# *Wind Turbine Design Standards:*
## *Influence on Reliability*

**Paul Veers**
Wind Energy Technology
Sandia National Laboratories

psveers@sandia.gov

# Outline: Look at The Impact of Design Standards in Broad, General Terms

- What are the sources of unreliability?
- Operation and design sides of the problem
- How design standards are intended to operate
- The siting problem
- Summary

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# Things break for different reasons

| Environment (Loads) | Strength (Resistance) | |
|---|---|---|
| Loads inadequately specified (Load estimation and extrapolation) | Strength not as great as assumed (Material and manufacturing evaluation) | **Design Errors** |
| Environment outside the specification (Siting and/or Operations) | As-built strength not up to specification (Manufacturing and Construction) | **Operating Errors** |
| Acts of God – You know the design is inadequate for the environment but you assess the frequency of occurrence to low enough to absorb the loss. (Purchase Insurance) | | |

Improvement is not possible without sustained feedback from experience in the field.

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# Reliability Activities

## Database

The information from the database drives the activities for both Design and Operations.

- **O&M and Users' Groups**
- **Partnerships w Operators**
- Reliability Analysis
- Regular Reporting

## Design

### Loads

Turbulence, Wakes & Extremes

Events: Storms, Jets, Earthquakes

Aeroelastic Analysis Tools

Design Standards

### Strength

Full-Scale Durability Testing
(Blades, Gearboxes & Generators, Systems)

Gearbox Collaborative

Structural Analysis Tools

Design Standards

## Operations

### Environment

Condition Monitoring

Operating Practices and Procedures

Wind Monitoring

Technician Training

O&M Tracking and Reporting

### Durability

Structural Health Monitoring

Maintenance

Manufacturing & Construction Quality
(as-delivered and as-built components)

O&M Tracking and Reporting

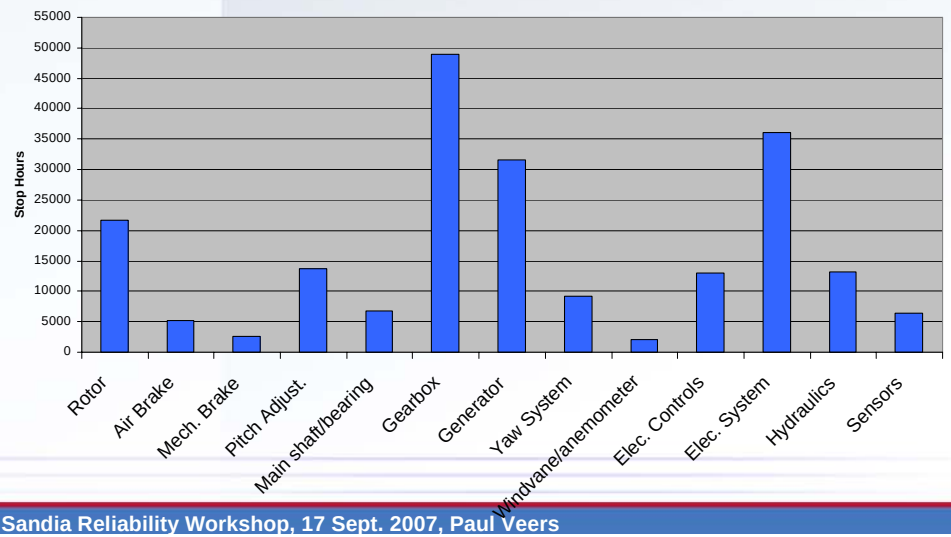
# Two Sides to the Reliability Problem

**The Database supports both activities**

## Operations

- Condition Monitoring (tracking, tracking, tracking)
- O&M
- Field Quality Assurance
- Personnel, Procedures and Practices

**Wind Stats: 2003-2005 Stop Hours per Turbine Subsystem**




## Design

- Loads and Environments
- Design Analysis (Aeroelastic Tools)
- Full-Scale Testing
- Design Standards

*The interface between these two sides has many challenges, especially at the component level.*

