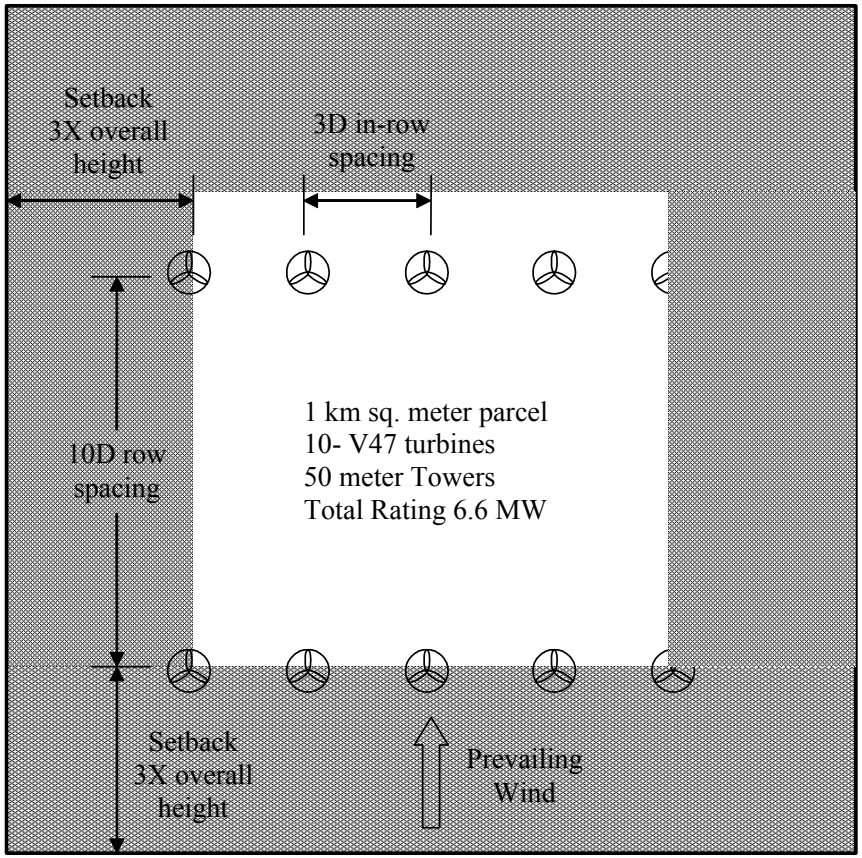


Example Parcel

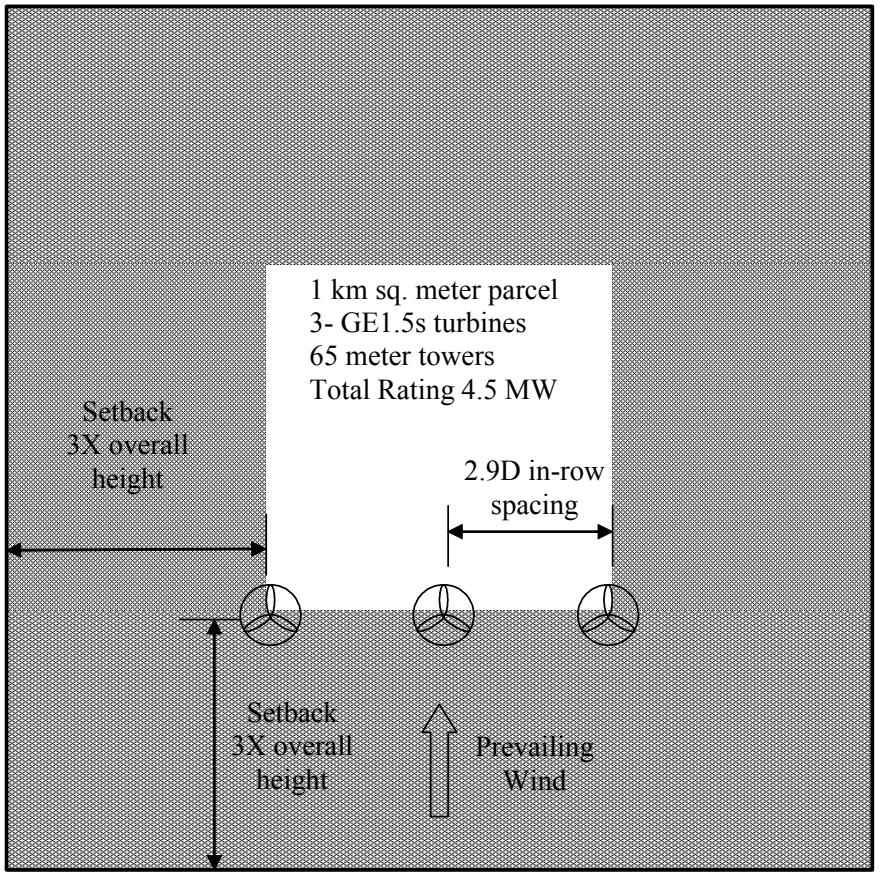
- One kilometer square parcel
- Setbacks are three times overall height
- Spacing requirements for turbine wakes
  - Three-diameters crosswind
  - Ten-diameters downwind
- Layouts for two turbine types
  - Vestas V-47, 660 kW, 47-m Ø, 50-m HH
  - GE 1.5s, 1.5 MW, 70.5-m Ø, 65-m HH



