Wind Turbine Testing and Certification

Walt Musial
National Wind Technology Center
National Wind Technology Center
Golden, CO USA

Walter_Musial@nrel.gov

Presentation Outline

- Why test blades?
- Testing methods
- Relevant standards and practices
- Future outlook

Why test blades?

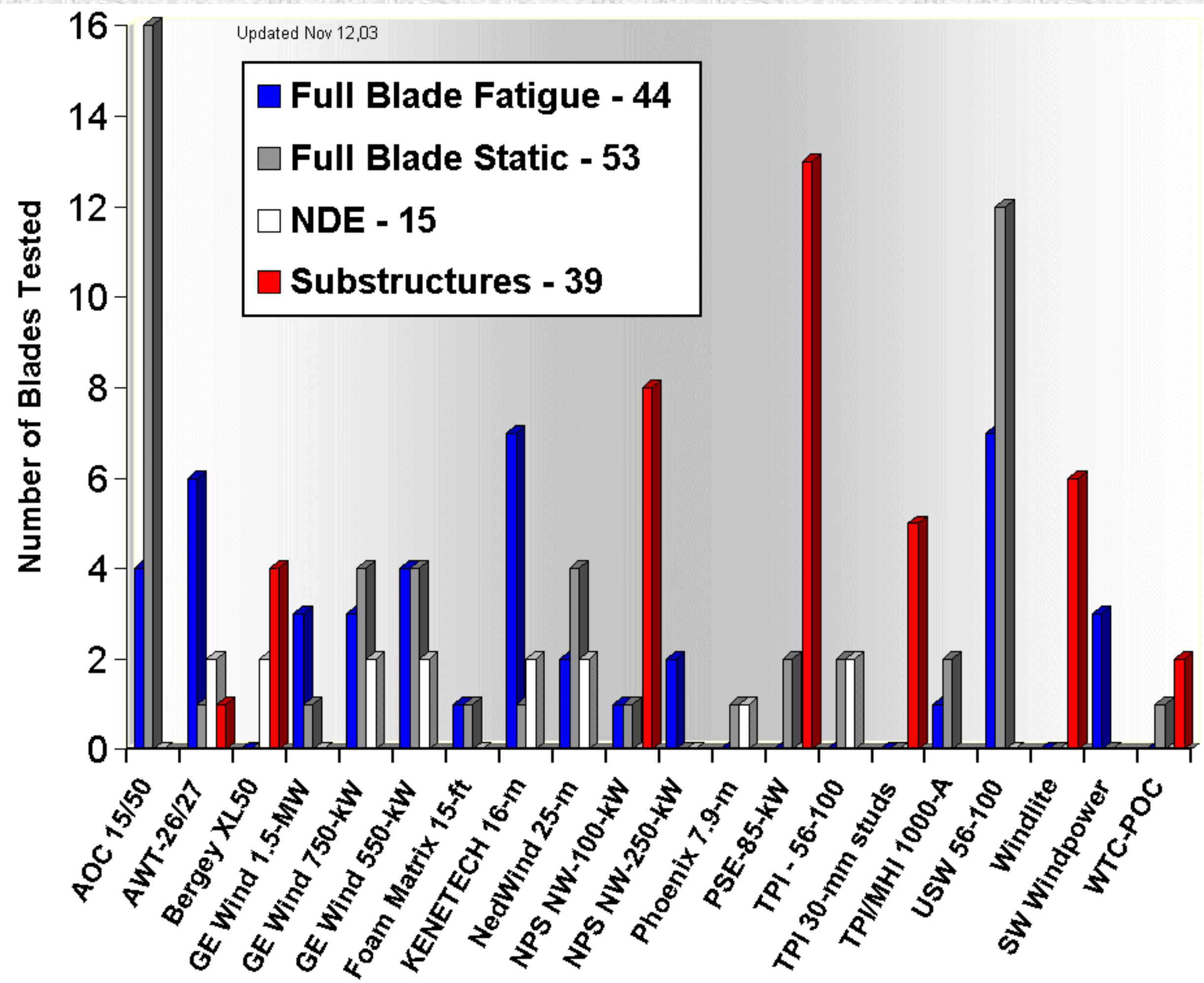
- Blades designs are altered in production.
- Blade strength is dependent on production process and facility, as well as design.
- Blade properties are not known at every location.
- Blade designs cannot be fully represented by design analysis.
- Field repairs are extremely expensive.

What can we learn?