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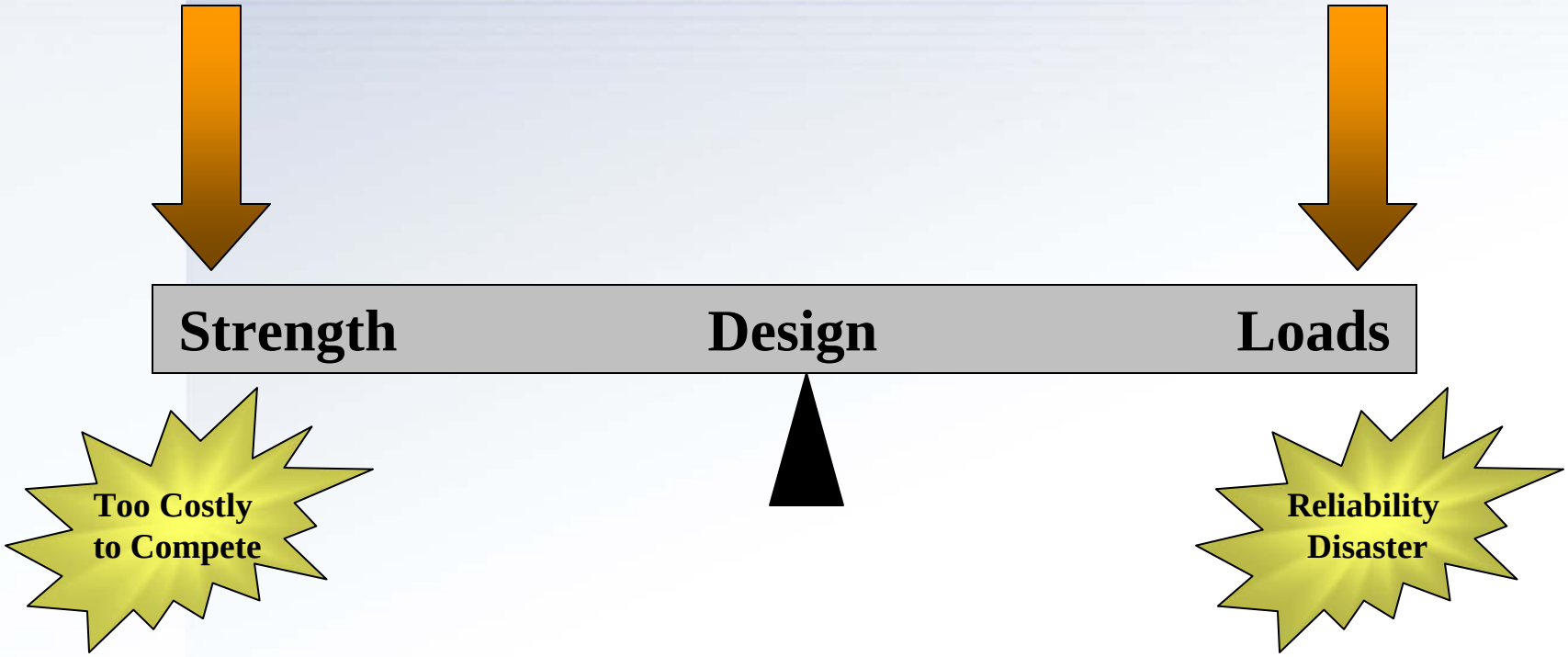
# Design Philosophy

- Balancing act of Strength vs. Loads
- Installed Cost balances against Reliability Cost (i.e., Capital vs. O&M and replacement cost)

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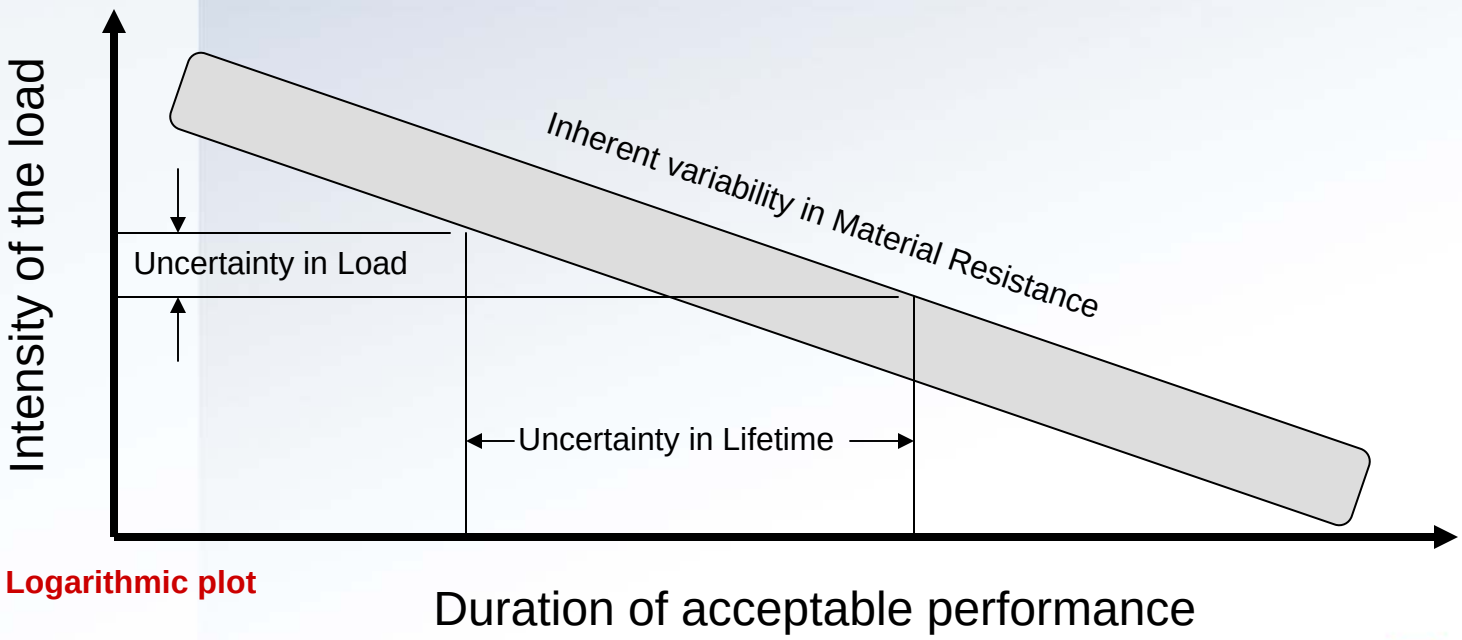
# Things wear out

