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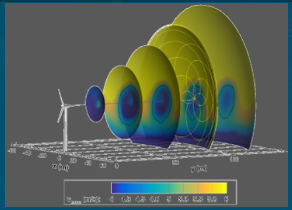
Sandia National Laboratories

Turbine tower strain gauge calibration for thrust measurements



PRESENTED BY

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National Rotor Testbed (NRT) Rotor

- Sandia-designed blades retrofitted to a 200 kW variable speed, variable pitch Vestas V27
- NRT Goals
  - Conduct wind turbine wake experiments relevant to megawatt scale turbines
  - Validate wind turbine models with an open source, well-documented, and highly instrumented wind turbine

NRT Scaled Wake Design

- Design NRT blades to create scaled wake of GE 1.5sle
- Scaled wake means equal normalized axial velocity at rotor plane
- Following quantities are equal for NRT and GE 1.5 sle turbines in region 2
  - $\frac{u}{U_\infty}\left(\frac{r}{R}\right)$ normalized axial velocity across the rotor normalized radius
  - $a\left(\frac{r}{R}\right)$ axial induction across the rotor normalized radius
  - $\Gamma'\left(\frac{r}{R}\right)$ dimensionless circulation across the rotor normalized radius
  - C_T thrust coefficient
  - λ tip-speed-ratio

