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Facility Capabilities

- **Structures and Materials Testing Laboratory**
  - Full-scale/scaled wind turbine blade testing up to 15 meters
  - New rotor blade designs with cost effective testing capabilities
  - Material selection, evaluation of the structural lay-out
  - New testing methodologies in support of NREL and SANDIA

- **Blade Test Facility**
CECET Blade Testing Facility Capabilities

- A comprehensive full-scale and scaled wind turbine blade testing for wind turbine blades up to 12 meters in length (with potential expansion to 15 meters).

- Support in development of new rotor blade designs with cost effective testing capabilities for sub-component and scaled blades.

- Help manufacturers with the material selection, evaluation of the structural lay-out, and system integration, including sensing and actuators, all very costly when performed on full scale systems.

- Help developing new testing methodologies in support of the U.S. Department of Energy’s National Renewable Energy Laboratory and Sandia National Laboratories.
A wide portfolio of services for Wind Turbine Blade Testing:

- A range of certification testing services
  - IEC 61400-2
  - IEC 61400-23
  - AWEA 9.1
  - MCS 006
  - RUK 2014 (formerly BWEA 2008)

- Rotor blade design validation
- Manufacturing quality verification
- Validation of repairs and design changes
- Rotor blade – hub integration
- Structural integrity static/dynamic uniaxial/combined loads

Additional wind structures services:

- Testing nacelles and towers
- Testing advanced blade sensing and actuators
- Testing of material/structural coupons (*)
- NDT methods developed for rotor blades (*)
- Testing advanced pitch and stall control algorithms (*)

Conducted via Center for Advanced Materials Processing
Blade Structural Testing

Test Layout
Blade Structural Testing

Static Test
Blade Structural Testing

**Applicable Testing Standards**

**International Electrotechnical Commission**
- 61400-2 “Design requirements for small wind turbines”
- 61400-23 “Full-scale structural testing of rotor blades”

**American Wind Energy Association**
- AWEA 9.1 “AWEA Small Wind Turbine Performance and Safety Standard”

**Germanischer Lloyd**
- “Guideline for the Certification of Wind Turbines”

**RenewableUK**
- “RenewableUK Small Wind Turbine Standard”

**The Microgeneration Certification Scheme**
- MCS 006
Blade Testing: Testing

Blade Testing (static, fatigue, and modal)

Safety Features
• Load Abort system
• Load Limiting Manifold
• Redundant interlocks
• Separate hydraulics per station
Test Instrumentation

MTS FlexTest System

- Controls and automates virtually any material, component, or structural test.
- High-speed closed-loop control
- Advanced function generation for precise control
- High resolution data acquisition for a full range of testing needs
- Precise and versatile signal conditioning
- Supports component and material testing, aerospace structural testing, and ground vehicle performance simulation
- Wide range of actuators, load cells, position sensors, and strain sensors for virtually any testing application
Test Instrumentation

LMS Test System

- Compact, mobile data acquisition platform with versatile signal conditioning and data acquisition capabilities
- LMS Test.Lab software optimized for a wide range of vibration, noise, and durability applications.
- Multiple control output channels allows for a dedicated modular frontend for vibration control applications
Modal Analysis: Modal Analysis performed to evaluate the resonant frequencies and mode shapes of the blade in edgewise, flapwise and torsional direction.

Static Testing: Static Testing performed for all required loading directions to evaluate blade deflection and strains measured at predetermined locations (flapwise, lead-lag, torsion).

Resonance Fatigue Testing: Resonance Fatigue Testing is performed (outside the scope of small wind turbine testing, but of interest for 12 m and larger blades) using an exciter saddle with linear masses mounted to the rotor blade. The dynamic load distribution and amplitude are adjusted to represent 20 years of cyclic field loads.

Bi-axial Dynamic Fatigue Test: Fatigue Test is completed simultaneously for edgewise and flapwise direction using a bi-axial test frame.