**Things wear out due to repeated loads or environmental effects (load, temperature, moisture, etc.)**

- **Material resistance to repeated loads is both sensitive and variable.**
- **A small load uncertainty results in an enormous lifetime uncertainty.**
- **A large margin on the mean life is required to avoid early failures**




**Logarithmic plot**

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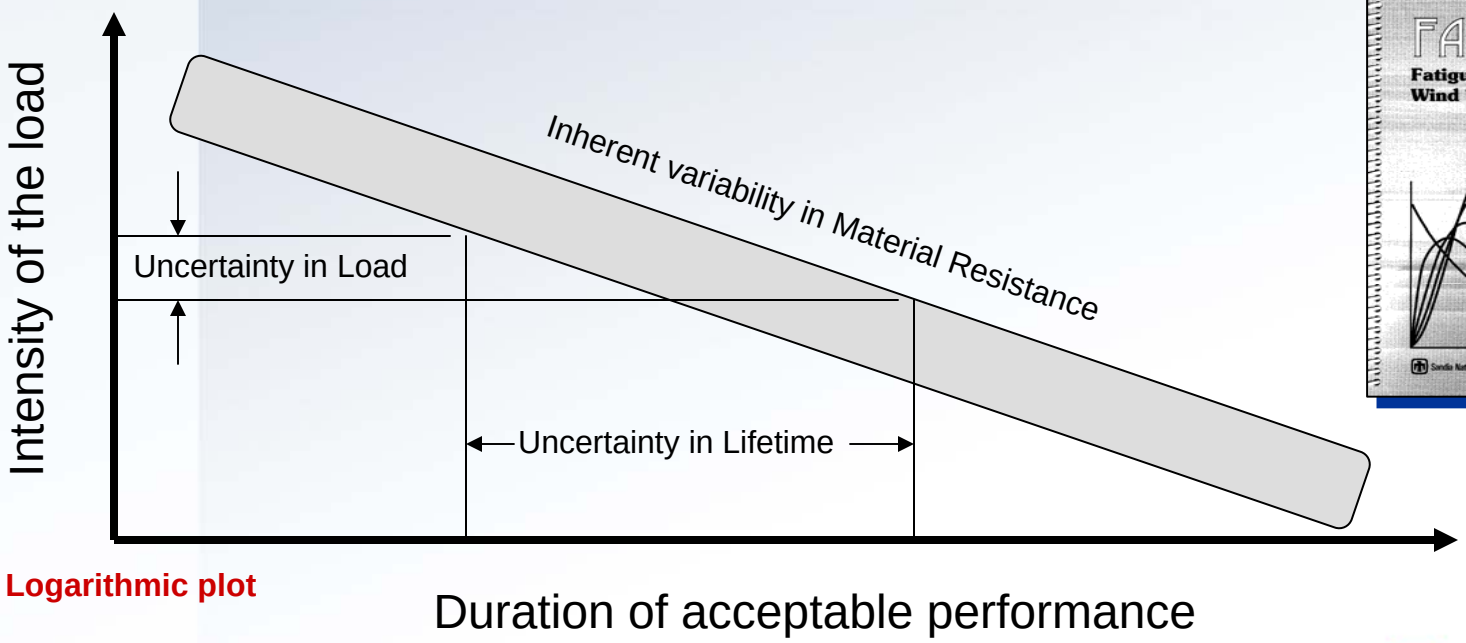
# When will Things wear out?

