

# IOWA STATE UNIVERSITY

Center for Nondestructive Evaluation

**ASA meeting – July 2017 Golden, CO.**

**Quality, reliability, safety and economics: the role of nondestructive evaluation (NDE) for energy systems in creation care and sustainability**

Leonard J. Bond

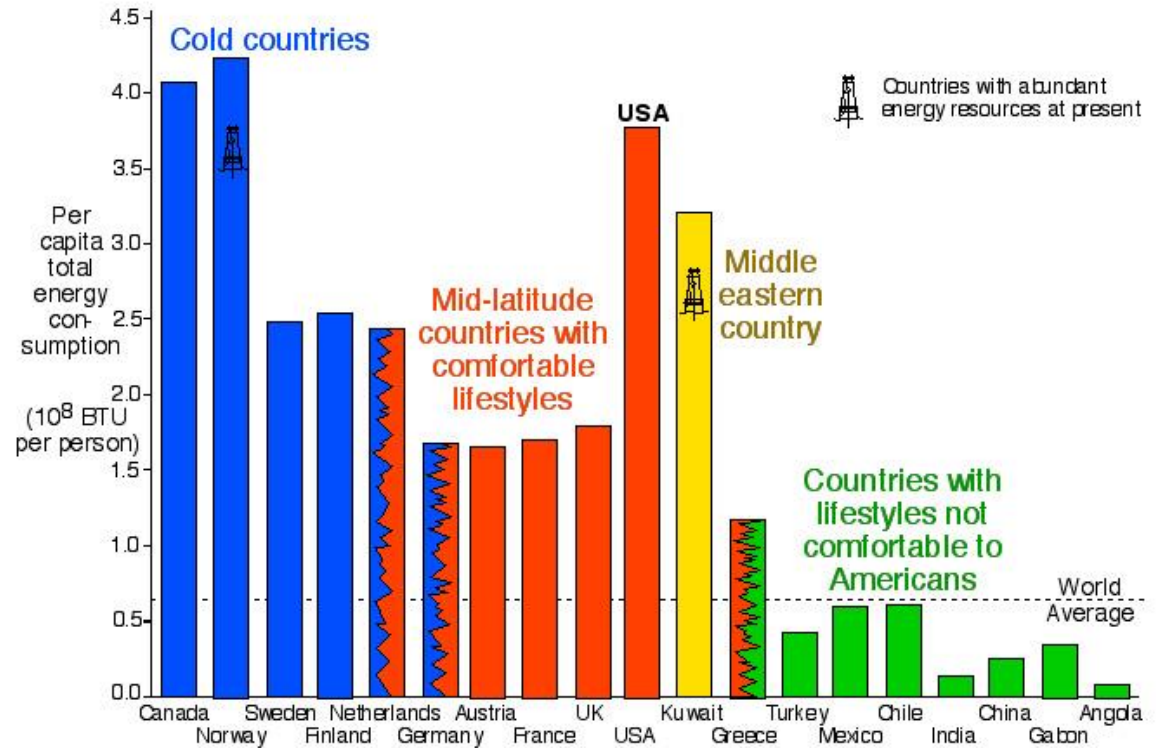


# World energy consumption\*

The lifestyle in the developed world depends on energy.

## SOME ISSUES

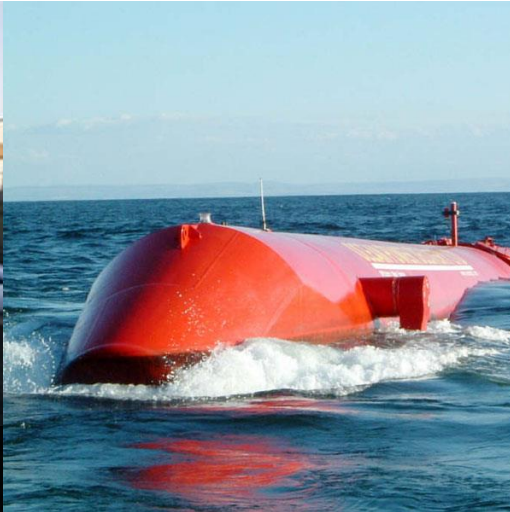
- Sustainable development
- Greenhouse gas emissions



