CAN LMD SUCCEED WHERE EHMS HAVE FAILED?

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Introduction

- What is an EHMS?
- The concept of PSCL
- Why EUMS are needed
- Oil Debris Monitoring
- A synopsis of where we are today
- The Future?

EHMS

- Engine Health Monitoring Systems
  - A prognostic system which
    - Accepts analogue data from various sensors
    - Analyses the data
    - Decides whether the engine is safe to continue
  - And, ideally
    - Gives advanced warning of impending failure.

PSCL

- Predicted Safe Cyclic Life
  - Measured in stress cycles
  - Defines the age before which there is a 10^{-n} probability of an “engineering” crack occurring
  - Used with safety-critical parts to set an upper age limit.
  - Determined using accelerated spin/rig tests

EUMS

- **Engine Usage Monitoring Systems**
  - Accepts analogue data from various sensors
  - Converts it to digital
  - And records it.
- **Ground Data Processing Station**
  - Reads the tapes
  - Calibrates and validates the data
  - Converts this through complex algorithms into stress cycles and accumulates these

Oil Debris Monitoring

- *Jet*SCAN
  - Scanning Electron Microscope
  - Using Spectroscopy
  - Determines the elements present in each particle
  - Hence identifies the source
  - Is used to estimate rates and amounts of wear
  - Predicts when a component needs to be replaced

Current Status

- EUMS fitted to a small sample of aircraft in each of the RAF fleets
- Data is collected, downloaded and analysed regularly
- Cyclic Exchange Rates are calculated
- These are used to decide when life-limited parts should be replaced.

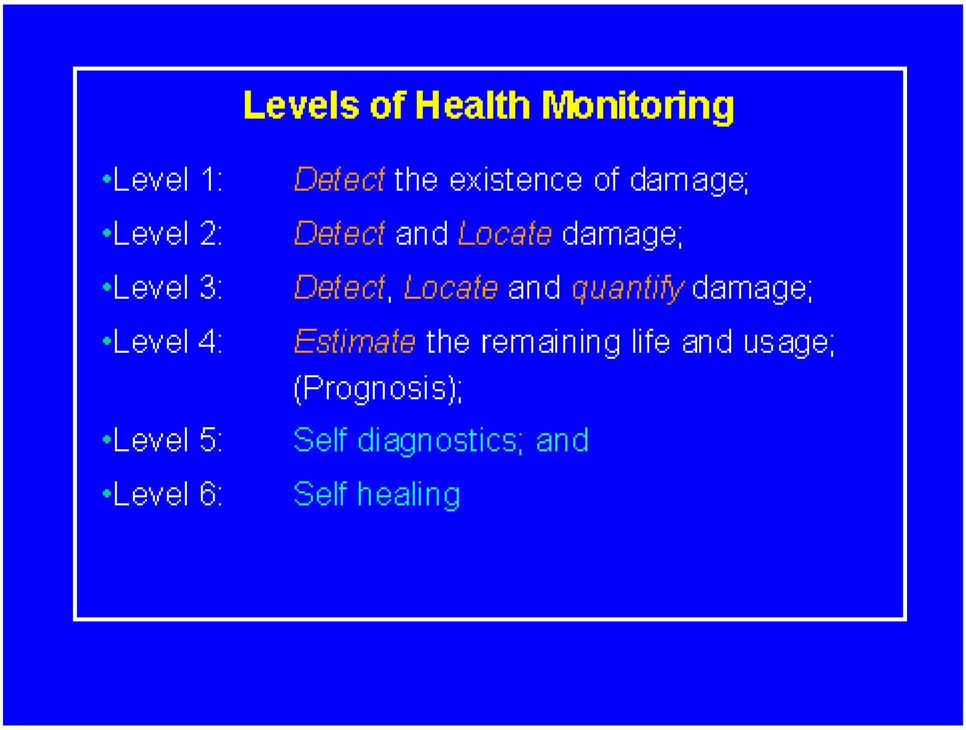
Near Future

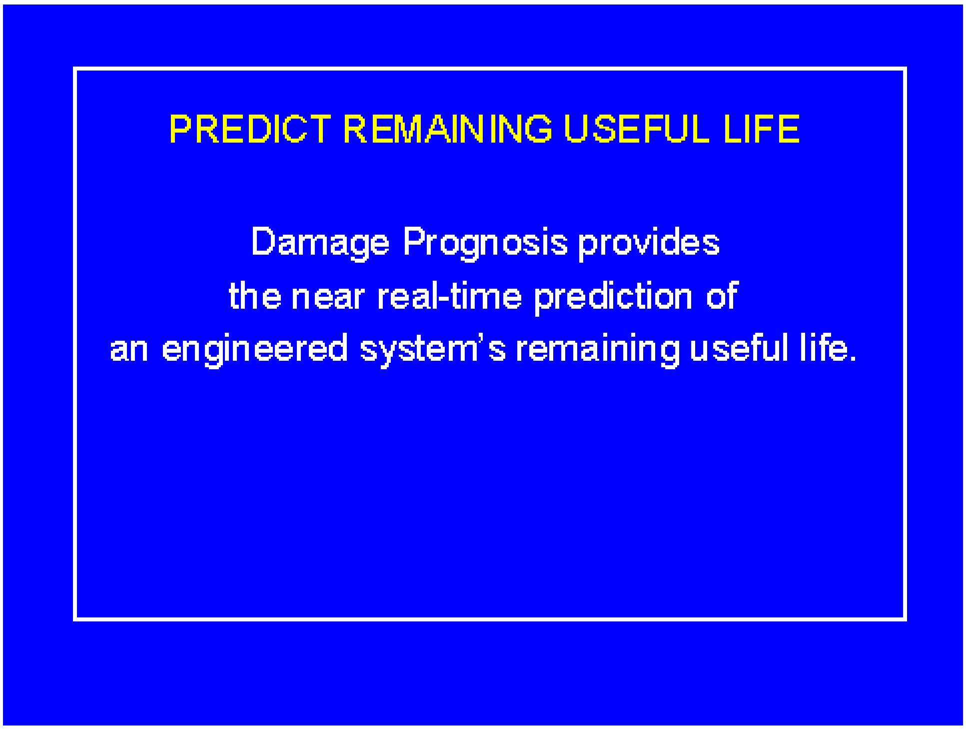
- EMS
  - Fleet-wide fit on Eurofighter
  - On-board analysis
  - Exchange rates only needed for fill-in
  - No prognostic capability.
- Oil Debris Monitoring
  - Off-wing
  - Expensive
  - Requires high skill levels