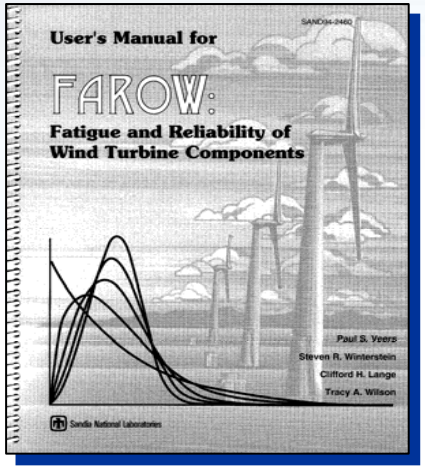
- **Asking the question of how long a certain component will last is not a well posed problem.**

**The better question is:**

- **How likely it is that the component will last long enough to fulfill its functional purpose?**




**Logarithmic plot**

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# Reliability Calculations are Difficult

- FAROW calculates the probability of component failure due to fatigue
- FAROW requires the user to define all the uncertain inputs
  - Material Properties
  - Wind Speed profile and turbulence
  - Dynamic response of the turbine to turbulence
  - Etc.
- This is not very user friendly, especially when the designer is trying to iterate to an optimal configuration.
- The usual practice in most industries is to use Safety Factors on the loads and resistances that adequately account for the inherent uncertainties in the design variables (LRFD).
- Certification Standards are the places where these safety factors are documented.

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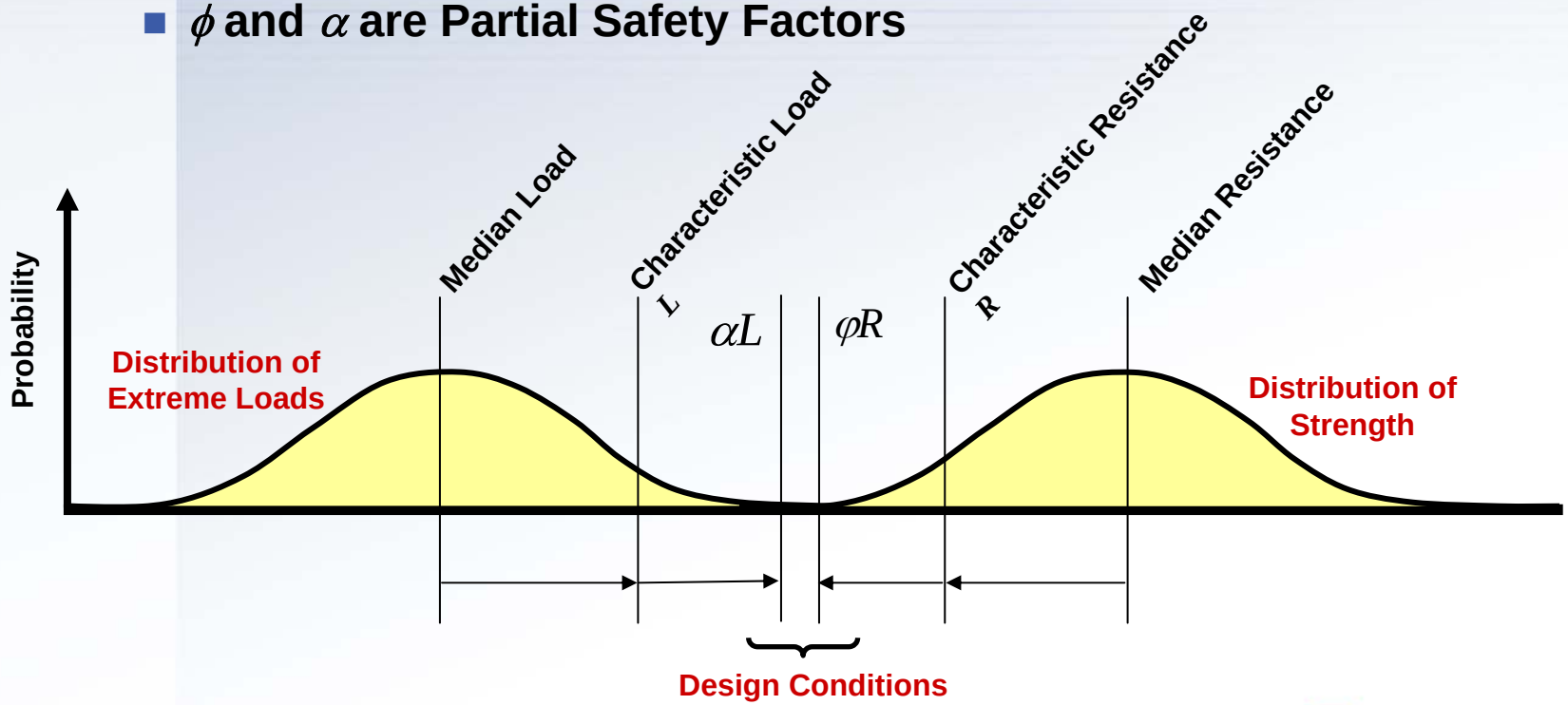
# Load and Resistance Factor Design