LBR 11/04/2001

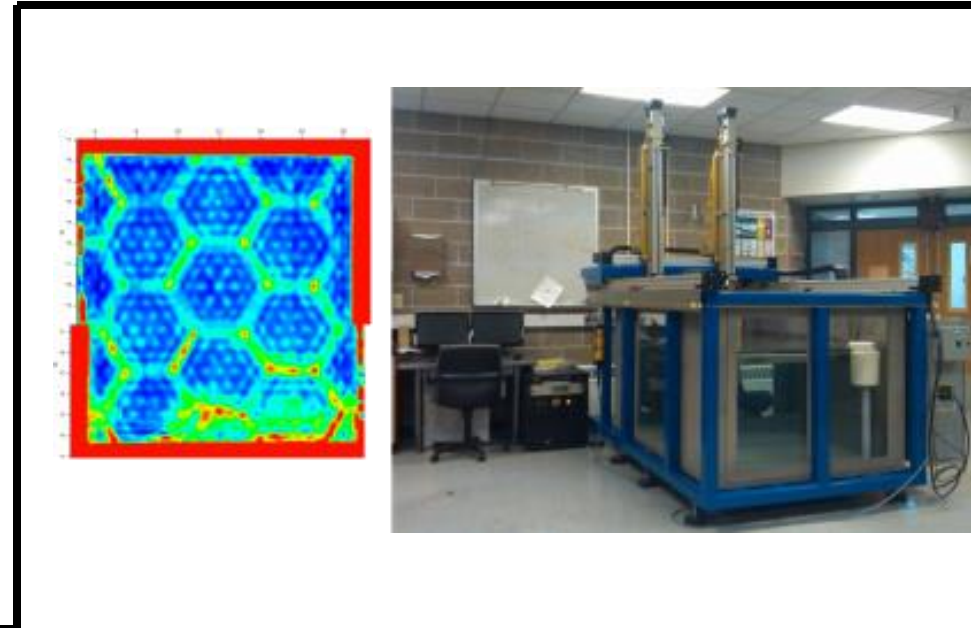
\*Pickens Plan

# Some examples of energy systems



# What is nondestructive evaluation (NDE)?

Medical NDE - ultrasound on people



Engineering NDE - ultrasonic, radiographic, thermographic, electromagnetic, and optic methods to probe interior microstructure and characterize subsurface features. Goal is to ensure initial quality, reliability in service and retire items before failure occurs.

# Trends in “traditional NDT/NDE”

- **Present:** hand held + C-scan and XYZ
- **Tomorrow:** Robotic
- **Future:** SHM with embedded, continuous and real time data evaluation

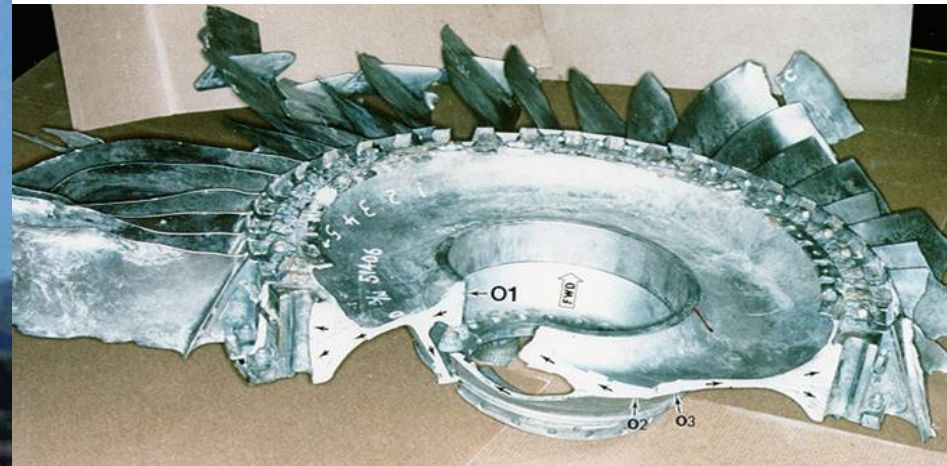


Guwahati, Assam, India

Attributed to Dick Bossie (2012?)