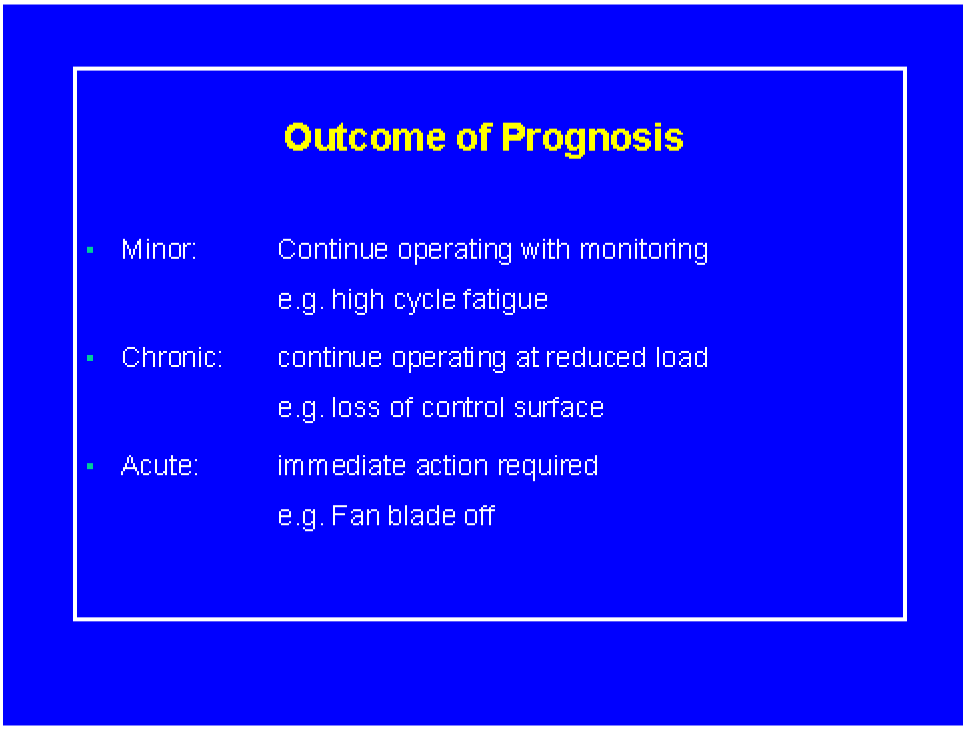
The Future?

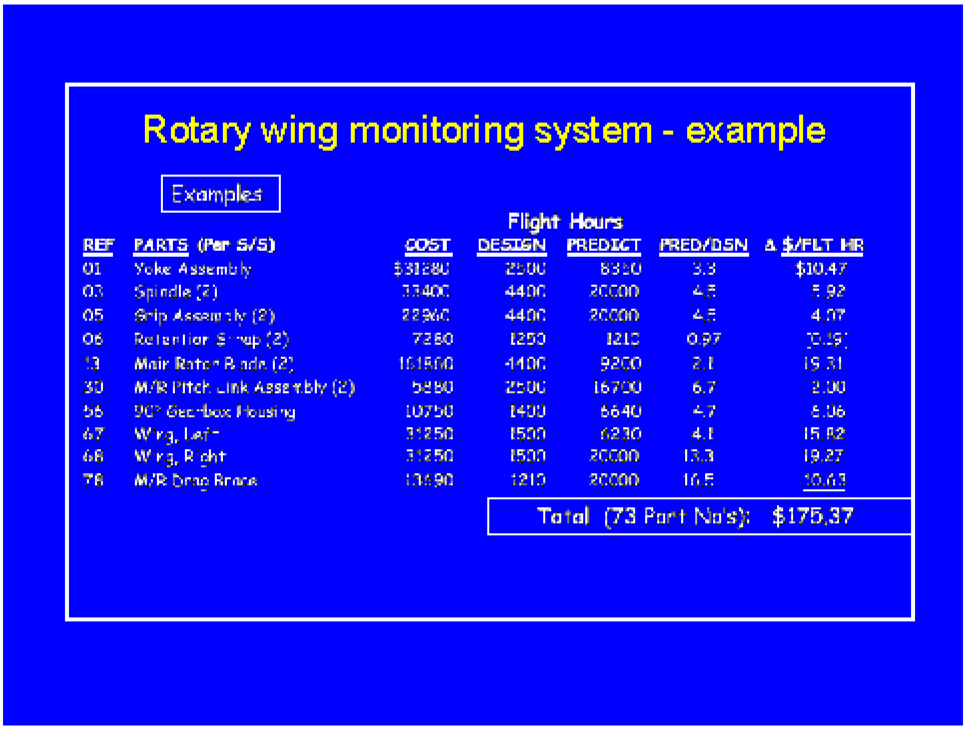
- EMS on wider range of parts
- Jet-path sensors
- Vibration monitors
- Life Monitoring Devices


The Need
Aircraft - power by the hour (airframe and engine)
Nuclear - life extension of power plants
Earthquake/terrorism - future use of buildings
Prosthetics
Military survivability
Environment


Levels of Health Monitoring
•Level 1: Detect the existence of damage;
•Level 2: Detect and Locate damage;
•Level 3: Detect, Locate and quantify damage;
•Level 4: Estimate the remaining life and usage; (Prognosis);
•Level 5: Self diagnostics; and
•Level 6: Self healing