- $R$ = the Characteristic Resistance (e.g., 95/95 strength level)
- $L$ = the Characteristic Load Level (e.g., 50-year extreme)
- $\phi$ and $\alpha$ are Partial Safety Factors

$$\varphi R \geq \alpha L$$

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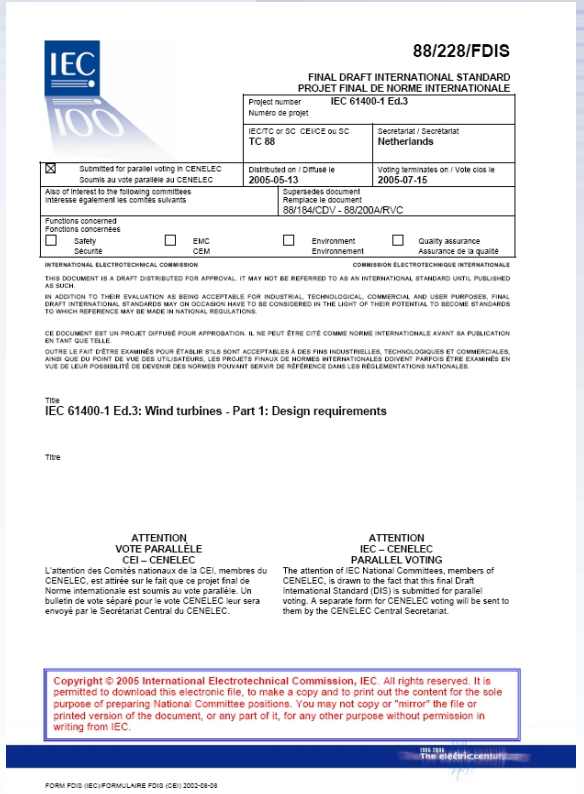
# Certification Standards Set the Criteria

**Much of the improvement in quality of wind turbine systems, from the high frequency of failures in the 1980's until today, has been driven by the industry drive to meet International Standards through design evaluation and testing.**



88/228/FDIS

FINAL DRAFT INTERNATIONAL STANDARD
PROJET FINAL DE NORME INTERNATIONALE

| | |
|---|---|
| Project number / Numéro de projet: IEC 61400-1 Ed.3 | |
| IEC/TC or SC / CEI/CE ou SC: TC 88 | Secretariat / Secrétariat: Netherlands |
| ☒ Submitted for parallel voting in CENELEC / Soumis au vote parallèle au CENELEC | Distributed on / Diffusé le: 2005-05-13 / Voting terminates on / Vote clos le: 2005-07-15 |
| Also of interest to the following committees / Intéresse également les comités suivants | Supersedes document / Remplace le document: 88/184/CDV - 88/200A/RVC |
| Functions concerned / Fonctions concernées: ☐ Safety / Sécurité ☐ EMC / CEM ☐ Environment / Environnement ☐ Quality assurance / Assurance de la qualité | |

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Title
IEC 61400-1 Ed.3: Wind turbines - Part 1: Design requirements

Titre

ATTENTION
VOTE PARALLÈLE
CEI – CENELEC
L'attention des Comités nationaux de la CEI, membres du CENELEC, est attirée sur le fait que ce projet final de Norme internationale est soumis au vote parallèle. Un bulletin de vote séparé pour le vote CENELEC leur sera envoyé par le Secrétariat Central du CENELEC.

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The attention of IEC National Committees, members of CENELEC, is drawn to the fact that this final Draft International Standard (DIS) is submitted for parallel voting. A separate form for CENELEC voting will be sent to them by the CENELEC Central Secretariat.

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**IEC, GL, DNV, etc.**

- **Characteristic Loads**
  - **Suite of "Design Load Cases" (DLCs)**
  - **Includes aeroelastic model to apply atmospheric conditions to the dynamic structure**
- **Characteristic Strength**
  - **Material properties**
  - **Damage rules**
  - **Statistical variation**
- **Factors of Safety**