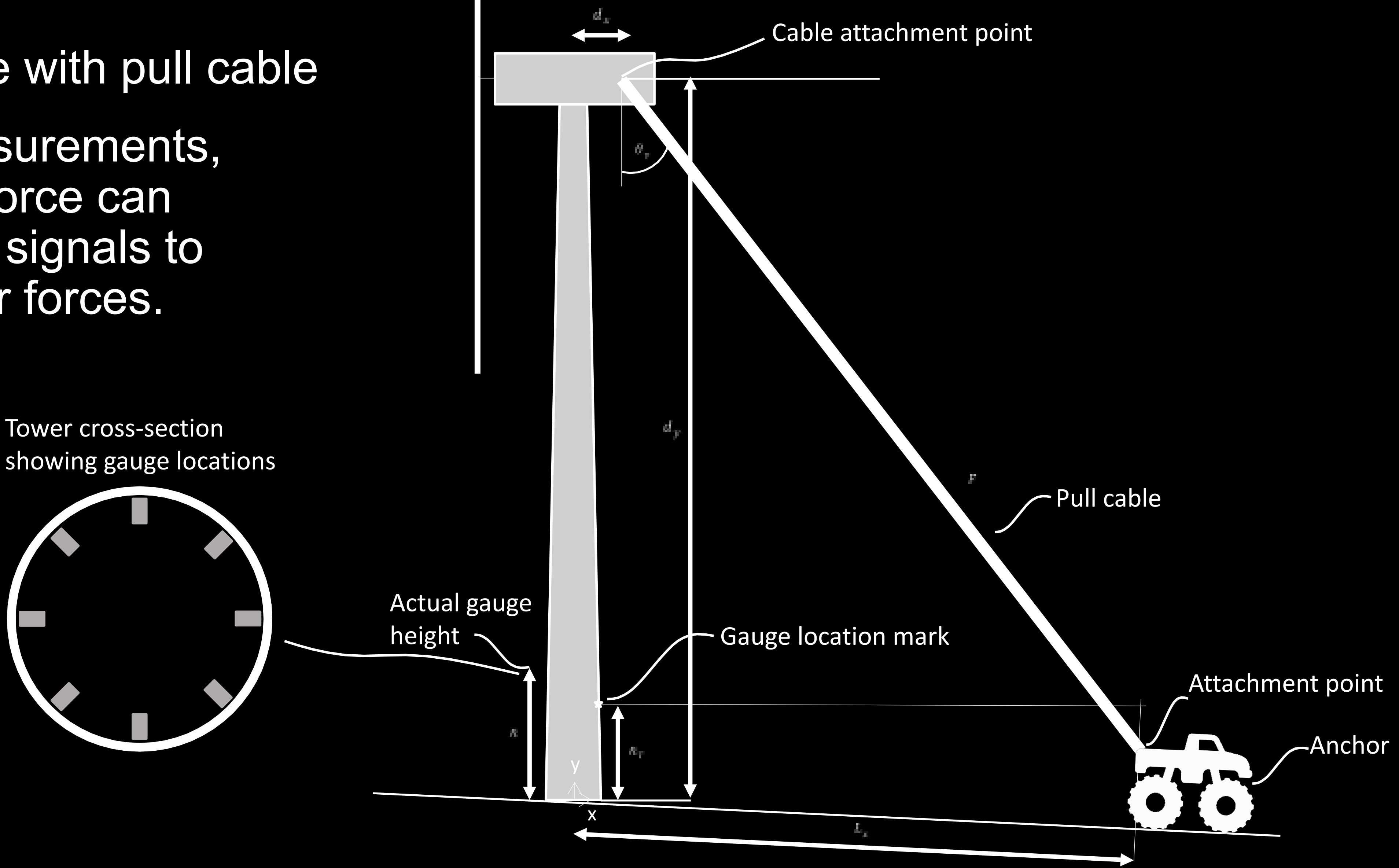
Motivation

- Part of our validation is a thrust measurement
- Thrust can be measured from strain gauges installed on the turbine tower
- Strain gauge signals must be calibrated
  - Typical procedure is to use a yaw sweep with known weights and CGs of nacelle and rotor components
  - But, on a smaller turbine, these signals are too small for a robust calibration

How can we calibrate our tower strain gauges?

Method – Pull on it!

- Load cell in line with pull cable
- With right measurements, measured pull force can calibrate gauge signals to moments and/or forces.



Calibration Math

- Convert measured force into components

$$F_x = F_{meas} \sin(\theta_v)$$
$$F_y = F_{meas} \cos(\theta_v)$$

- Convert forces to total moments

$$M = F_x(d_y - h) + F_y d_x$$

- Fit moments to gauge signals to determine calibration slopes and intercepts
- Knowing those, data are processed as such:

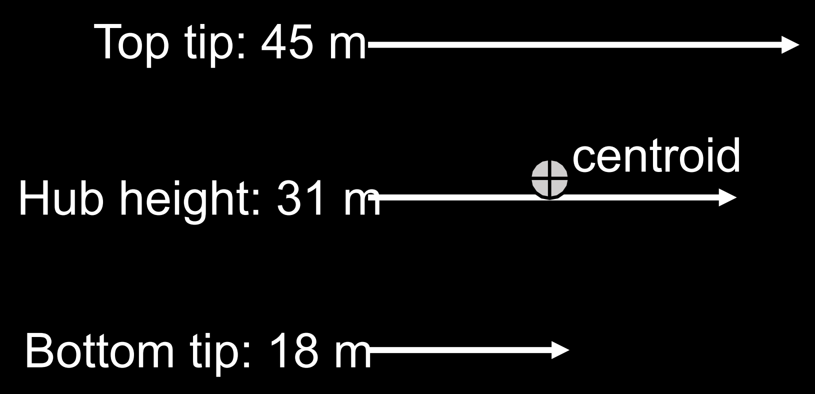
$$\begin{bmatrix} M_{FA} \\ M_{SS} \end{bmatrix} = \frac{1}{\sin(\beta - \alpha)} \begin{bmatrix} \sin(\theta - \beta) & -\sin(\theta - \alpha) \\ \cos(\theta - \beta) & -\cos(\theta - \alpha) \end{bmatrix} \begin{bmatrix} M_\alpha \\ M_\beta \end{bmatrix}$$

θ, yaw heading
α, β, gauge locations around tower azimuth
M_α, M_β, moments in direction of respective gauge locations determined from calibrations
M_{FA}, fore-aft moment
M_{SS}, side-side moment