Ultimate Load Testing: Ultimate Testing is performed by quasi-statically loading the blade until ultimate failure for blade lengths up to 12 m.
Blade Testing: Static Test pull (8X)
Blade Testing: Fatigue Testing
Blade Testing: Results

Test results
Test data
Data analysis
Reporting
Failure criteria
Blade Testing: Results

![Nondimensional Blade Strain Stiffness, Spar Caps](image1)

![Spar Cap Strain Guages Strain to Moment Relation](image2)

![Flat Back Strains perpendicular to blade axis at 1.575 m](image3)

![Nondimensional Blade Strain Stiffness, Blade Root](image4)
CECET Blade Testing Services

- **CeCeT BTF Composite Fabrication Facility**
  - Composite coupon and other specimen preparation
  - Assist companies in components and structures preparation
  - Rotor blades components preparation
  - Assist with fabrication process selection

- **CeCeT BTF Component Tests Facility**
  - Turbine sub-components concepts and procedure for testing development
  - Static and dynamic sub-components and coupon testing, ASTM standard testing
  - Sub-components testing under extreme environmental conditions
  - Assistance with reliability and life assessment predictions of blade and sub-component
Clarkson University Wind Tunnel

Clarkson University Subsonic Tunnel # 1
80 m/s subsonic tunnel outfitted for aerodynamic testing with a 6 component force balance, several position control systems, particle image velocimetry (PIV), laser doppler velocimetry (LDV) and flow visualization. Suitable for aerodynamic testing, scale and small wind turbine testing.

Clarkson University Subsonic Tunnel # 2
12 m/s subsonic tunnel with high inlet air quality, established through 228 sq. ft. of HEPA filter. Suitable for aerosols testing and environmental / low speed wind testing.
Visualization systems (PIV, PDPA, high speed camera)

**Particle Image Velocimetry (PIV):** Used for non-intrusive laser optical measurement. Measurement data include velocity, concentration, temperature, combustion species and particle size.

**Phase Doppler Particle Analyzer/Laser Doppler Velocimetry (PDPA/LDV):** Pre-configured three-component (3D) PDPA/LDV system is used to get all three components of velocity simultaneously.

**High Speed Camera:** 5,000-100,000 frames per second used to capture images of rapidly moving objects or interfaces.
CECET Blade Testing Services

- **CeCeT BTF Materials Development Facility**
  - Assist companies with materials selection for wind turbine rotor blades
  - Experimental studies on material behavior in CAMP facilities
  - Determination of the aging properties of materials in CAMP facilities
  - Life assessment and strength of materials under extreme environmental conditions

- **CeCeT BTF Material Testing Facility**
  - Static loads and cyclic loads testing, ASTM standard testing
  - Metal, fiber composite and other materials testing
  - Modeling and simulation capabilities of material
  - Evaluation of material response and degradation due to environmental conditions
Reaction frame can accommodate test specimens in an 14 m long, 8 meter wide, and 5 m tall test volume.

Reaction frame floor and walls are outfitted with anchorages that are positioned in a 1.2 m uniform grid.

5 ton overhead crane.

Testing equipment includes a range of hydraulic actuators, 60GPM Instron hydraulic power supply, servo controllers, a modular structural steel testing frame, two axial load testing frames, an axial-torsion combined loading frame, state-of-the-art high-speed control and data acquisition systems.

Folding safety partitions (blast walls) protect technicians from injury during destructive testing and to protect IP from observation during closed-door testing.
Blade Test Design – Strain Gauge Instrumentation
## Blade Test Design – FEA Test Predictions

<table>
<thead>
<tr>
<th>Saddle location (m)</th>
<th>Neutral axis of deformed blade at 100% load</th>
<th>Actual turning block location (effective)</th>
<th>Angle Error</th>
<th>Max load chain length (m)</th>
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</thead>
<tbody>
<tr>
<td>Z(m)</td>
<td>Zg(m) Yg(m) Xg(m) Angle(°)</td>
<td>Zg(m) Yg(m) Xg(m) Xg-Zg (°) Yg-Zg(°)</td>
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<table>
<thead>
<tr>
<th>Saddle</th>
<th>Location (m)</th>
<th>Preload (kN)</th>
<th>25% Load (kN)</th>
<th>50% Load (kN)</th>
<th>100% Load (kN)</th>
<th>Deflection 25% (mm)</th>
<th>Deflection 50% (mm)</th>
<th>Deflection 100% (mm)</th>
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<td>163</td>
<td>327</td>
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</table>
The BTF supports industry participation & continuing education through Distance Learning and Workforce Development Program.
Additional Testing Capabilities