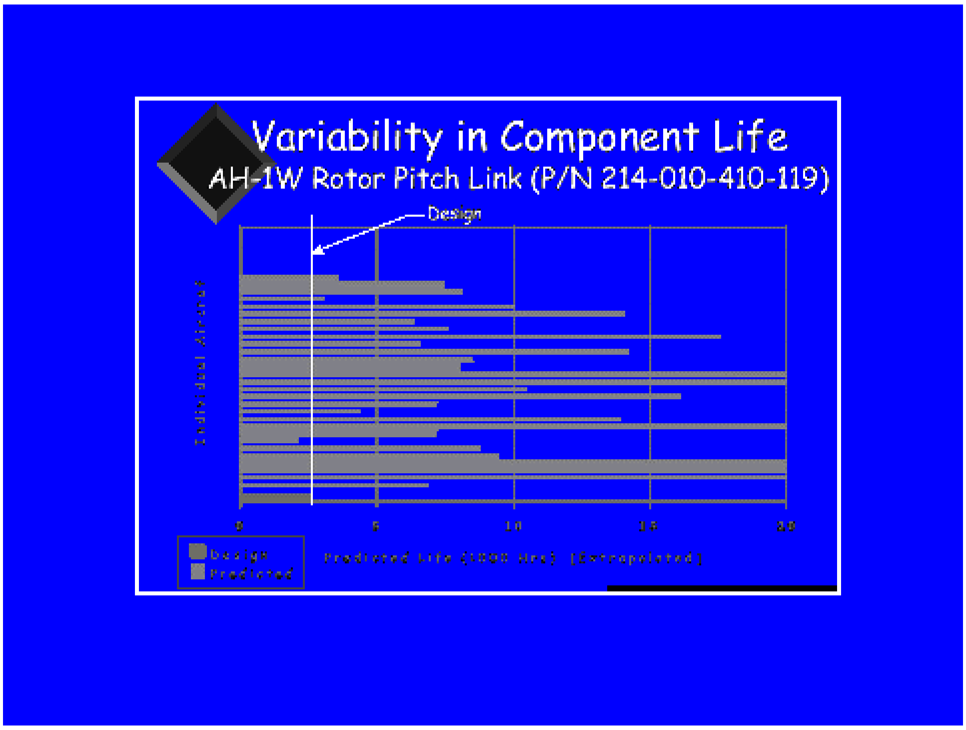

PREDICT REMAINING USEFUL LIFE
Damage Prognosis provides
the near real-time prediction of
an engineered system's remaining useful life.

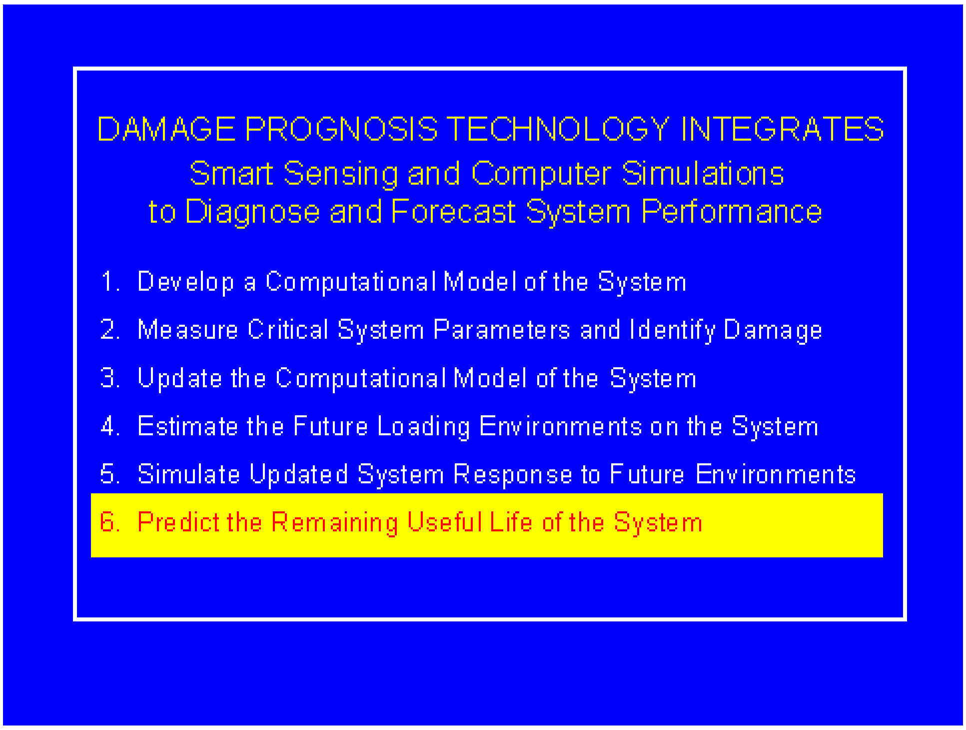

Outcome of Prognosis
Minor: Continue operating with monitoring
e.g. high cycle fatigue
Chronic: continue operating at reduced load
e.g. loss of control surface
Acute: immediate action required
e.g. Fan blade off