  **(taken from other industries)**
- **Requirements for Testing**

  **(Static and Fatigue)**

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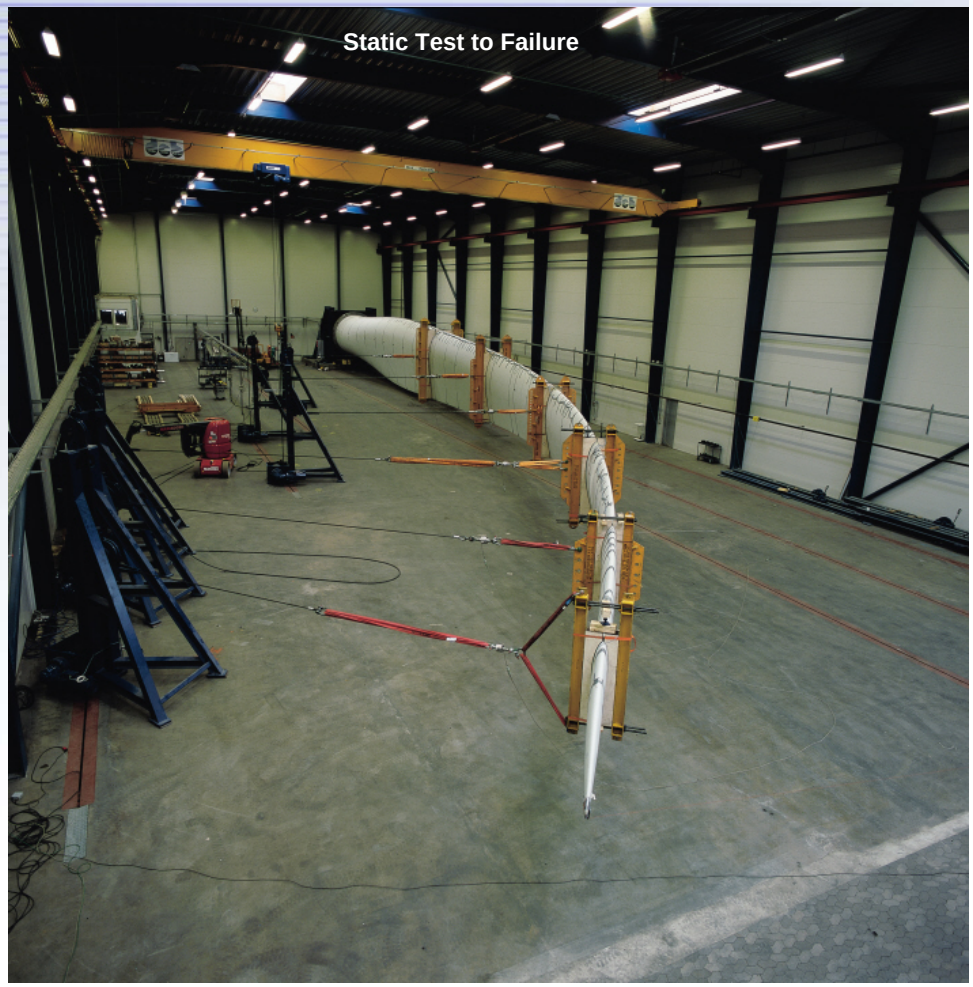
# Blade full-scale testing is now the norm

Courtesy of LM Glassfiber

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# Fatigue testing – the movie

Video courtesy of NREL

**Fatigue test of a 34 meter blade**

**(the tip has been cut off)**

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# Static test to failure

Courtesy of LM Glassfiber

**Static test to failure of a 42.5 meter blade**

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# IEC Turbine Safety Classifications

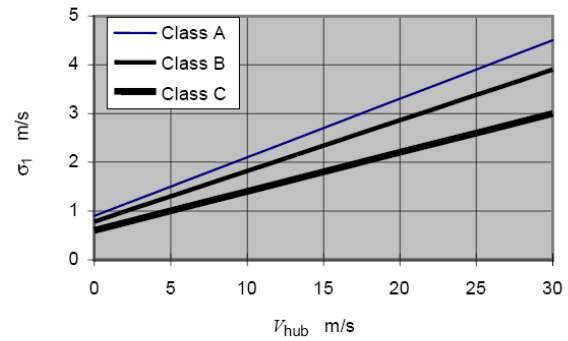


Figure 1a –Turbulence standard deviation for the normal turbulence model (NTM)

Average and Extreme Wind Speed →

Turbulence Level

| Wind Turbine Class | I | II | III | IV |
|---|---|---|---|---|
| $V_{gust}$ (m/s) | 50 | 42.5 | 37.5 | 30 |
| A $I_{15}$ | 0.16 | 0.16 | 0.16 | 0.16 |
| B $I_{15}$ | 0.14 | 0.14 | 0.14 | 0.14 |
| $V_{ave}$ (m/s) | 10 | 8.5 | 7.5 | 6 |

(source: IEC 61400-1,3rd edition, dated 2005-08)

Stolen from Dan Bernadette – next talk…

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# Standards attempt to create load cases that cover the full range of potential field events.

- At the Allianz Technology Center (AZT) in Munich, the bits and pieces from wind turbine meltdowns are closely examined. "The force that comes to bear on the rotors is much greater than originally expected,“ says AZT evaluator Erwin Bauer. Wind speed is simply not consistent enough, he points out. "There are gusts and direction changes all the time," he says.  (NYT, 09/10/2007)

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# IEC Standards have a suite of Design Load Cases