# Sioux City, Iowa, July 19, 1989 : United Airlines Flight 232

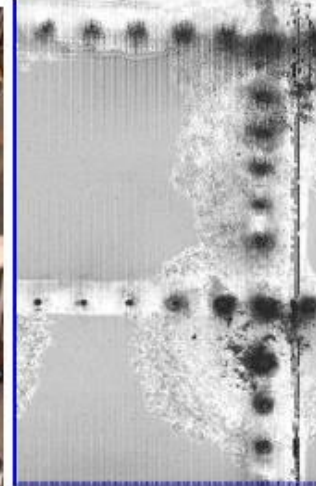
A defect that went undetected in an engine disk was responsible for the crash.



# Aging Aircraft.....



Aloha Airlines Flight 243  
Near Maui 1988

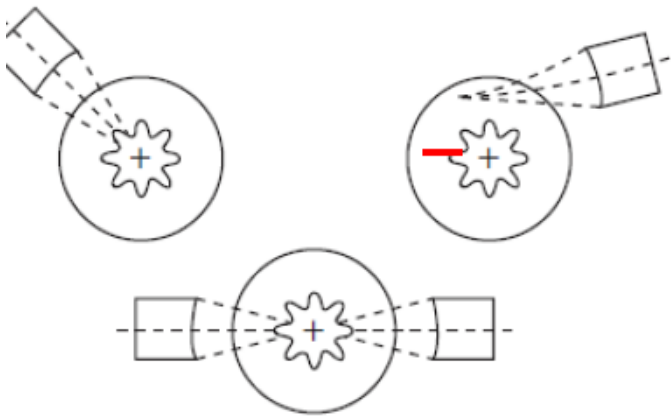


- Dripless Bubbler enabled high resolution water coupled ultrasonic scan in the field.
- Instrument was patented, commercialized, and awarded an R&D100 Award (1996)

# Early Rocket Motor Failures (Hydra)



<https://www.shephardmedia.com/news/rotorhub/general-dynamics-wins-us-army-hydra-70-rocket-cont/>



- Manufacturing & stockpile issue – failure when fired.
  - Ultrasonic replaced X-ray which had been found to be ineffective
  - Screening of the US national stockpile increased safety
- About \$2B in savings to the US DOD (Cost Savings Award)
- Implement at the Radford Army Ammunition on new motors.

# Life Cycle Management

--- effective NDE now critical

- Retirement for Cause was projected to result in life cycle *cost savings* in excess of \$1 billion (1987) using the *F100* Life Cycle Cost Model.