- **Design Verification**
  - Can the blade withstand the design loads?
  - Used in most certification testing.
- **Strength Verification**
  - Does the actual blade strength match the design strength?
  - Used to verify blade structural design.
- **Verify Blade Properties**
  - deflections - maximum requirements for most standards
  - stiffness
  - stress/strain

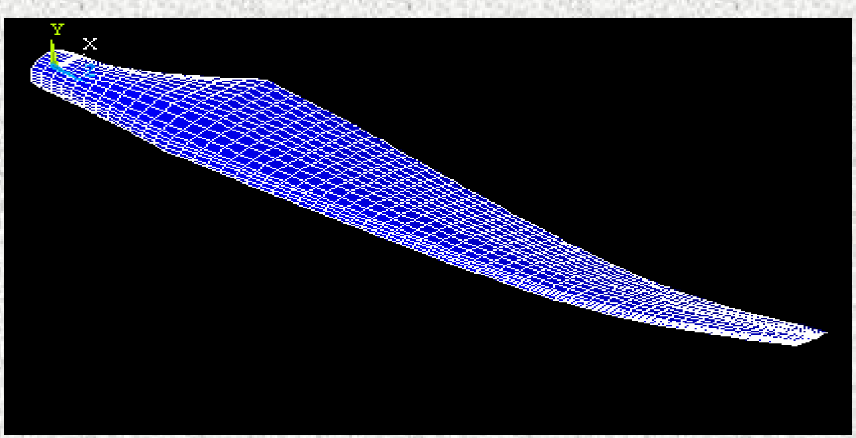
Blade Test Labs

Blades Tested at NREL



- **NREL -** National Wind Technology Center – USA
- **WMC / TU Delft** Netherlands
- **RISO -** National Laboratory – Denmark
- **NaREC –** United Kingdom
- **Private labs --** LM Glasfibers, NEG Micon, MHI, other manufacturers.

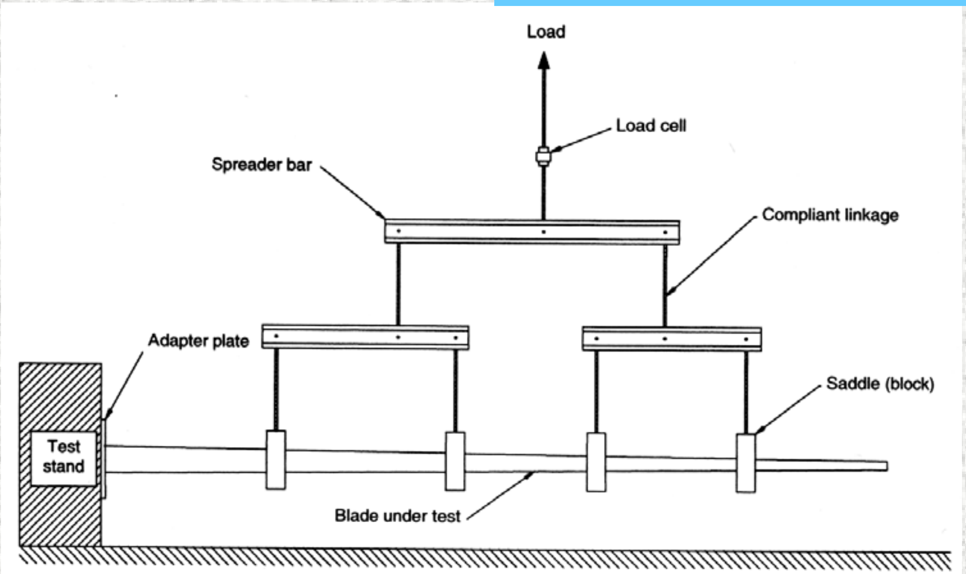
Static Testing



- Tests the blade's ability to withstand extreme design load cases (e.g. 50 year gust)
- Four load quadrants – worst case in each direction.
- Verification of buckling stability
- Loads applied with cranes, actuators, etc.
- Required by all international certification authorities.
- Failure beyond limit load is recommended but not required.
- Property measurements – deflection, strain verification, frequency – performed in conjunction