- **Micro- and nano-scale testing capabilities**
  - Nanoindentation
    - Protective Coatings
    - Nanomechanical testing of thin films for integrated Circuits
    - Thin films for composites, disks, and passivation layers
  - Scanning Tunneling Electron Microscopy
  - Atomic Force Microscopy
    - Used to study NanoMechanics
    - Nondestructive measurement of specimens down to molecular size
    - Capable of viscoelastic characterization
  - Hardness and Microhardness
    - Rockwell, Knoop, and Vickers hardness
    - Leco Microhardness Tester
  - Dynamic Mechanical Analyzer
    - Characterize Polymer and composites viscoelastic properties
    - Thin film / single fiber tensile testing
  - Thermo Mechanical Analyzer
    - Characterize material dimensional responses to time, temperature, or force
    - Measures coefficient of thermal expansion, heat distortion temperature, stress/strain ramps, creep, stress relaxation
    - Suitable for dynamic thermomechanical analysis and modulated thermomechanical analysis
Additional Testing Capabilities

Macro-scale mechanical testing capabilities
- Hardness
- Wear resistance facility
- Creep related facility and Environmental chamber
- Fouling and corrosion accelerated testing facilities
- Wabash Hydraulic Heated Platen Press
  - Composite Molding
  - Ceramic Molding
- High temperature Mechanical Testing System
- Spin Coater for thin film processing
- Multi-gravity research welding system
- Oven and Laboratory hoods
- Advanced Welding and Welding Metallurgy facility
- Mechatronics Lab and prototyping shop
- Research Machine Shop
- Vibration and Control Systems Testing facility
Additional Testing Capabilities

**Wear Resistance Facility**

Pin on Disk Configuration for Measuring Wear Coefficient
Additional Testing Capabilities

Creep Related Facility and Environmental Chambers

- Electromechanical load frames
- Bending creep test machine
- Coefficient of thermal expansion testing of long gage-length specimens
- Load frame temperature chambers
Additional Testing Capabilities

Fouling and Corrosion Accelerated Testing Facilities

G300 Gamry® Potentiostat
- Corrosion Measurements
- Battery testing
- Sensor development
- Physical electrochemistry

Deposit Accumulation Testing System (DATS)
- microprocessor based data acquisition system
- designed to control, monitor and record all parameters necessary to perform heat transfer analysis.

Polishing Machines

Clarkson University

Defy Convention
Additional Testing Capabilities

Mechatronics Lab and Prototyping Facility

VICON MX+ Motion Capture and Kinetic Gait Analysis System
Additional Testing Capabilities

Research Machine Shop Fabrication Capabilities

- Standard and CNC milling machines
- Standard and CNC lathes
- Rapid Prototyping
  - Stereolithography
  - 3D Printing (Makerbot)

Stereolithography
http://www.clarkson.edu/rapidprototype/docs/Stereolithography_Pres.ppt
Clarkson is using a Viper Si2 ® SLA system with epoxy resin
Computational Capabilities

Site license for ANSYS ver. 14 (workbench, multiphysics, structural mechanics, fluid dynamics, (FLUENT, CFX, GAMBIT, ICEM-CFD, TGRID)), NASA CFD codes (such as CFL3D, and TetrUSS), HYPERMESH, PATRAN-NASTRAN, ABAQUS, COMSOL, UG-NX, iSIGHT, a number of CAD packages (SOLIDWORKS, SOLIDEDGE, PRO-E, AUTOCAD, Autodesk Inventor, etc) MATLAB, MAPLE, MATHEMATICA, TECPLOT, etc.

**CARES Cluster**: IBM Blade Center Cluster with 28 dual core 2.8 GHz Intel Xeons and 14 quad core 3.0 GHz Xeon processors coupled with Myrinet networking.

**A³L Computing Facility**: 6 quad core 3.0 GHz Xeon processor, 64 Gb RAM, 2 1TB hard drive, 2 quad core 3.0 GHz Xeon processor, 16 Gb RAM, 2 1TB hard drive.

**BTF Compute Server**: 12 core (2 processor) 3.4 GHz Xeon Server, 48 GB RAM, with separate 6 TB (expandable) RAID file server running ZFS.
Computational Capabilities

**MAE Advanced Computational Laboratory**

**Hardware**
- 5 4 processor 3.0 GHz Xeon processor, 64 Gb RAM, 2 1TB hard drive

**Software**
- FLUENT, CFX, GAMBIT, ICEM-CFD, TGRID),
- HYPERMESH, PATRAN-NASTRAN, ABAQUS,
- COMSOL, UG-NX, iSIGHT, a number of CAD packages (SOLIDWORKS, SOLIDEDGE, PRO-E, AUTOCAD, etc)
- MATLAB, MAPLE, MATHEMATICA, TECPLLOT, etc.
Current staff includes 4 core faculty, a dedicated facility manager, three graduate students, two undergraduate students, and three external consultants.