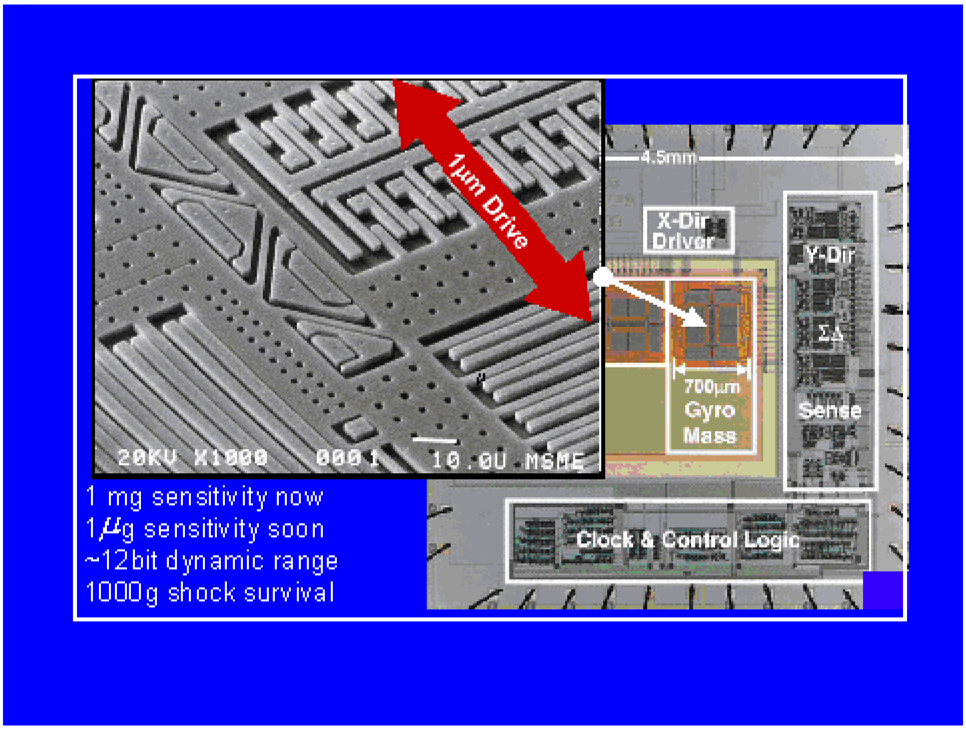
REF	PARTS (Per S/S)	COST	DESIGN	PREDICT	PRED/DSN	Δ $/FLT HR
01	Yoke Assembly	$31280	2500	8350	3.3	$10.47
03	Spindle (2)	33400	4400	20000	4.5	5.92
05	Grip Assembly (2)	22960	4400	20000	4.5	4.07
06	Retention Strap (2)	7280	1250	1210	0.97	(0.19)
13	Main Rotor Blade (2)	161500	4400	9200	2.1	19.31
30	M/R Pitch Link Assembly (2)	5880	2500	16700	6.7	2.00
56	90° Gearbox Housing	10750	1400	6640	4.7	6.06
67	Wing, Left	31250	1500	6230	4.1	15.82
68	Wing, Right	31250	1500	20000	13.3	19.27
78	M/R Drag Brace	13690	1210	20000	16.5	10.63