Types of Static Loading

Distributed Loading

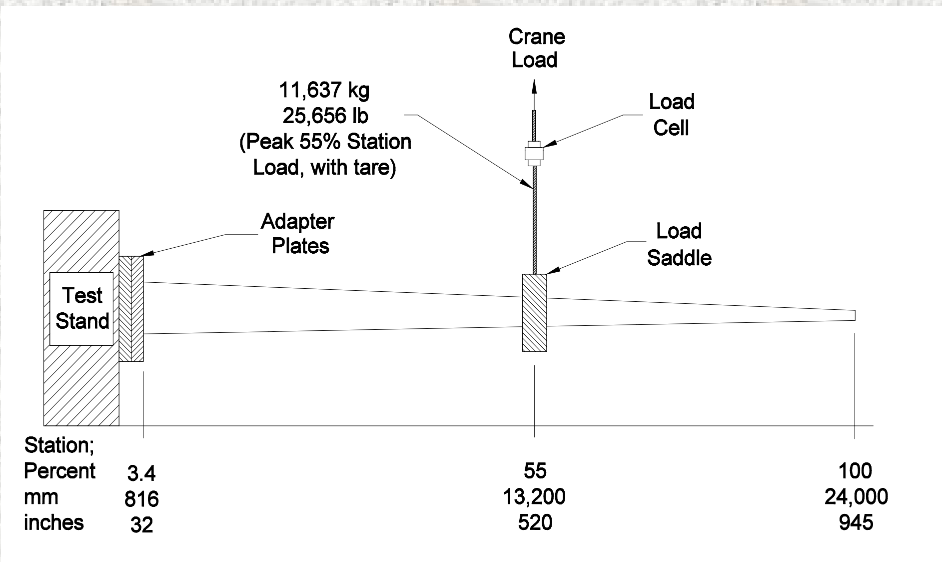


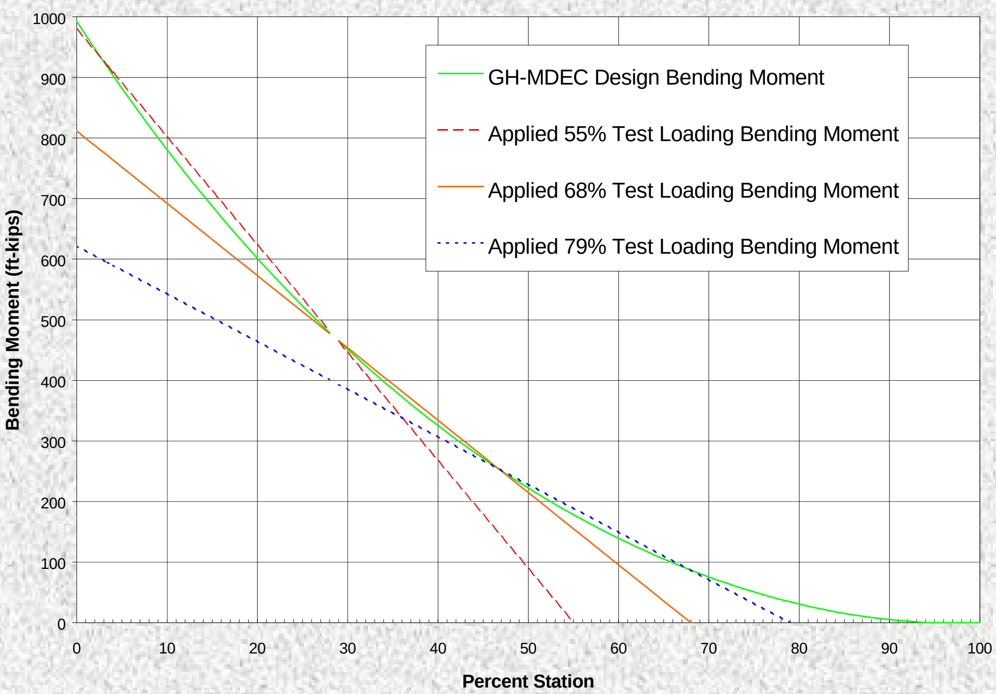
Whiffle Tree

Winches – LM Glasfibers

Hydraulic Actuators - NREL

Types of Static Testing

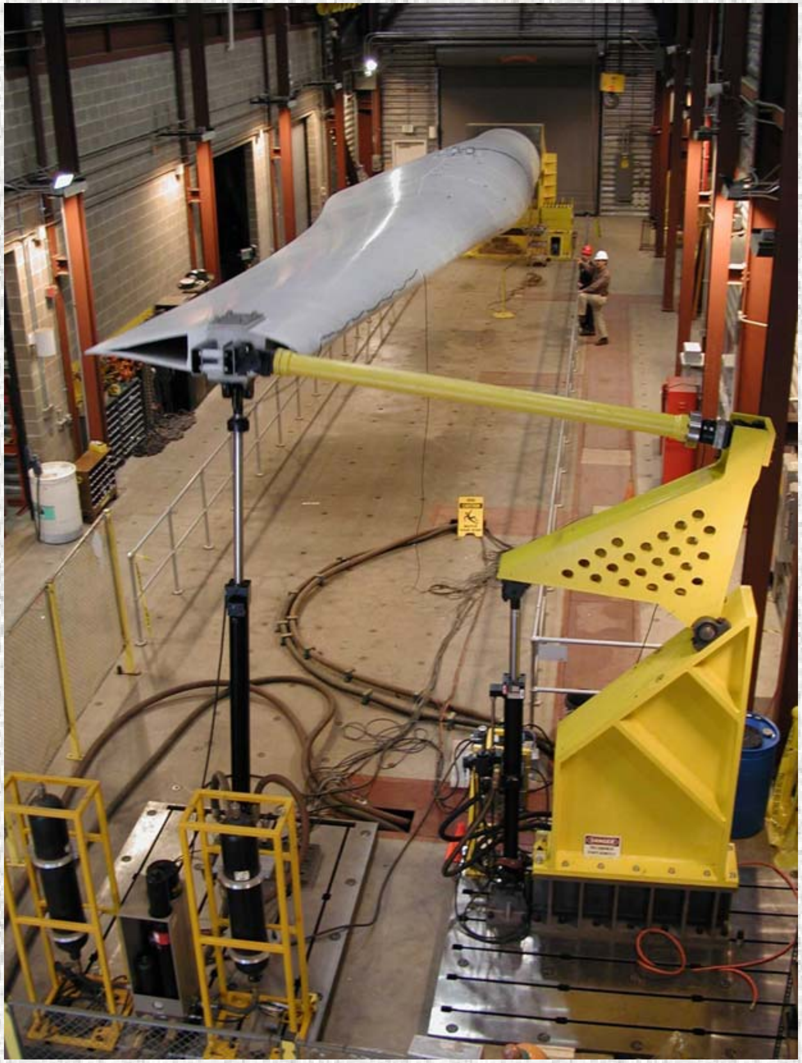




Progressive Loading

- Portions of the blade are tested in multiple tests.
- Test loads can be applied at single station.
- Allows rapid execution of multiple load cases.
- Shear loads are higher.

Fatigue Testing



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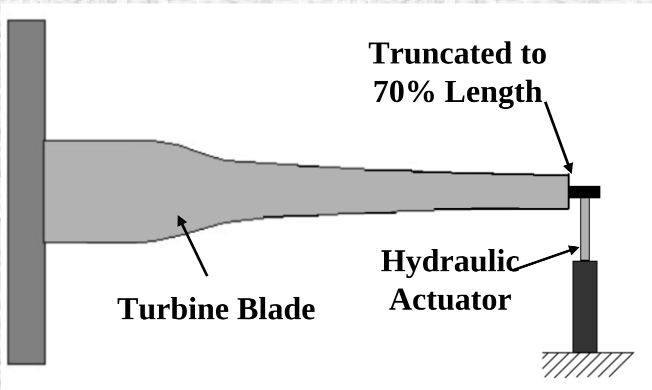
Forced Hydraulic Loading

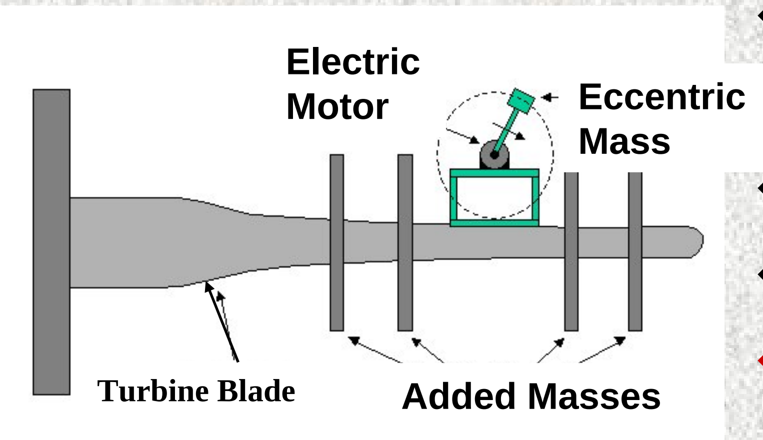
- Verifies the blade's ability to withstand the operating loads for a full design life.
- 30 year life > 5 x 10^8 cycles applied with accelerated load history to 1 to 10 million cycles.
- Required by IEC-61400-23, IEC WT01, Danish Energy Agency
- Load applied on one or two axes.
- Load methods vary among labs.

Blade Fatigue Test Systems



Forced-displacement

- ❖Used at NREL, WMC/TU delft, CRES
- ❖Hydraulic actuators – accurate load replication
- ❖Dual axis capability – representative loading
- ❖High equipment cost
- ❖Large energy consumption
- ❖Lower test speeds - limited by hydraulic capacity
- ❖Cannot test entire blade length