- Finally, $Thrust = \sqrt{\left(M_{FA}(L-h)\right)^2 + \left(M_{SS}(L-h)\right)^2}$

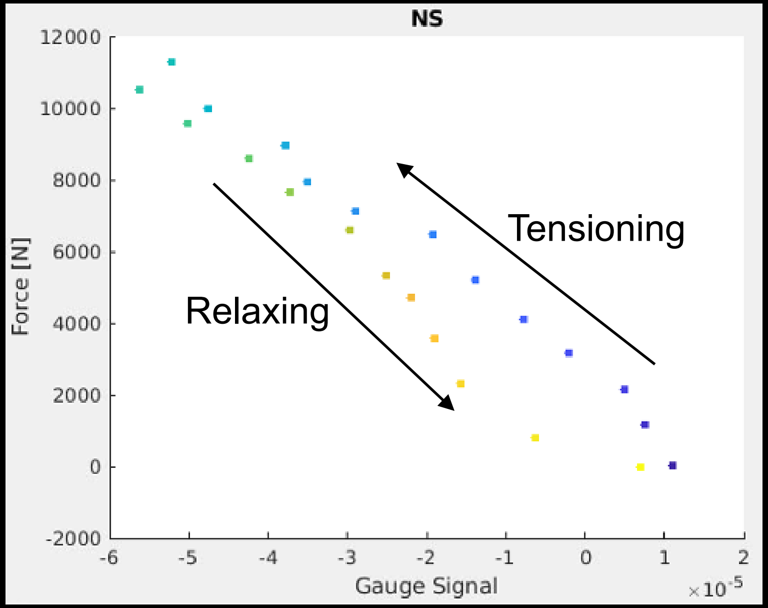
But what is *L*?

- L should be the height of the thrust force
- With only one height of gauges, we do not know the height of the thrust force
- We use three met tower heights to estimate the centroid of the inflow profile
- Average thrust height over 7 months is 31.89 m, compare to hub height of 31.2 m