## Detection Importance

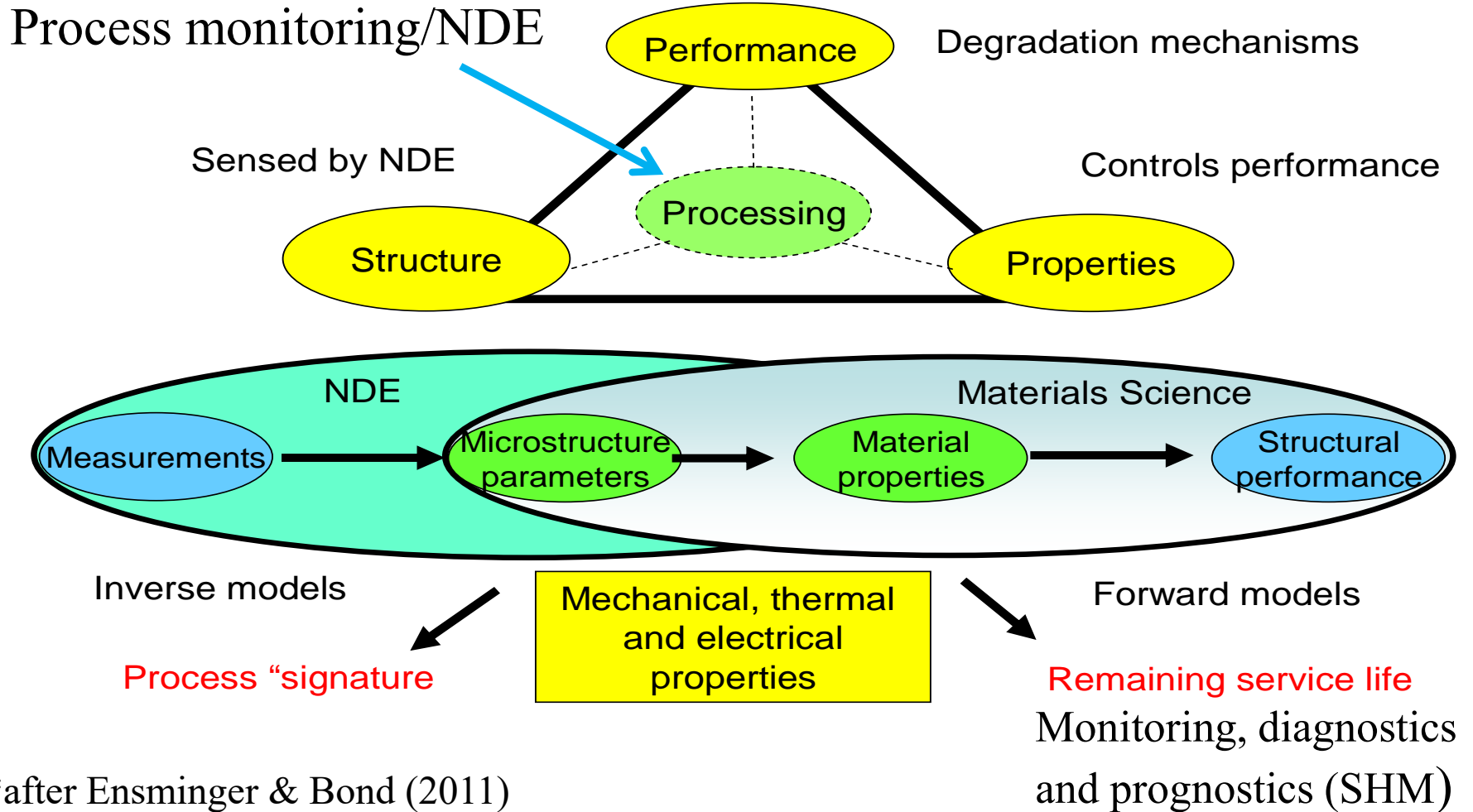
Not smallest  
flaw ever

Detected

But largest  
flaw ever

Missed

# NDE and Materials Science\*



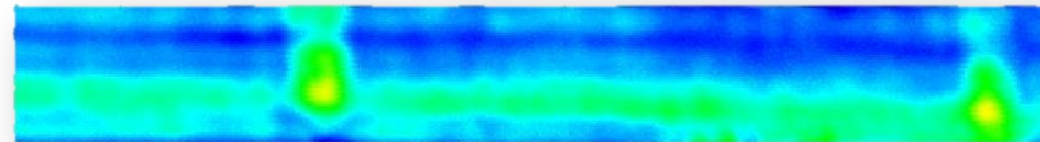
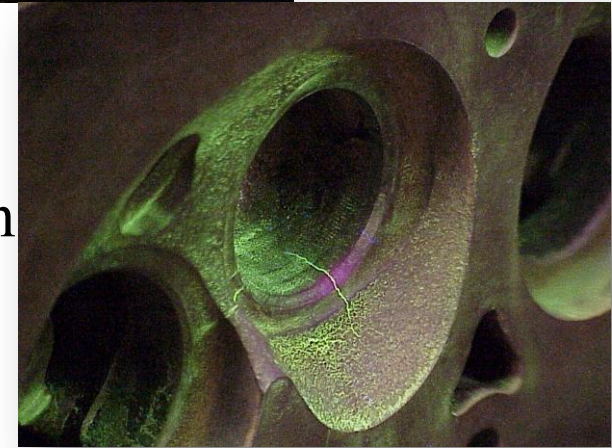
\*after Ensminger & Bond (2011)