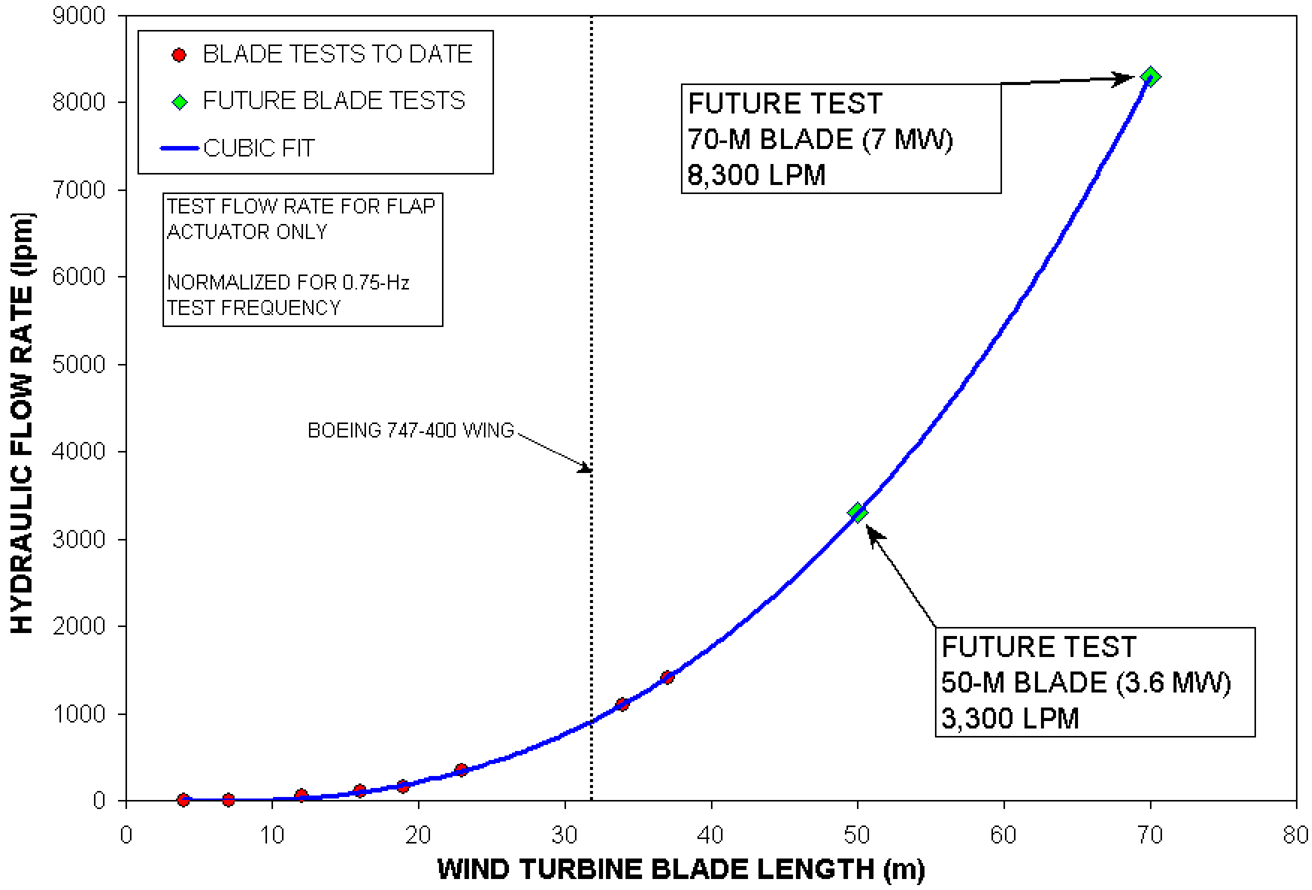


Eccentric Mass Resonance Excitation

- ❖ Denmark – RISO, LM, Vestas, NEG Micon/UK
- ❖Low Equipment Cost
- ❖Fast test speed
- ❖Can test the whole blade span.
- ❖Adds unwanted moments due to axial loads
- ❖Cannot simultaneously apply flap and lead-lag

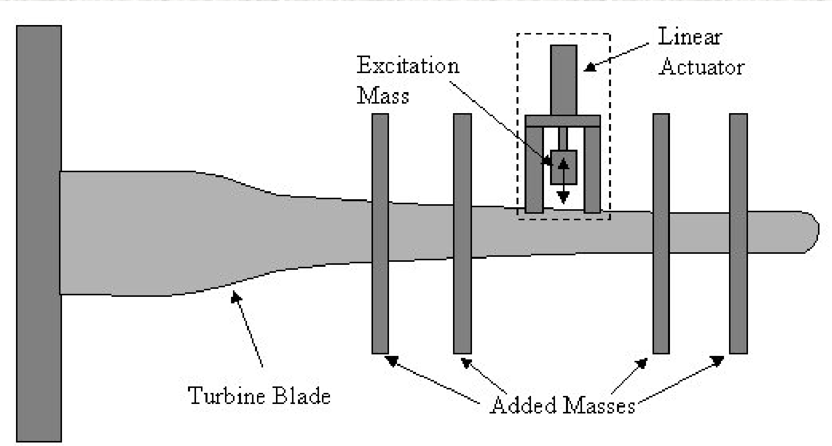
Forced Hydraulic Loading

Scaling to Large Blades



- Blade fatigue resource requirements grow cubically with blade length
- Test speed limitations on Hydraulic Flow and energy use.
- High capital expense to expand test hardware for current method.
- New fatigue method was developed