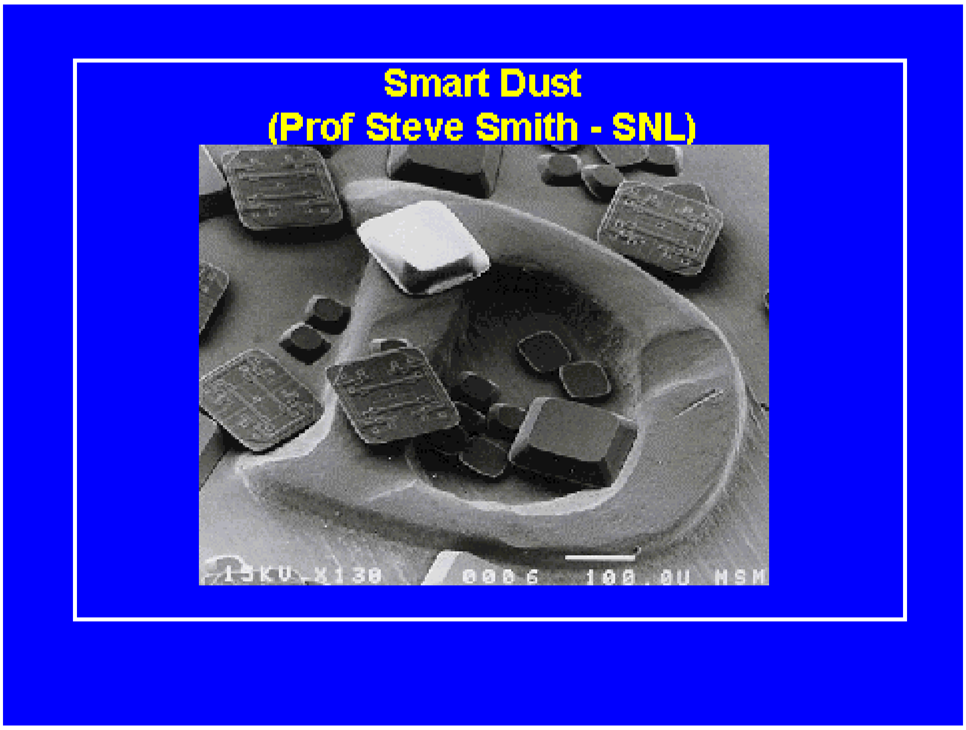
Total (73 Part No's): $175.37

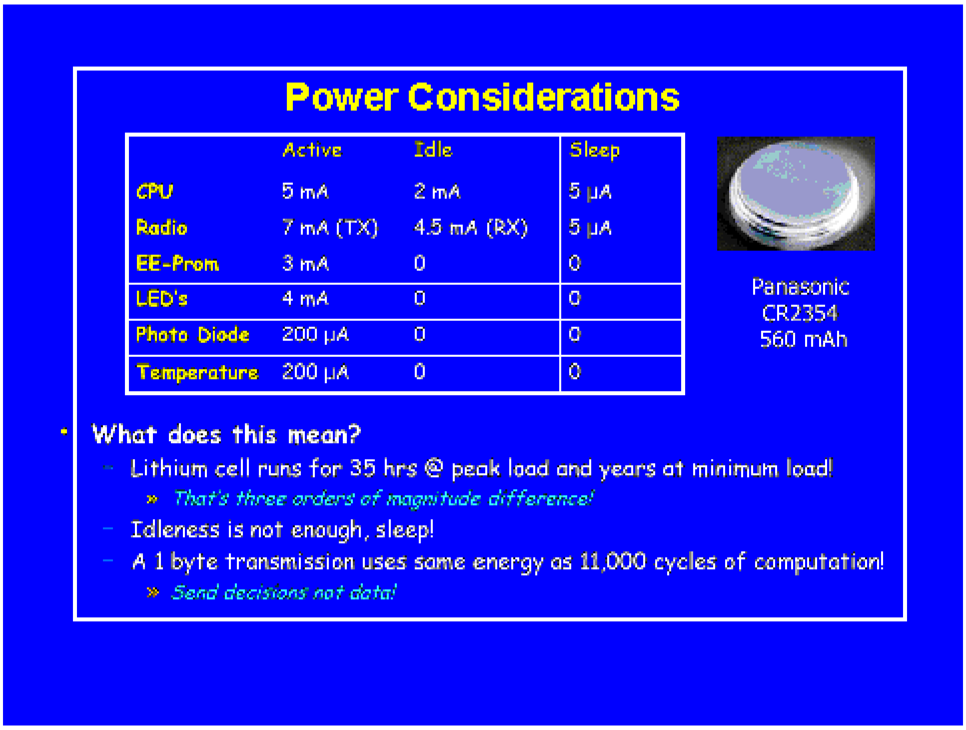


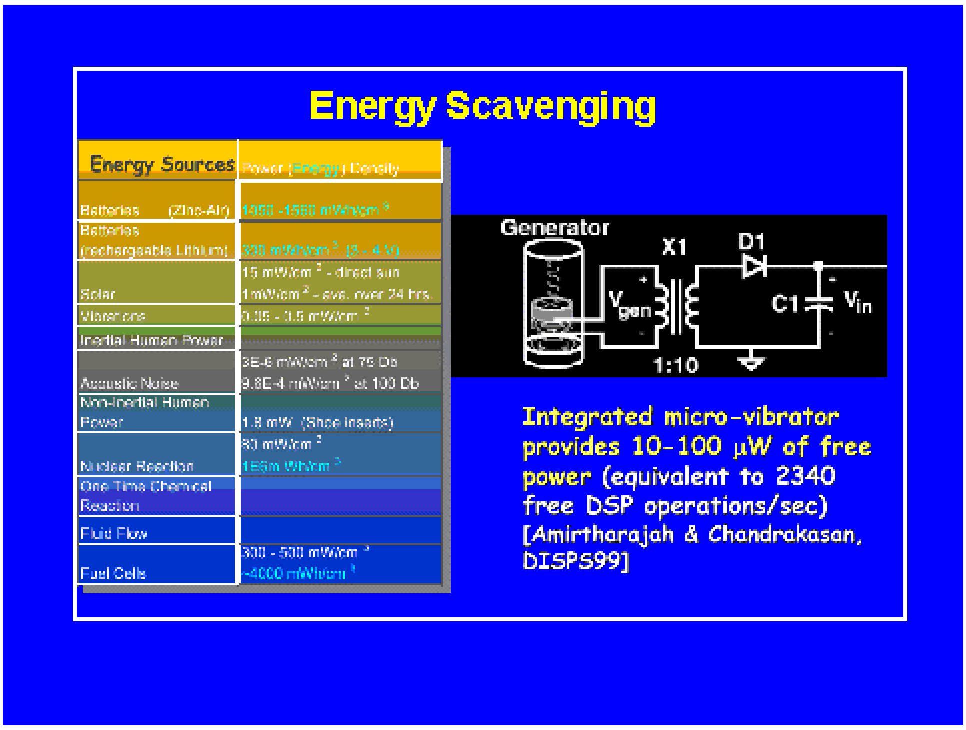

DAMAGE PROGNOSIS TECHNOLOGY INTEGRATES
Smart Sensing and Computer Simulations
to Diagnose and Forecast System Performance
1. Develop a Computational Model of the System
2. Measure Critical System Parameters and Identify Damage
3. Update the Computational Model of the System
4. Estimate the Future Loading Environments on the System
5. Simulate Updated System Response to Future Environments
6. Predict the Remaining Useful Life of the System


WHAT CAN BE DONE TO ADVANCE
DAMAGE PROGNOSIS TECHNOLOGY?
A coordinated, multidisciplinary effort is required to capitalize on recent revolutionary advances in:
Smart microelectronic sensing technology
Tera-scale computer simulations of damage evolution
Machine learning and information technology for model compression large-scale data management, model correlation and probabilistic system life prediction
2.5 cm
LANL


1µm Drive
4.5mm
X-Dir Driver
Y-Dir
ΣΔ
700µm
Gyro Mass
Sense
Clock & Control Logic
20KV X1000 0001 10.0U MSME
1 mg sensitivity now
1µg sensitivity soon
~12bit dynamic range
1000g shock survival


Smart Dust
(Prof Steve Smith - SNL)

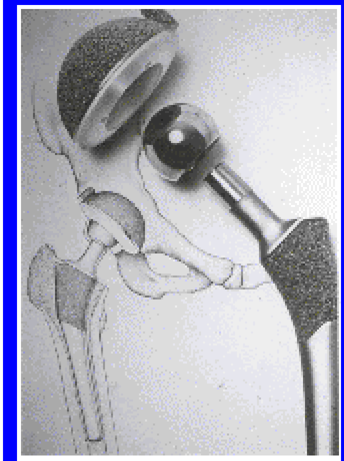

Power Considerations
Active Idle Sleep
CPU 5 mA 2 mA 5 µA
Radio 7 mA (TX) 4.5 mA (RX) 5 µA
EE-Prom 3 mA 0 0
LED's 4 mA 0 0
Photo Diode 200 µA 0 0
Temperature 200 µA 0 0
Panasonic CR2354 560 mAh
What does this mean?
Lithium cell runs for 35 hrs @ peak load and years at minimum load!
That's three orders of magnitude difference!
Idleness is not enough, sleep!
A 1 byte transmission uses same energy as 11,000 cycles of computation!
Send decisions not data!