# Motivation for NDE and Structural Health Monitoring

- Local damage detection – NDT widely used
- NDE methods have difficulty when large areas or lengths need inspection and limited access
- More global damage, quantifiable and automated methods needed



Penetrant inspection



Ultrasound – c-scan -composite

# NDE – SHM and the Motivation for Prognostics

- Increase in need for life extension and maintain legacy systems
- Periodic NDE methods challenged by aging systems – **frequency of inspection and inspection technology need to be reviewed in light of known (and unknown) degradation mechanisms**
- Condition-based maintenance (CBM) philosophies, on-line monitoring and diagnostics can reduce operation and maintenance (O&M) costs



Petrobras 36 (2001)



San Bruno (2010)

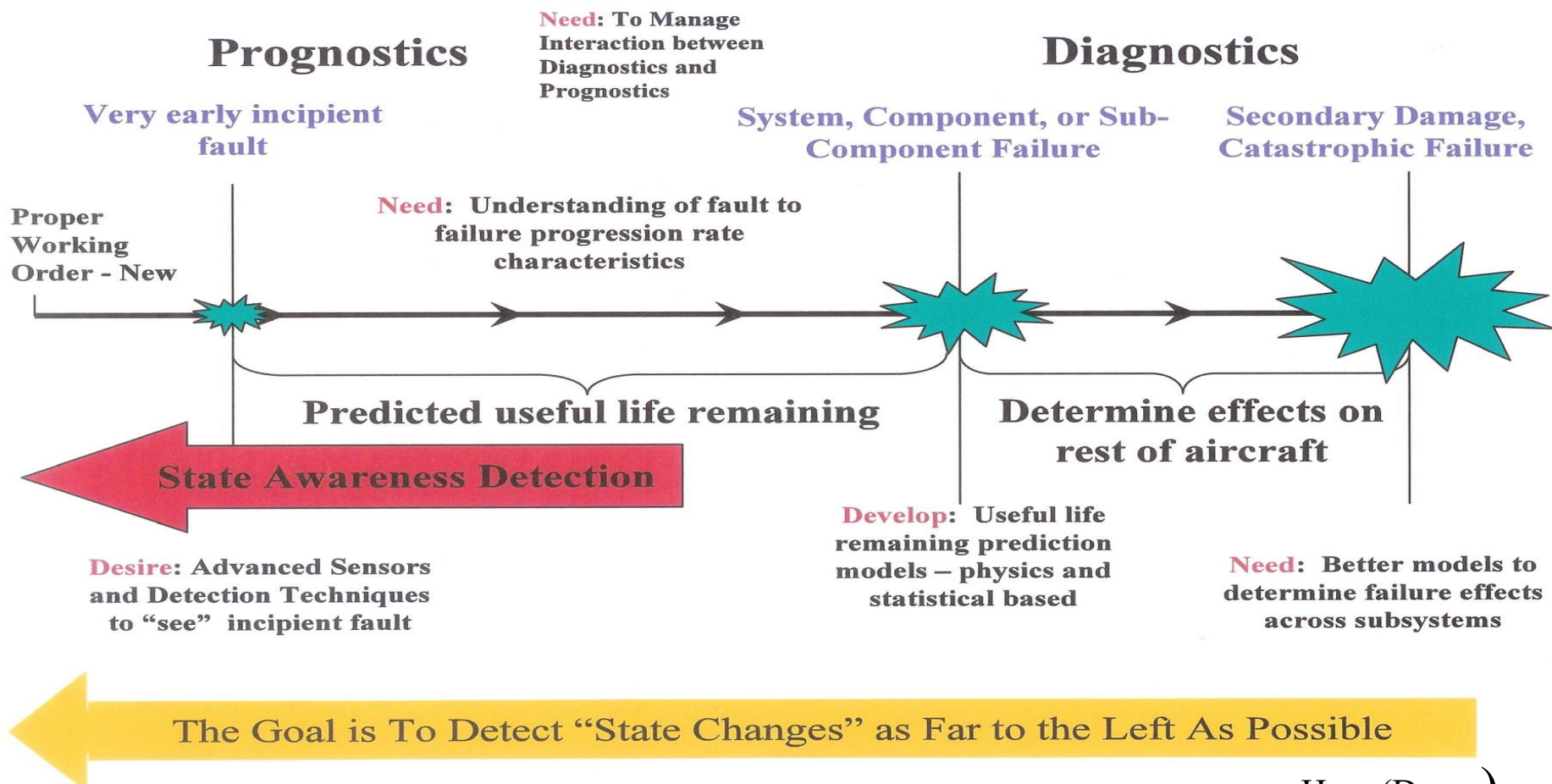
# Structural Health Monitoring (SHM)