Implementation of Hybrid Resonance Blade Fatigue Test System



GE Wind 37a Blade Fatigue Test

- Large flap actuator is replaced by a smaller hydraulic exciter.
- Edge actuator uses existing bell crank.
- Uses 1/3 the energy and cycles 2x faster. ***0.35-Hz <<0.70-Hz***
- Tests full-blade length
- Can be scaled up to 70-m blades
- Uses existing equipment and experience at NREL.
- PCT patent application filed

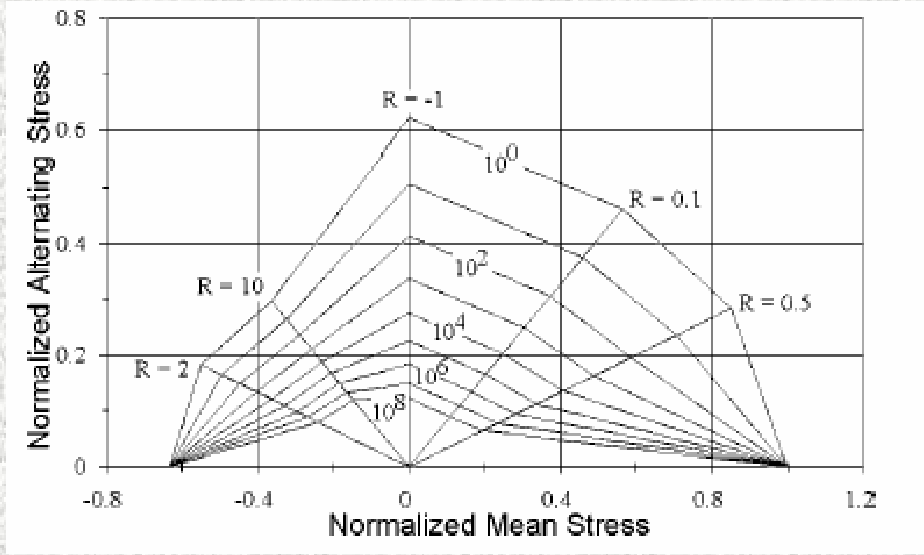
Small Blade Fatigue Test System

H-40 Rotor Blades
South West Windpower

- New testing capability to test small turbine blades
- Single axis fatigue test using resonance excitation.
- Multiple blades tested on a single rotor.
- 3-6 Hz cycling using base excitation.
- Scalable to 3-4 meter blades.