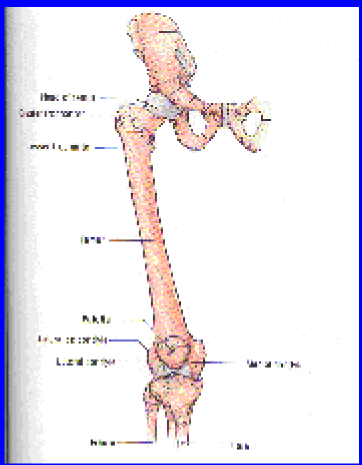

Energy Scavenging
Energy Sources
Power (Energy) Density
Batteries (Zinc-Air)
1050 -1560 mWh/cm 3
Batteries (rechargeable Lithium)
300 mWh/cm 3 (3 - 4 V)
Solar
15 mW/cm 2 - direct sun
1 mW/cm 2 - avg. over 24 hrs.
Vibrations
0.05 - 0.5 mW/cm 2
Inertial Human Power
Acoustic Noise
3E-6 mW/cm 2 at 75 Db
9.8E-4 mW/cm 2 at 100 Db
Non-Inertial Human Power
1.8 mW (Shoe inserts)
Nuclear Reaction
80 mW/cm 2
1E6m Wh/cm 2
One Time Chemical Reaction
Fluid Flow
Fuel Cells
300 - 500 mW/cm 2
~4000 mWh/cm 3
Generator
X1
D1
C1
Vin
Vgen
1:10
Integrated micro-vibrator provides 10-100 µW of free power (equivalent to 2340 free DSP operations/sec)
[Amirtharajah & Chandrakasan, DISPS99]

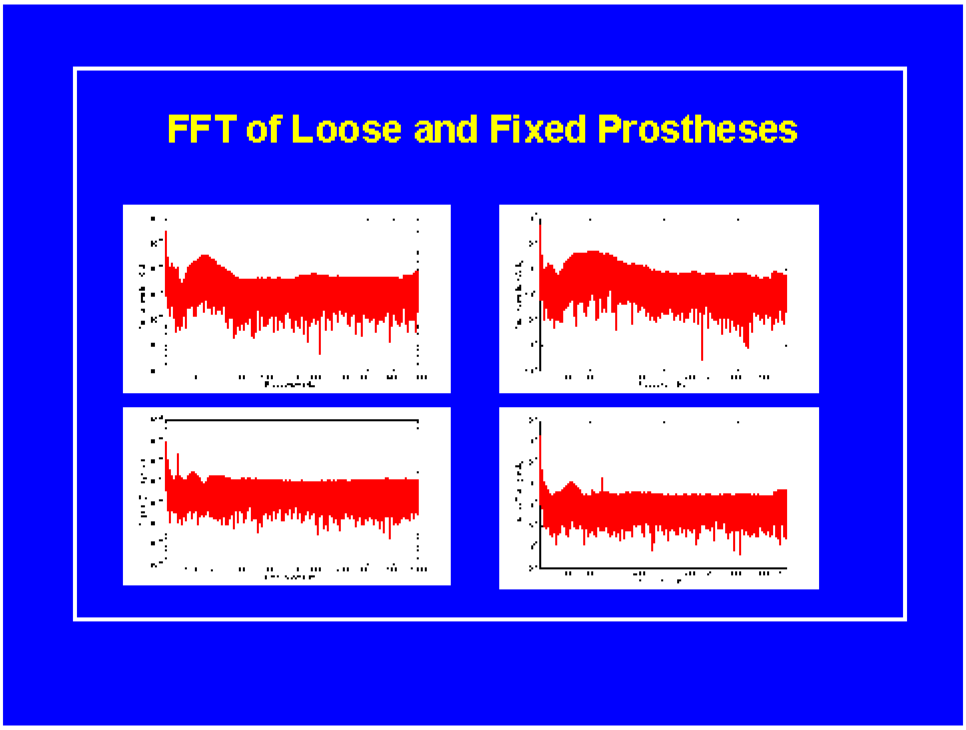
DAMAGE PROGNOSIS SOLUTIONS. . . .

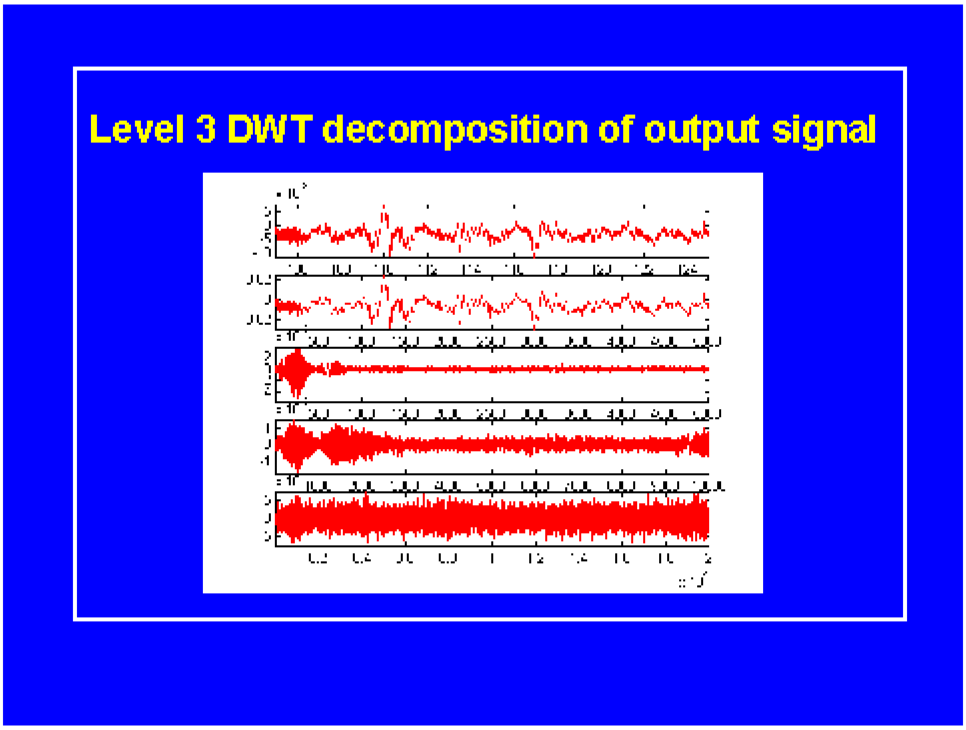
- **Require coordinated advances in**
  - Wireless microelectronic sensing technology coupled with embedded microprocessors
  - Tera-scale computer simulations of damage evolution
  - Machine learning and information technology for model compression, large-scale data management, model correlation and probabilistic system life prediction
- **Can only be solved in an environment that promotes multi-disciplinary research.**