Indian River Inlet Bridge, Structural Health Monitoring System, Univ. Delaware (2012)

Goal is to proactively address potential future degradation in operating plants to avoid failures and to maintain integrity, operability and safety

## Failure Progression Timeline



Hess (Darpa)

# Some common components & issues

- Pipes
- Pressure vessels
- Some issues
  - Cracks
  - Corrosion, erosion, thermal and load cycling
- Composite materials (e.g wind blades)
- Steel
- Concrete
- Semi-conductors (photovoltaics)

# NDT & NEW ENERGY

Under the new energy economy the Nation (USA) is faced with an enormous task if it is to make the least painful transition from its current energy sources (chiefly coal, petroleum and natural gas) to ones more abundant, and ultimately to those that are inexhaustible. This transition will require an unprecedentedly large and rapid shift to different, if not new, technologies. **In this transition, the role of nondestructive evaluation (NDE) is certainly clear to its practitioners, but unappreciated or ignored by almost everyone else. It will not be possible to rely on accumulated wisdom to predict the safety, reliability and predicted lifetime of the new components that must be developed.** Yet such knowledge (*or lack*) can have a major effect on the cost of the new energy systems as they are deployed industrially.

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Yet such knowledge (*or lack*) can have a major effect on the cost of the new energy systems as they are deployed industrially.

James Kane **(1978)**. Associate Director, DOE - Basic Energy Sciences – at a DARPA/AF meeting (La Jolla)

# State-of-the-art - monitoring

- Nacelle Monitoring
  - Displacement Monitoring
  - Temperature Monitoring
  - Vibration Sensors
  - Accelerometers



Ludeca, Inc

The green arrows indicate sensor (accelerometer) locations for standard wind turbines.

# Wind turbines: Inspection



UK Daily Mail (2014)  
Windaction (2010) La Salle, IL

Rope access  
technicians

Blade access  
platforms

Telescope and  
camera

- Inspect for damages  
and leading edge  
erosion
- 3-4 turbines per day
- Thermography
- Ultrasound