Equivalent Damage Calculation

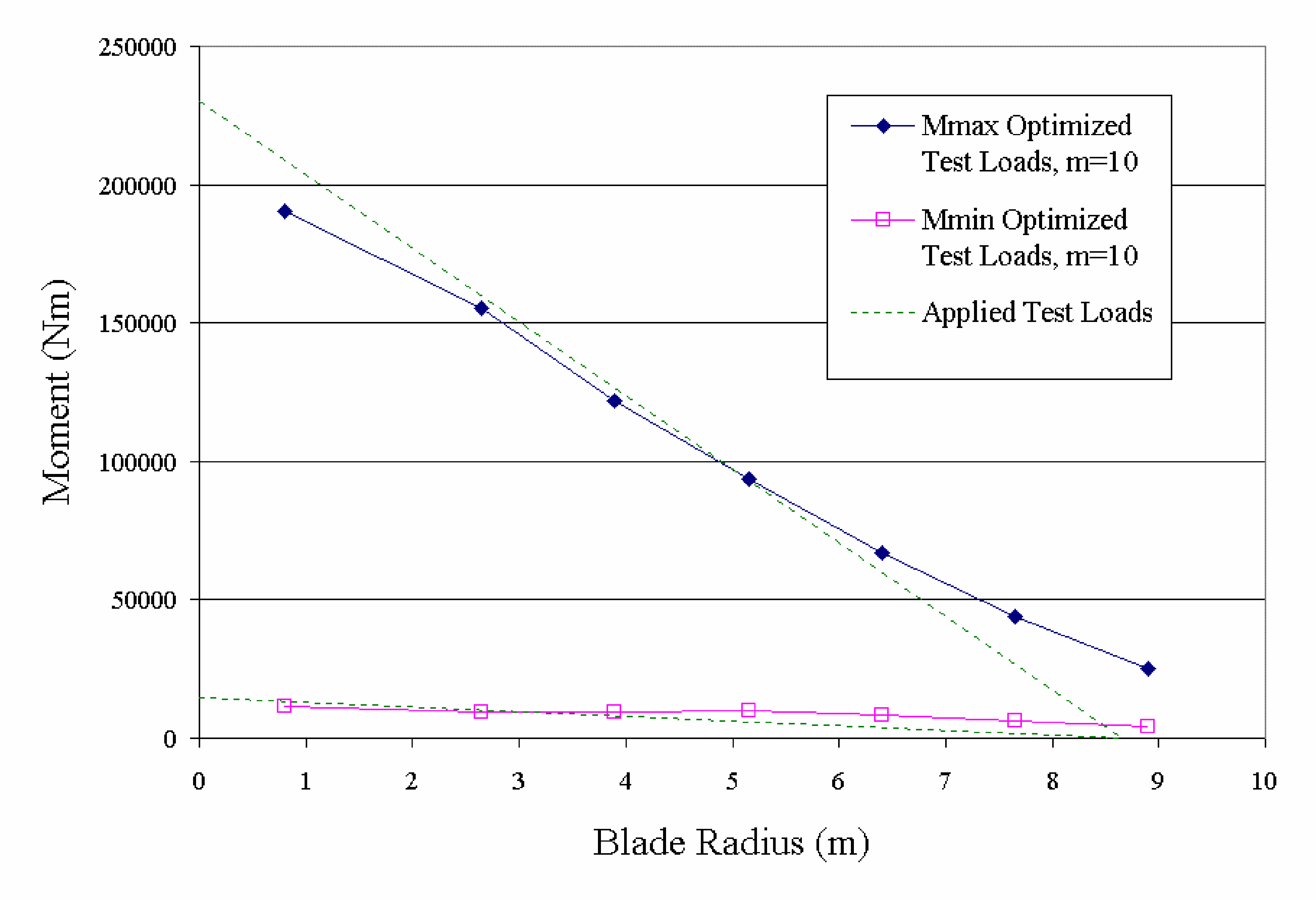
- Blade section properties
- Convert load to stresses
- S-N data for each location
- Goodman diagram
- Miner's rule



Mandell et al, "New Fatigue Data for Wind Turbine Blade Materials" ASME Transactions, Nov 2003

- Determine fatigue load for equivalent damage
  - Load acceleration – Define Number of test cycles
  - Define test load ratio
  - Define phase relationship between flap and lead-lag

Flap Bending Test Loads - Example



Relevant Codes for the Certification of Rotor Blades

IEC WT01 “IEC System for Conformity Testing and Certification of Wind Turbines, Rules and Procedures”

IEC 61400-1 “Wind Turbine Generator Systems – Part 1: Safety Requirements”

IEC 61400-23 “Wind Turbine Generator Systems – Part 23: Full-scale Structural Testing of Rotor Blades”

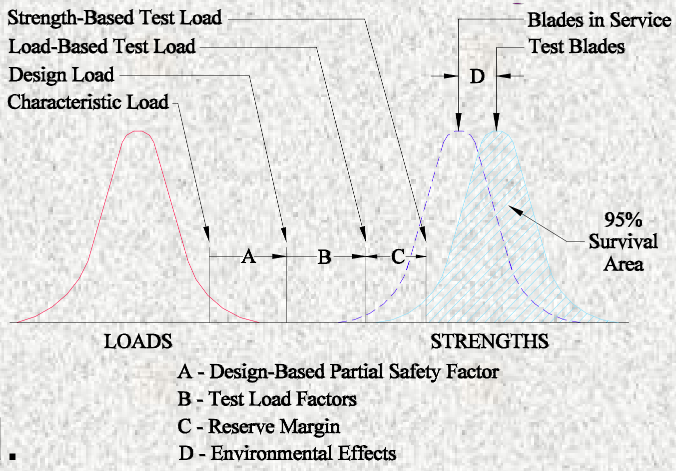
IEC 61400-24 “Wind Turbine Generator Systems – Part 24: Lightning Protection”

Germanischer Lloyd “Regulations for the Certification of Wind Turbines”

Danish Energy Agency DS-472 – Type Approval Scheme for Wind Turbines – Recommendation for Design Documentation and Test of Wind Turbine Blades.

NVN 11400-0 “Wind Turbines - Part 0: Criteria for Type Certification – Technical Criteria”

Application of IEC 61400-23 Design and Test Load Factors



- **Design load factors**
  - Loads provided by manufacturer
  - Understand what factors have been applied.
- **Design Material factors**
  - Material factors are embodied in the blade
  - Not used again for test.
  - Environmental factors must be considered.
- **Test load factors (TLF)**
  - TLFs recommended by IEC 61400-23
  - Account for uncertainty introduced in the lab.