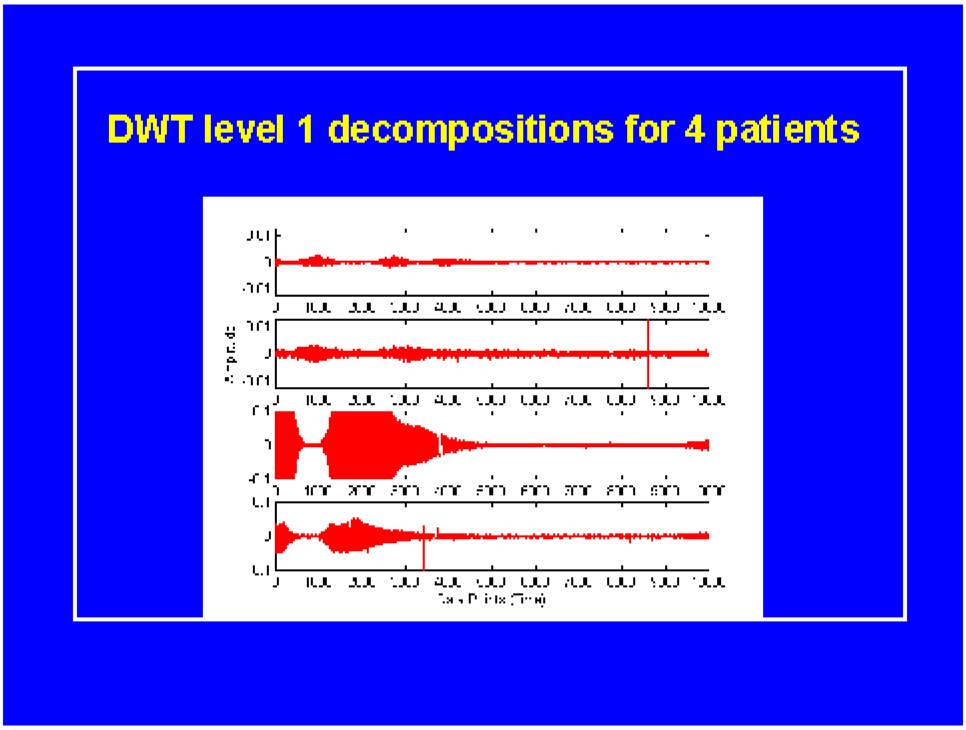
Example

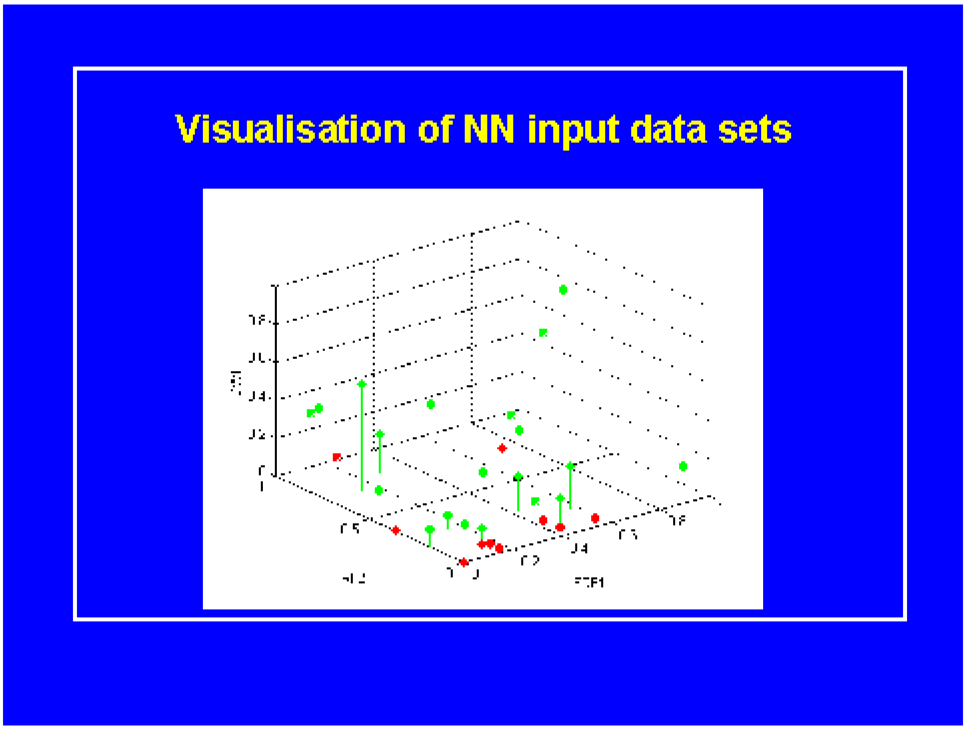


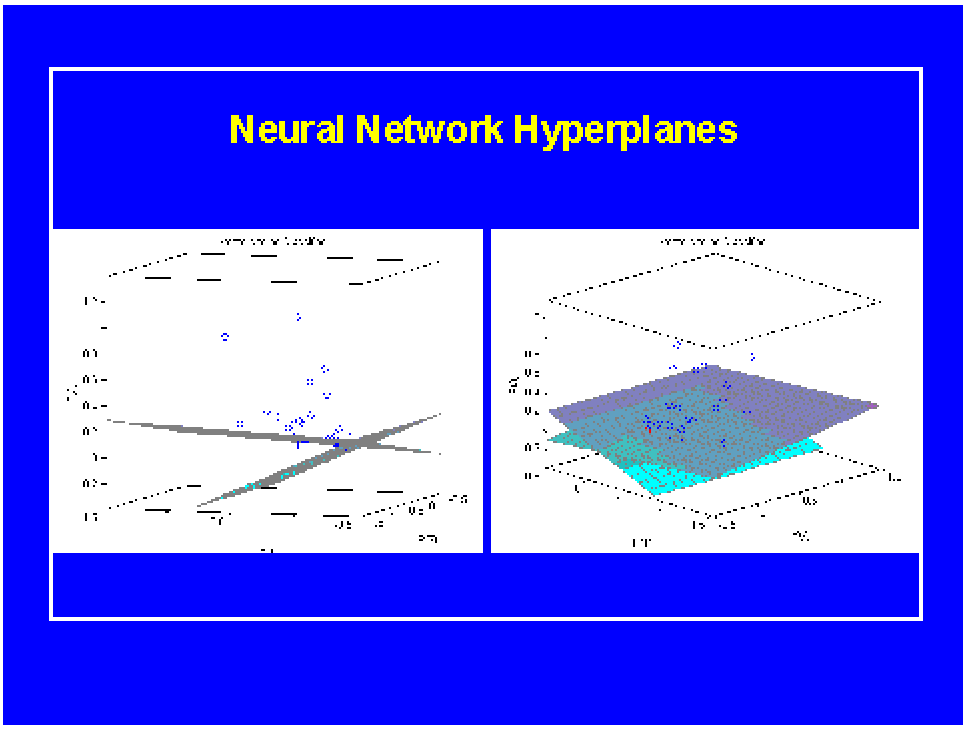


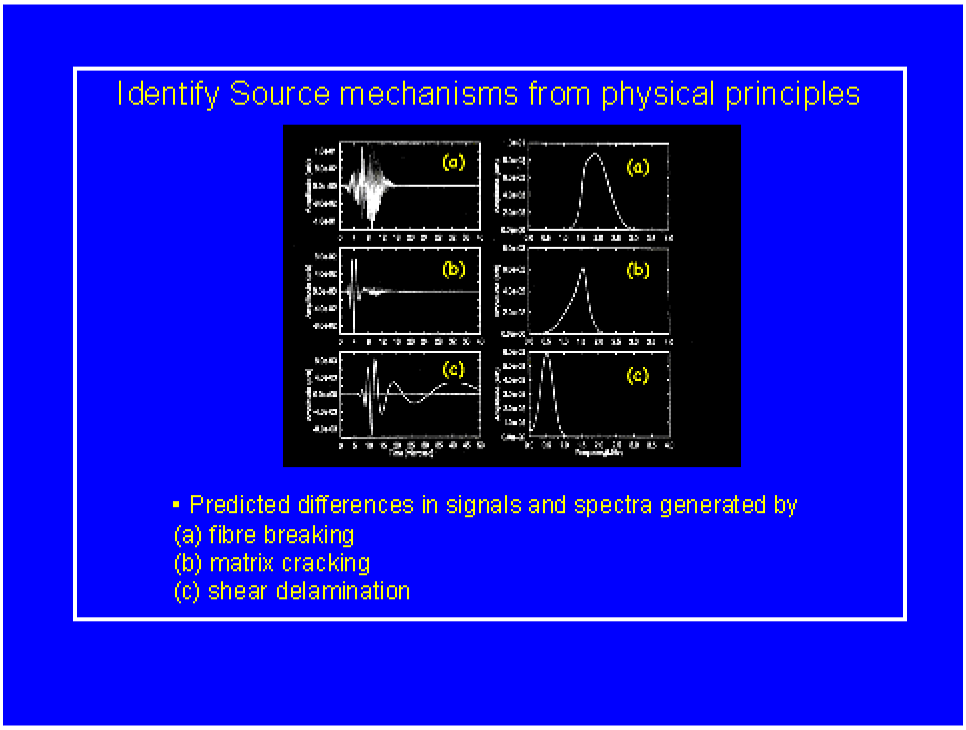

FFT of Loose and Fixed Prostheses


Level 3 DWT decomposition of output signal


DWT level 1 decompositions for 4 patients


Visualisation of NN input data sets


Neural Network Hyperplanes


Identify Source mechanisms from physical principles
(a)
(a)
(b)
(b)
(c)
(c)
▪ Predicted differences in signals and spectra generated by
(a) fibre breaking
(b) matrix cracking
(c) shear delamination

Present State vs Future Vision

Usage Monitoring	Damage Prognosis
Time-based maintenance	Condition-based maintenance
Sparse sensing (10's of sensors)	Densely distributed sensing (1000's of sensors)
Prediction by observation and experience	Near-real-time prediction with validated computational models
Data trending	Adaptive data interrogation and model updating
Run to maintenance interval or failure	Predict required maintenance interval or failure

Significant Challenges

- Sensing: What to measure, how to measure it
  - Densely distributed fault-tolerant micro-sensor technology
  - Reconfigurable and adaptable sensing system
- Information Technology: Data interrogation and fusion
  - Distributed and adaptive on-board micro-processing
  - Model compression and updating
  - Large-scale data management
- Predictive Modeling: Damage evolution
  - Evolution of micro-scale damage initiation to system level failure