**Table 2 – Design load cases**

| Design situation | DLC | Wind condition | | Other conditions | Type of analysis | Partial safety factors |
|---|---|---|---|---|---|---|
| 1) Power production | 1.1 | NTM | $V_{in} < V_{hub} < V_{out}$ | For extrapolation of extreme events | U | N |
| | 1.2 | NTM | $V_{in} < V_{hub} < V_{out}$ | | F | * |
| | 1.3 | ETM | $V_{in} < V_{hub} < V_{out}$ | | U | N |
| | 1.4 | ECD | $V_{hub} = V_r$-2 m/s, $V_r$, $V_r$+2 m/s | | U | N |
| | 1.5 | EWS | $V_{in} < V_{hub} < V_{out}$ | | U | N |
| 2) Power production plus occurrence of fault | 2.1 | NTM | $V_{in} < V_{hub} < V_{out}$ | Control system fault or loss of electrical network | U | N |
| | 2.2 | NTM | $V_{in} < V_{hub} < V_{out}$ | Protection system or preceding internal electrical fault | U | A |
| | 2.3 | EOG | $V_{hub} = V_r$±2 m/s and $V_{out}$ | External or internal electrical fault including loss of electrical network | U | A |
| | 2.4 | NTM | $V_{in} < V_{hub} < V_{out}$ | Control, protection, or electrical system faults including loss of electrical network | F | |
| 3) Start up | 3.1 | NWP | $V_{in} < V_{hub} < V_{out}$ | | F | |
| | 3.2 | EOG | $V_{hub} = V_{in}$, $V_r$± 2m/s and $V_{out}$ | | U | N |
| | 3.3 | EDC | $V_{hub} = V_{in}$, $V_r$± 2m/s and $V_{out}$ | | U | N |
| 4) Normal shut down | 4.1 | NWP | $V_{in} < V_{hub} < V_{out}$ | | F | * |
| | 4.2 | EOG | $V_{hub} = V_r$±2 m/s and $V_{out}$ | | U | N |
| 5) Emergency shut down | 5.1 | NTM | $V_{hub} = V_r$±2 m/s and $V_{out}$ | | U | N |
| 6) Parked (standing still or idling) | 6.1 | EWM | 50-year recurrence period | | U | N |
| | 6.2 | EWM | 50-year recurrence period | Loss of electrical network connection | U | A |
| | 6.3 | EWM | 1-year recurrence period | Extreme yaw misalignment | U | N |
| | 6.4 | NTM | $V_{hub} < 0{,}7\ V_{ref}$ | | F | * |
| 7) Parked and fault conditions | 7.1 | EWM | 1-year recurrence period | | U | A |
| 8) Transport, assembly, maintenance and repair | 8.1 | NTM | $V_{maint}$ to be stated by the manufacturer | | U | T |