Vestas V-47 Layout

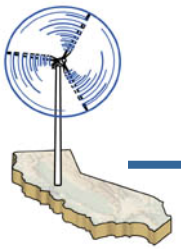


GE 1.5s Layout



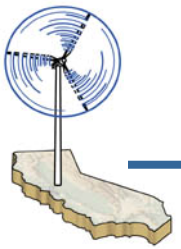
Setbacks for California Counties

	Property Line	Dwelling	Roads	Reductions in Setbacks
Alameda County	3x/300 ft (91 m), more on slope	3x/500 ft (152 m), more on slope	3x/500 ft (152 m), 6x/500 ft from I-580, more on sloped terrain	maximum 50% reduction from building site or dwelling unit but minimum 1.25x, road setback to no less than 300 ft (91 m)
Contra Costa County	3x/500 ft (152 m)	1000 ft (305 m)	None	exceptions not spelled in ordinance can be filed with county
Kern County	4x/500 ft (152 m) <40 acres or not wind energy zone, 1.5x >40 acres	4x/1000 ft (305 m) off-site	1.5x	With agreement from adjacent owners to no less than 1.5x
Riverside County	1.1x to adjacent Wind Energy Zones	3x/500 ft (152 m) to lot line with dwelling	1.25x for lightly traveled, 1.5x/500 ft (152 m) for highly traveled.	None
Solano County	3x/1000 ft (304 m) adjacent to residential zoning, 3x from other zonings	3x/1000 ft (304 m)	3x	Setback waived with agreement from owners of adjacent parcels with wind turbines



Blade Failure Probabilities

- Types and Causes
- References in the Literature
- Alameda County Data
- WindStats Data

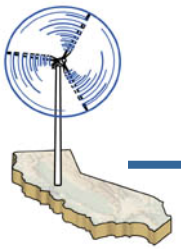


Types and Causes

- Types
  - Root connection failure
  - Partial failure from lightning
  - Failure at outboard aerodynamic device
  - Tower strike
  - Partial failure due to defect
  - Extreme load buckling
- Causes
  - Unforeseen events out of design envelope
  - Failure of control system
  - Human error
  - Incorrect design for fatigue/ultimate loads
  - Poor manufacturing quality
  - Usually a combination of above

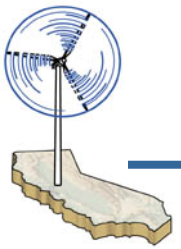
References in the Literature

- Putnam 1948
  - 1.25 MW turbine, 750 ft (230 m) throw
- SERI 1979
  - Analysis at 1.2×10^{-2} per year
- Eggwertz 1981 Sweden
  - Estimate of 10^{-5} per year
- De Vries 1989 Netherlands
  - Netherlands 2×10^{-2} per year
  - Denmark 3 to 5×10^{-3} per year
  - US 3×10^{-3} per year



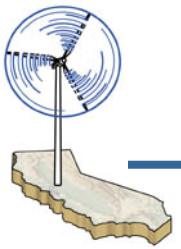
Alameda and WindStats Data

- Operators in Alameda County notify Building Official of Blade Throw
  - Jan 2000 to Fall 2003, Kenetech 56-100s
  - 5.4×10^{-3} blade failures/turbine/year
- WindStats Quarterly Publication
  - Denmark 1993-2004; 3.4×10^{-3} failures/turbine/year
  - Germany 1996-2004; 1.5×10^{-2} failures/turbine/year
    Unclear if failure resulted in blade throw
  - No apparent time trends
- Recommend using 10^{-2} per year as baseline probability