  - Near-real-time predictive capability capturing relevant mechanics
- System Integration & Deployment on Real-World Hardware

Key Technology Elements

- **Engineering Mechanics:** Transient Nonlinear Computer Simulation, System Performance Analysis, Damage Evolution Models
- **Reliability Engineering:** Probabilistic Inferencing, Probabilistic Risk Assessment, Reliability Methods
- **Electrical Engineering:** MEMS, Wireless Telemetry, Power Management, Integrated Computing Hardware
- **Computer Science:** Networking, Machine Learning, Computing Hardware Architecture
- **Information Science:** Data Compression and Communication, Large-Scale Data Management, Signal Processing
- **Material Science:** Smart Materials, Material Failure Mechanisms, Self-Healing Materials
- **Statistics and Mathematics:** Statistical Process Control, Model Reduction, Pattern Recognition, Uncertainty Propagation
- **Systems Engineering:** Requirements Flow-Down, Functionality Analysis, Systems Integration, Control Optimisation, Concurrent Engineering

What next?

- Development of LMDs
- Clean room development of power devices
- Demonstrator using cellular LAN

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Summary

- LMD can detect structural changes
  - Has its limitations (excess temperature and vibration)
  - Has wide area of applicability
  - Cheap
  - Fit and forget (?)
  - Useful for determining reliability and crack propagation times.