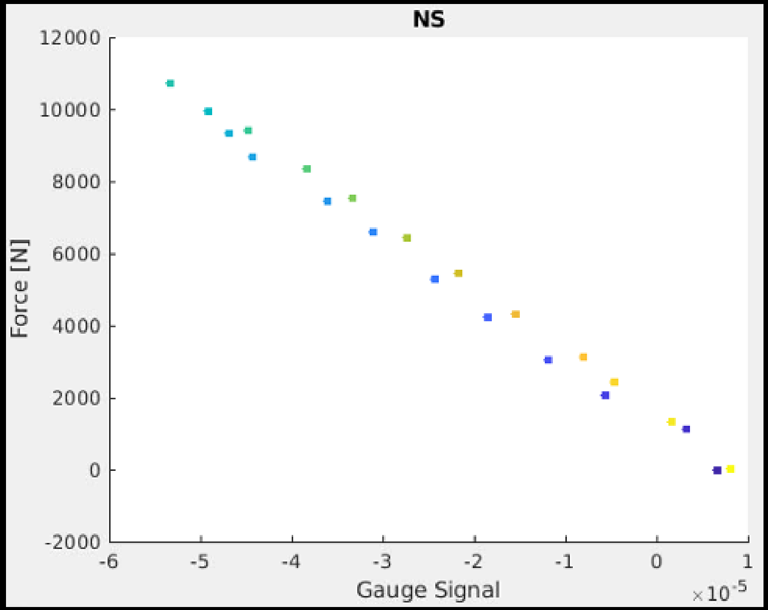


Learning Curve

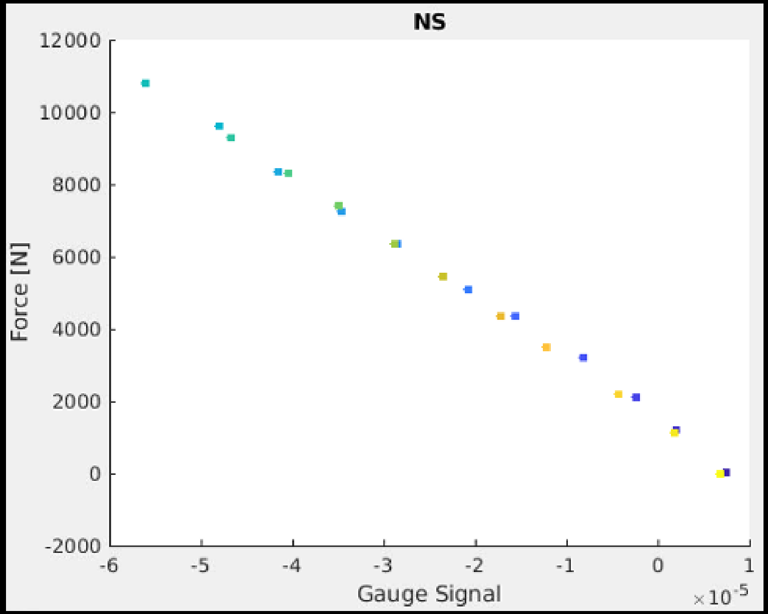
First pull



Second pull



Third pull

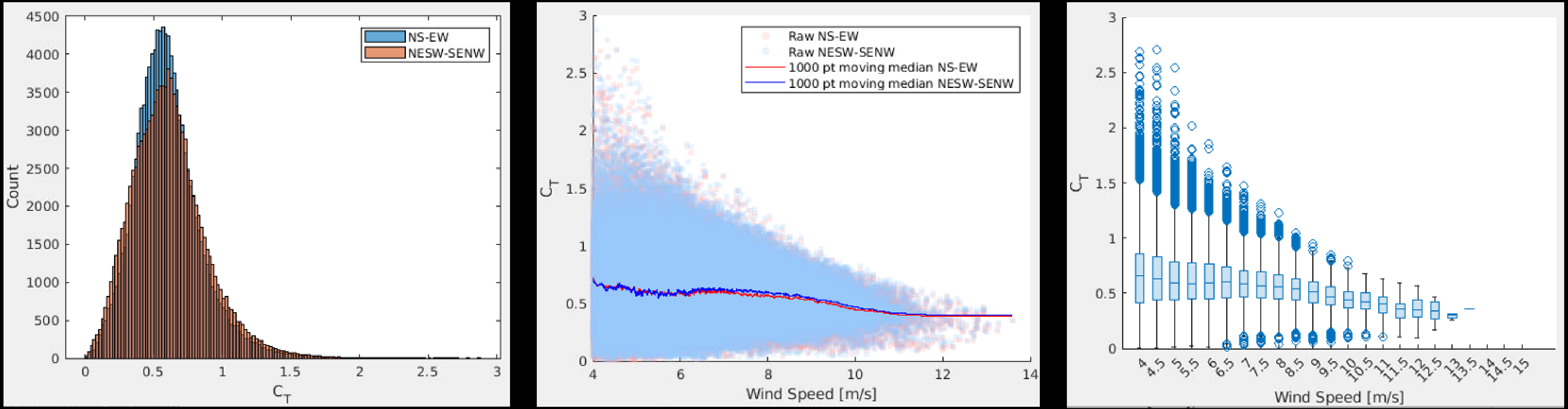


Data Processing for Results

- About 7 months of run time were filtered to calculate C_T
- Data were filtered for
  - Wind speeds between cut-in and cut-out
  - Steady yaw
  - Minimal yaw error
- Final data set is ~37 hours

Results

Using ~37 hours of turbine operating in full power production



Conclusions

- Pulling on the tower is a viable method for small wind turbine tower strain gauge calibrations
- Using the centroid of the inflow over the rotor appears to be a good proxy for thrust height
- Tower response time must be considered while interpreting data
- Current dataset exhibits wide spread in thrust measurements particularly at low wind speeds
  - This needs to be examined to determine the cause

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Thanks!

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