IEC 61400-23 Test Load Factors

- **Blade to Blade Variations**
  - Accounts for possible strength variations-single blade test
  - IEC 61400-23 recommends a factor of 1.1
- **Test Load Uncertainty**
  - Accounts for uncertainty in fatigue formulation
  - IEC 61400-23 recommends a factor of 1.05 on fatigue loads.
- **Environmental**
  - Accounts for more benign laboratory test conditions.
  - No specified level - Properties vary commonly 1.05 to 1.3

Lightning Protection

IEC 61400-24 "Wind Turbine Generator Systems
Part 24: Lightning Protection"

- Rotor blades shall have at least one receptor at each shell.

- More than one receptor recommended for larger blades (blade length greater than 30m)

- Minimum dimensions of down conductors given.

Summary of Full-Scale Blade Test Requirements

- Static test is required in all international standards.
- Fatigue test is required in IEC WT01 and DS 472
- Tests in flapwise direction and in lead-lag direction
- Performed by a recognized testing body or supervised by the certification body
- Blade shall withstand the tests without showing significant damage regarding safety or blade function

[Requirements for the Certification of Rotor Blades – Germanischer Lloyd]

Blade Testing –Future Requirements

DOE/NREL Test Facilities

1989
FIRST BLADE
TEST FACILITY
IN USA

1996
INDUSTRIAL
USER FACILITY
TESTING FOR
BLADES UP TO
37-METERS

1999
DYNAMOMETER
TEST FACILITY
FOR TURBINES
UP TO 2.0-MW

Wind Turbine Size

NO LARGE TURBINE TEST FACILITIES EXIST IN THE USA

2005
2500-kW
45-METER
BLADES

2007
5000-kW
60-METER
BLADES

2010
7000-kW
70-METER
BLADES

Average Commercial Turbine Sizes

1989
100-kW
9-METER
BLADES

1996
500-kW
19-METER
BLADES

1999
750-kW
24-METER
BLADES

2003
1500-kW
37-METER
BLADES

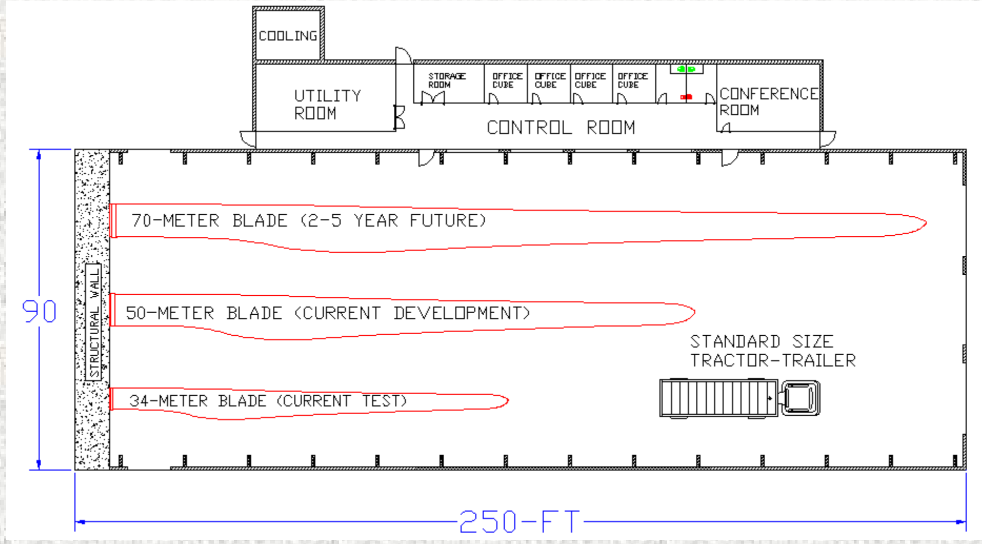
Structural Testing
Future Facilities

Capacity of current facilities at NREL is inadequate

- Stronger test stand foundation is being developed
- Higher strength for 45-m blades – $8x10^6$ ft-lbs
- Greater stroke / larger force capacity for loading apparatus

Long-term – Larger Test Facilities are planned.

- 70- meter capacity
- 3 test bays
- 50,000 kN-m static load capacity



Blade Trends

- Standards compliance increasing.
- Blades are getting longer.
- Offshore drivers – Transportation and erection issues are less important.
- Land-based turbines may not follow trend.
- Facilities are too small for 2MW + blades.
- Current test facilities busy – driven by innovations.