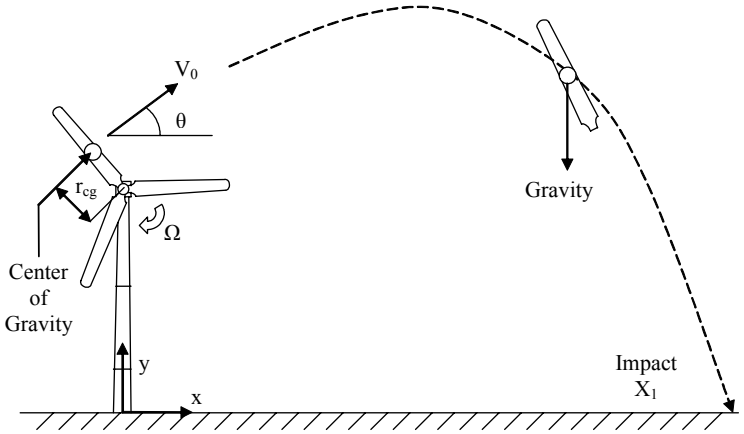


Blade Throw Analyses

- Simplified Model
- Literature
- Recommendations



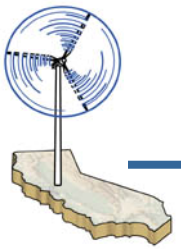
Simplified Model



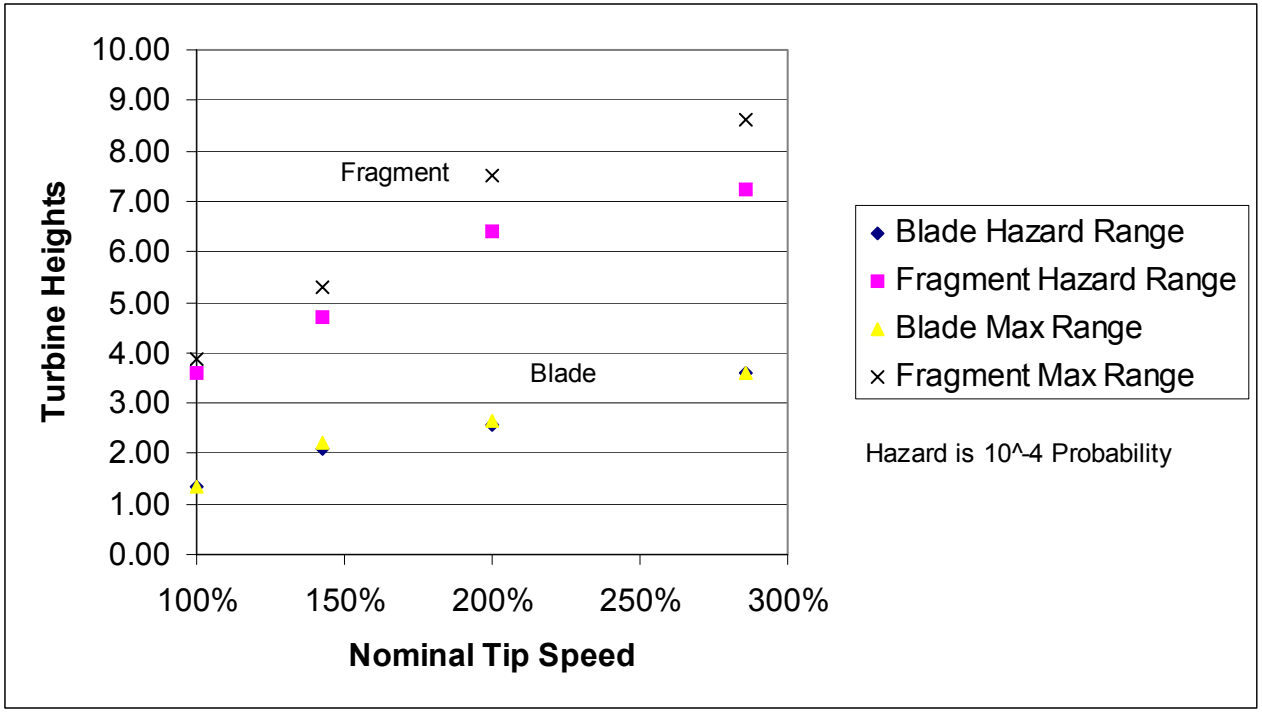
- Turbine Tip Speed
  - $V_{tip} = \Omega R$
- Projectile Release Velocity
  - $V_0 = \Omega r_{cg}$
- Projectile Range in Vacuum
  - $X_1 = \frac{V_0^2}{g} \sin 2\theta$
- Projectile Maximum Range in Vacuum
  - $X_{\max} = \frac{V_0^2}{g}$