Performance Composites

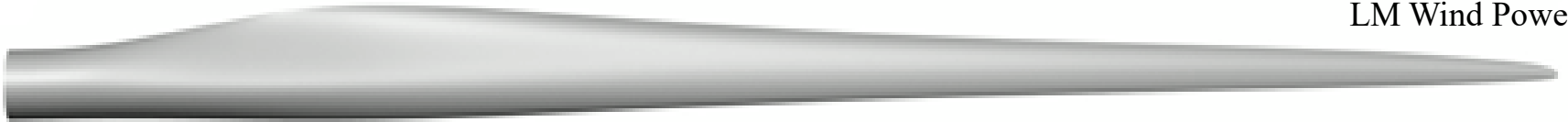


Performance Composites

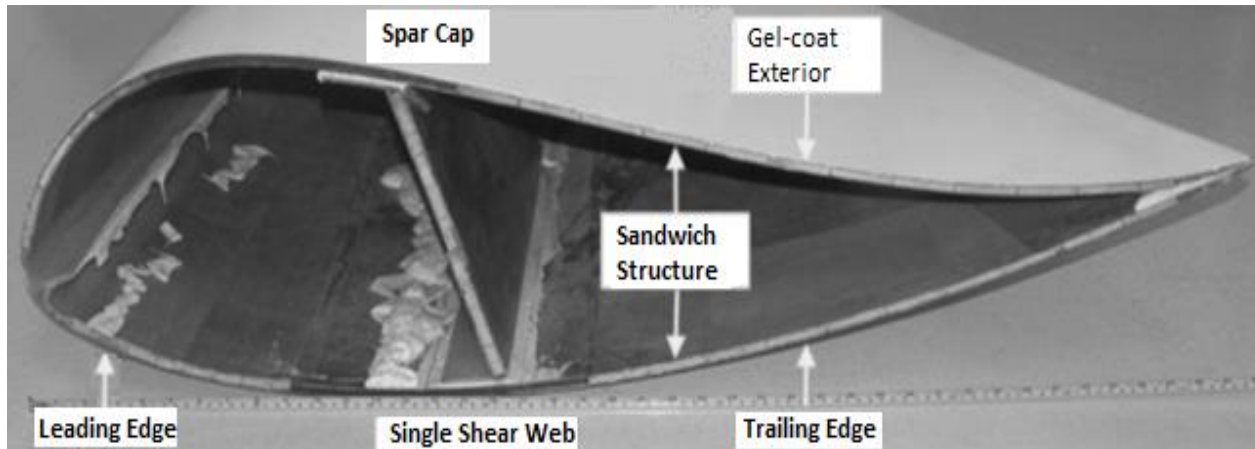
# Example of Wind Turbine Blade

Typical wind turbine blade shape – 47.5m average length

LM Wind Power



Cross-section of Sandia CX-100 9m blade



Primary Materials

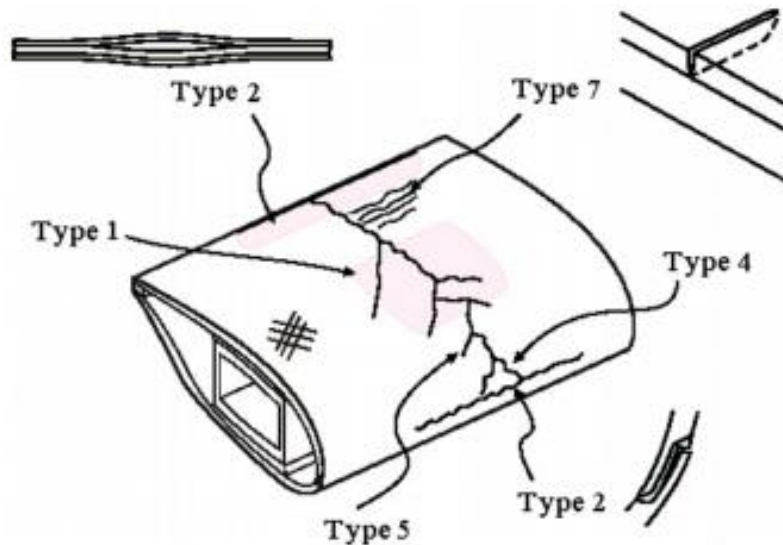
- Glass Fiber Reinforced Polymer
- Balsa Wood
- Epoxy Paste

# Examples of blade structure



(a) the sandwich structure leading up to the trailing edge and (b) the complete GFRP spar cap connected to wooden shear webs, which are 5 cm thick.

# Blade Damage



<u>Type</u>	<u>Damage</u>
Type 1	Adhesive debonding between spar cap and shear webs
Type 2	Adhesive debonding along leading and trailing edge
Type 3	Adhesive debonding between core and laminate materials
Type 4	Delamination in the laminate sections
Type 5	Fiber breakage in the laminate sections
Type 6	Adhesive debonding due to buckling
Type 7	Gel coat cracking

Ciang et al., "Structural health monitoring for a wind turbine system: a review of damage detection methods," Measurement Science and technology. Vol 19, 2008.