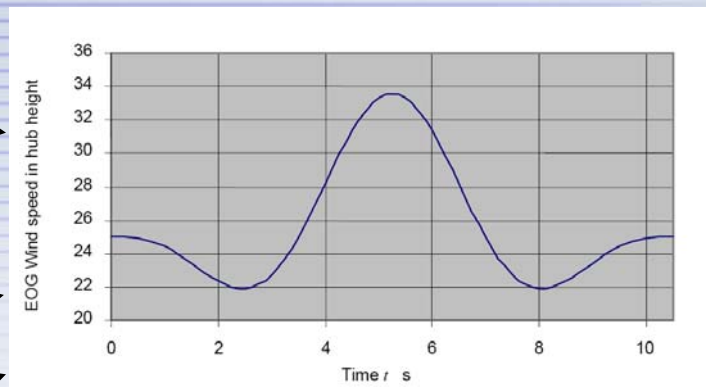


**Figure 2 – Example of extreme operating gust**

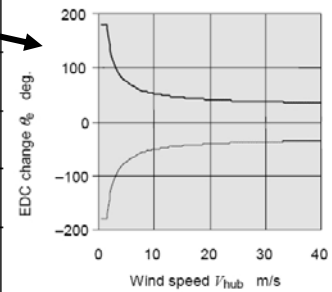


**Figure 3 – Example of extreme direction change magnitude**

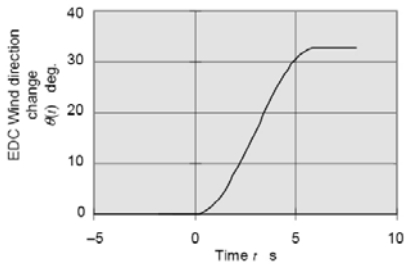


**Figure 4 – Example of extreme direction change**

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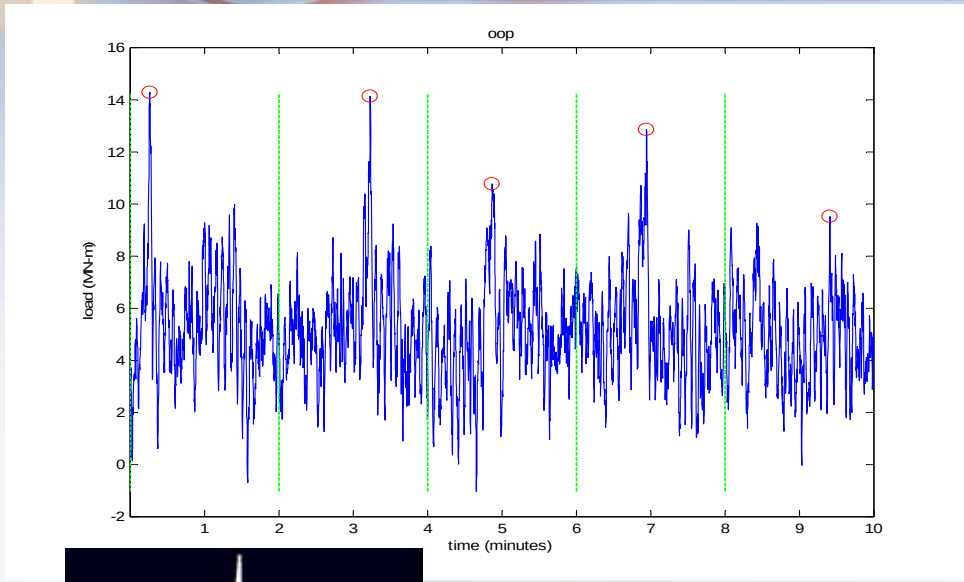
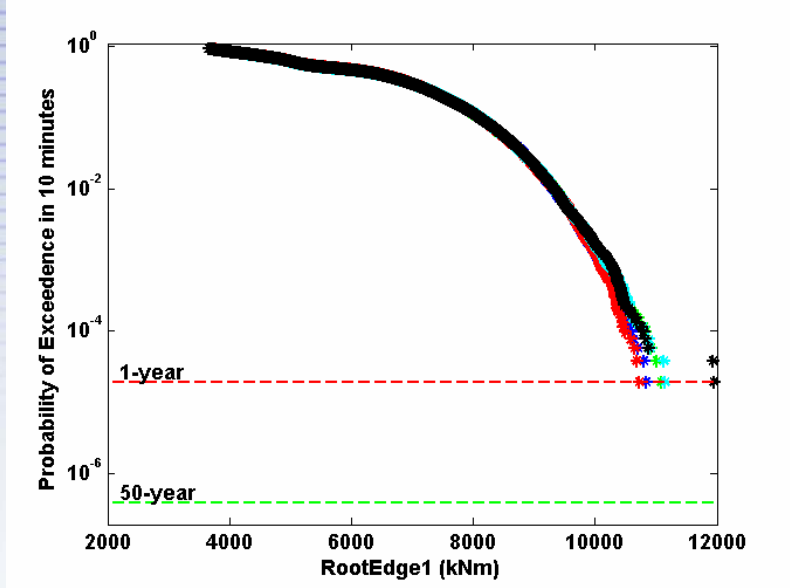
# The new IEC standard requires extrapolation of normal operations to the 50 year extreme



- Simulate wind conditions with standard turbulence characteristics
- Run the aeroelastic model of the turbine structure to calculate loads
- Find the extremes
- Extrapolate to 50 years
- Combine with deterministic load cases

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# Site Assessment

- Take a turbine designed for a standard-generated set of site characteristics and site it in a real location.
  - No sites have exactly the same wind conditions as a Standard Class definition (IA, IIB, etc.)
  - Need to consider turbine wakes, terrain, etc.
  - Attention is most often focused on the energy potential
  - Structural load effects can be just as important for the economics of the project
- Dan Bernadette, the next speaker, will discuss this issue.

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# Certification Standards – Value and Risks

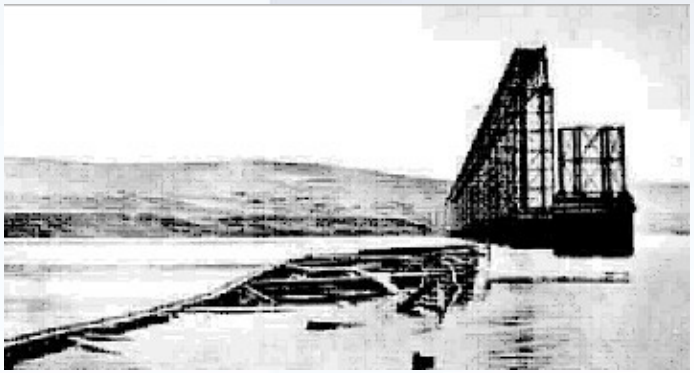
## Value

- Mandatory testing – fewer surprises
- Objective design criteria – standard designs
- Standard products – volume manufacturing
- Consistent specifications - multiple vendors
- Feedback from field performance to design requirements

## Risks

- Changing Scale – criteria no longer applicable
- Changing configurations or controls
- Site assessment inadequate
- Lack of feedback from field
- Lack of communication to component suppliers

**The Tay Bridge Collapse, December 28, 1879**



**Structural design was based solely on experience. No codes had been written for Sir Thomas Bouch (the designer) to follow.** http://filebox.vt.edu/users/aschaeff/tay/tay.html

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