Literature

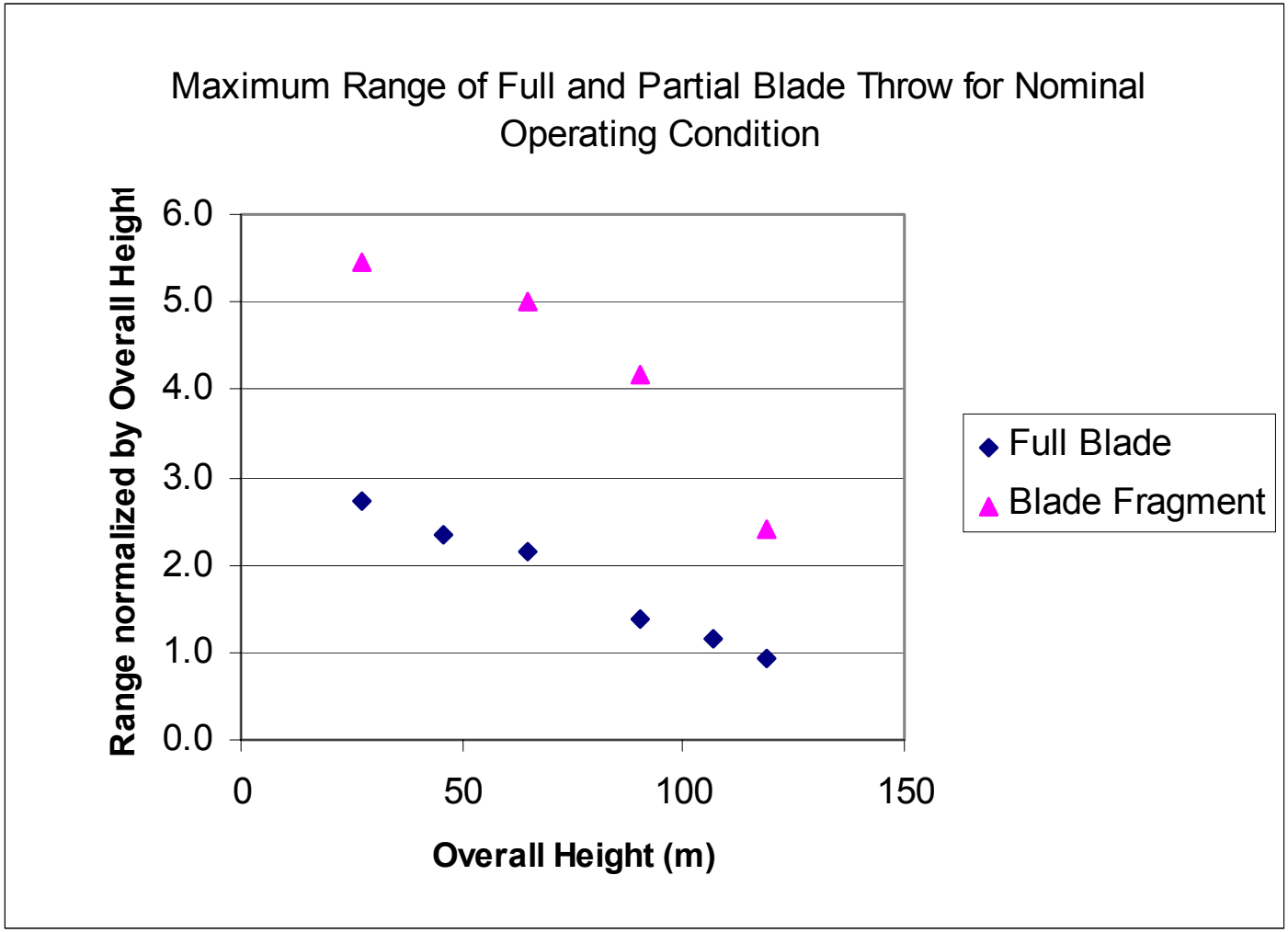
- Eggwertz 1981 Sweden
  - Random Probability of blade failure position
- MacQueen 1983 UK
  - Upper limit of tip speed 310 m/s
  - Comparison to lightning strikes in UK 10^{-7} per year
- Sørensen 1984 Denmark
  - Comprehensive aerodynamic analysis shows limitations of other models
  - Study of three turbines of increasing size
- Eggers 2001
  - Closed form solutions for impact probabilities



Sørensen 1.5-2.0 MW Turbine Blade Throw Probabilities

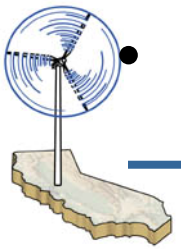


Comparison of Analyses



Recommendations

- Develop consistent analysis method to provide guidance on setbacks
- Failure 10^{-2}; Overall hazard- 10^{-6} (one in a million)
- Study variety of current turbines
- Use Sørensen's model and Eggwertz probability and impact method
- Determine probability and range for failure tip speeds
- Validate with actual failure data and/or field test



Conclusions

- Setbacks were based on collaboration with industry but not applied consistently
- Current regulations can “squeeze out” modern turbines
- Blade failure rate is surprisingly high and not showing improvement
- Blade throw has been studied extensively but no setback guidance
- Proposed approach to develop set back guidance