# Wind Operations & Maintenance

O&M costs - average share over the lifetime of the turbine of approximately 20%-25% of total levelized cost per kWh produced.

Monitoring and then condition based maintenance (CBM) of wind turbine blades has the potential to reduce the overall cost of wind energy, for example by simply reducing, or even eliminating, the need of sending maintenance personnel to remote locations to examine increasingly longer blades.

# Condition monitoring approaches

- Fiber Optic Sensors (FOS)
  - Integrated optical fibers provide strain, temperature, displacement, and vibration measurements.
- Acoustic Emission/Ultrasonic Sensor (AE/US)
  - Bonded sensors detect AE or investigate with ultrasonic

# Condition monitoring for blades

	<b>Costs (2014 USD) Besnard and Bertling (2004)</b>	<b>Costs (2014 USD) Nilsson and Bertling, (2007)</b>
Inspection	276	
Minor Repair	4,823	4,554
Major Repair	48,230	6,072
Blade Replacement	537,240	303,600
Condition monitoring System	20,670	30,360

Van Dam & Bond (2015)

# Economics of Condition Monitoring for Wind

Study 1: On-line CBM optimal for crack rates higher than 0.006% and crack time to failure lower than 1.1 years

- US \$75,784 in savings per turbine ---- [2]

Study 2: O&M ~54% reduction from corrective maintenance (CM) to preventative maintenance (PM) ---- [3]

Study 3: O&M savings ~47% conversion of CM to PM

- 0.43% increase in availability ---- [4]

Study 4: Return on investment achieved for SHM

- Worst Case – 19 years
- Most Likely Case – 3-4 years
- Best Case – 1 year ---- [5]

Van Dam & Bond (2016)

# Creation care & good economics!

Advanced NDE and structural health monitoring for energy systems and managing costs of operations and maintenance, minimize environmental impact, and reduce risks.

Creation care, good engineering practices and economics can all align as we address climate change and meet the needs of a growing population, (at least up to some limits!)

# Acknowledgements

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# NDT Resource Center [www.ndt-ed.org](http://www.ndt-ed.org)

- International resource
  - 230,000 + unique visitors per month

Resource for people ranging from high school to university researchers

The screenshot shows the homepage of the NDT Resource Center. At the top, there is a navigation menu with links for Home, About NDT, Resources, Careers, and Site Navigation. A search bar is located in the top right corner. The main header features the text "The Focal Point for NDT Education" over a background image of a person working with a device. Below the header, there is a welcome message: "Welcome to the NDT Resource Center. This site was designed to be a comprehensive source of information and materials for NDT and NDE technical education. The site was created by NDT professionals and educators from around the world." To the left of the main content, there is a sidebar with a list of resources for various groups: Jr. & Sr. High Students, College Students, Counselors & Parents, Educators, and NDT Professionals. Below this list, there are "Hot Items" including a link to "NDT Careers Video" and "Intro to NDT Presentation". To the right of the main content, there is a "Featured Site" section for NSF and a "Quick Links to" section with icons for Basic Science and NDT Course Material (Eddy Current, Penetrant, Magnetic Particle, X-ray, Ultrasound).



# References

Van Dam, J. and Bond, L.J. (2015) Economics of online structural health monitoring of wind turbines: cost benefit analysis, Proceedings, 41st Annual Review of Progress in Quantitative Nondestructive Evaluation, Volumes 34, Eds. D.E. Chimenti, D.E., and L.J. Bond, American Institute of Physics (AIP), Conference Proceedings # 1650, Boise, ID (July 2014) pp 899-908.

Bond, L.J. (2015) Needs and opportunities: nondestructive evaluation for energy systems, Smart Materials and Nondestructive Evaluation for Energy Systems, SPIE Conference 9439, Town & Country Resort and Convention Center, San Diego, California, United States, 8 - 12 March 2015 ,Ed. N.G. Meyendorf, SPIE Vol 9439, Paper # 943902, 14 pp.