Robert M. Cranwell, Manager

Readiness & Sustainment Programs

Sandia National Laboratories (SNL)

Albuquerque, NM 87185

Phone: (505)844-8368 Fax: (505)844-3321

Email: rmcranw@sandia.gov

Web Site: reliability.sandia.gov

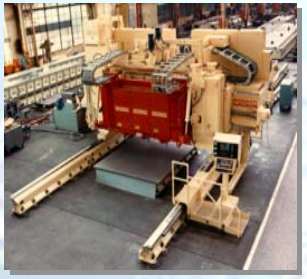
Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under contract DE-AC04-94AL85000.

Technologies & Customer Base

- Modeling & Simulation
- Concept/Design Exploration
- Prognostics & Health Management
- Fault Isolation/Fault Detection
- Optimization Algorithms
- Supply Chain/Spares Inventory Management
- Human Factors Engineering
- Failure Modes & Effects Analysis
- Risk Assessment/Management
- Sensitivity/Uncertainty Quantification

Technologies Support Broad Customer Base

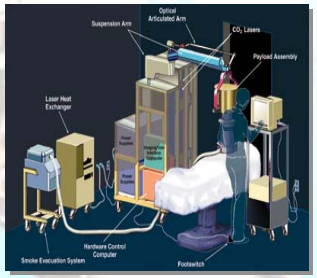
Defense

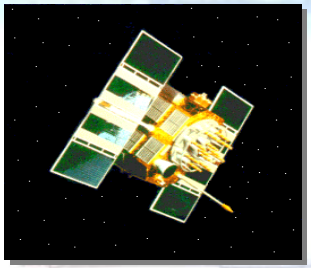

Machine Tool

Farming

Semiconductor

Boating


Health Care


Satellites

Aviation

Automotive

Nuclear Power

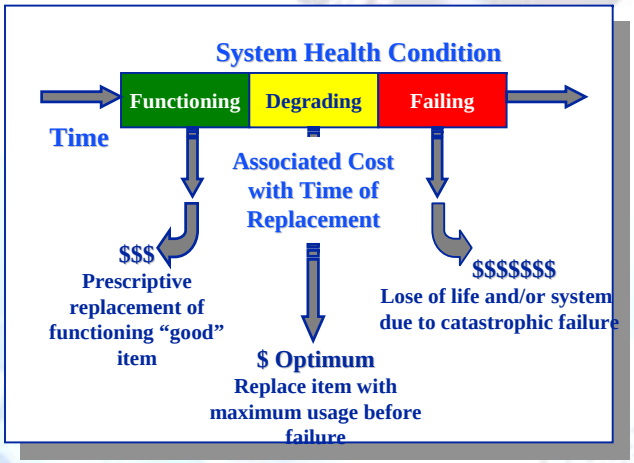
Power Grid

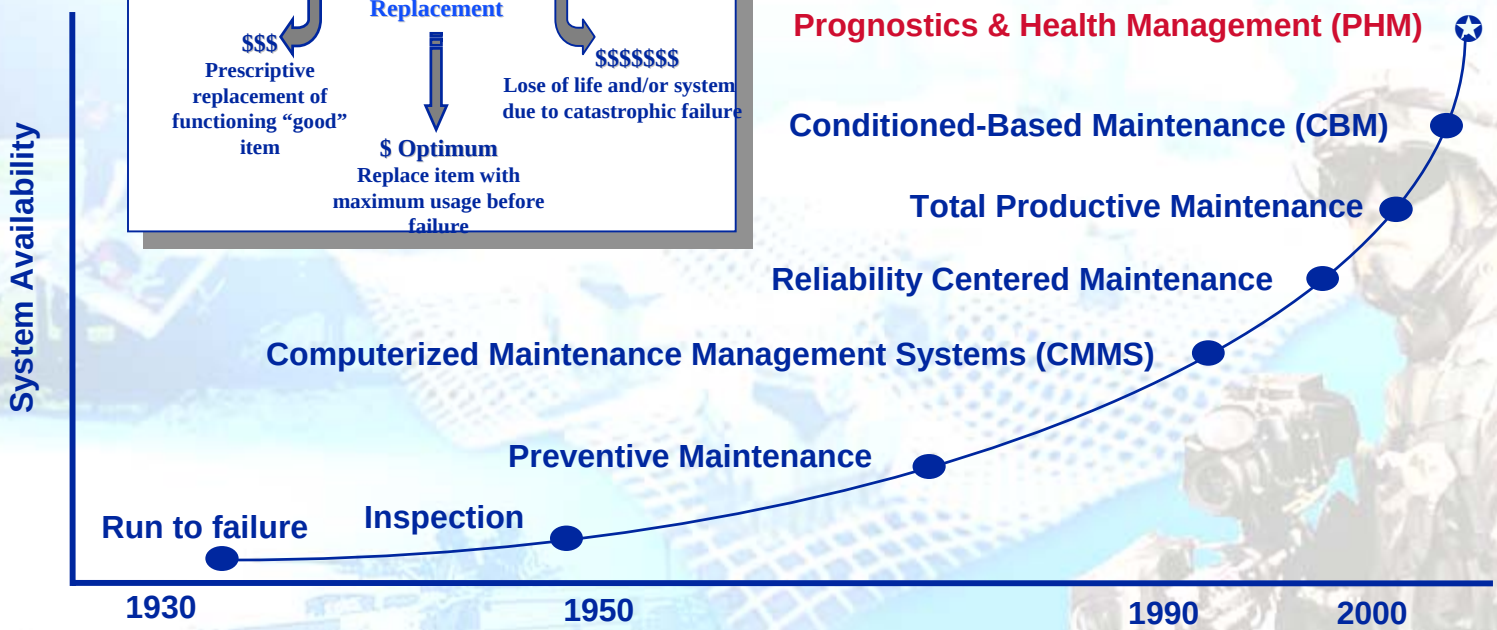
Textile

Tools & Technologies Validated Through Broad Use

Evolving Maintenance Strategies

Prognostics & Health Management (PHM) optimizes the maximum useful life of components, subsystems and systems.



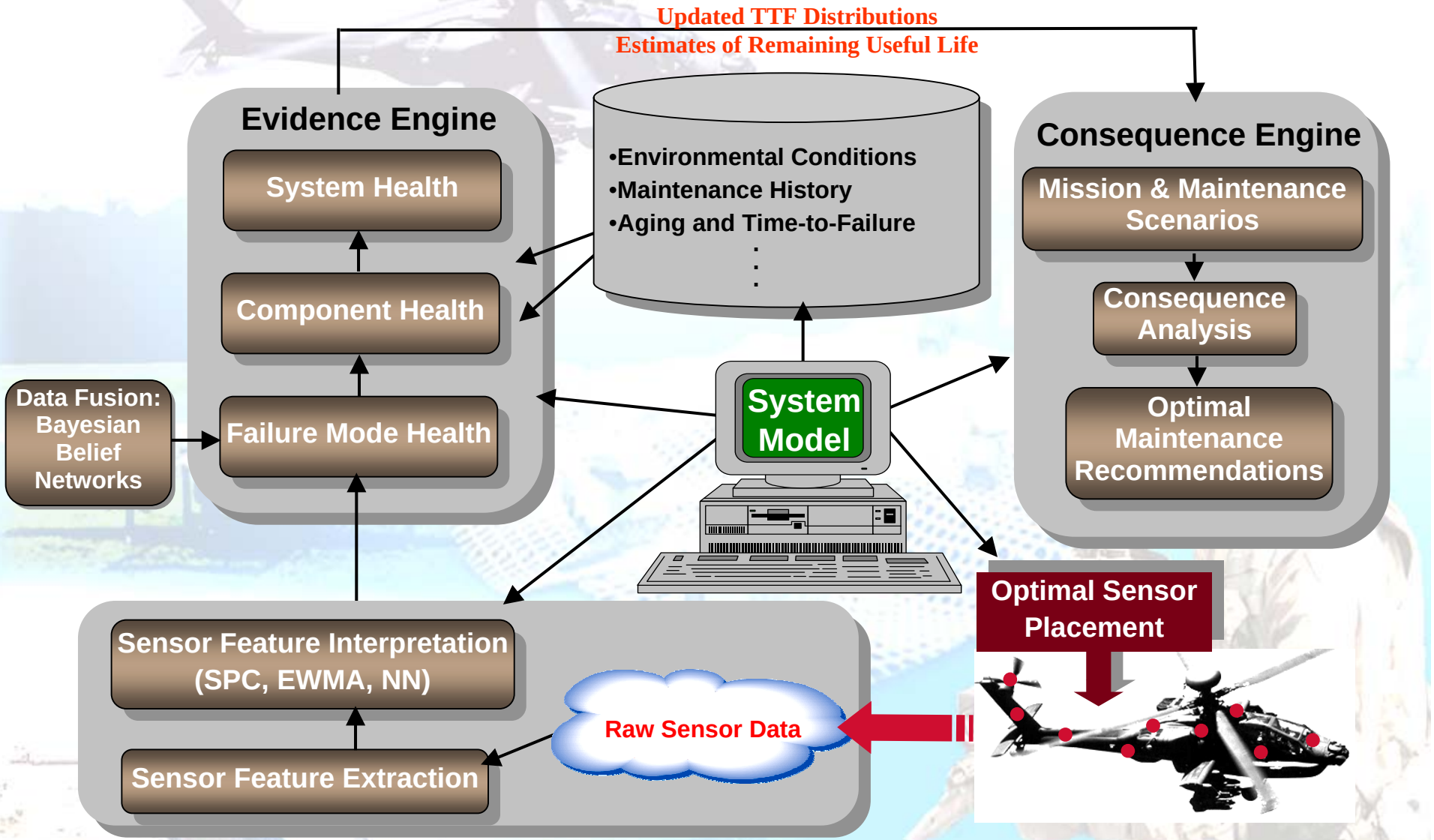


"The function of maintenance in a world-class operating environment is not to simply maintain, but to provide reliable systems and to extend the life of systems at optimum costs." **Stanley Lasday, June 1997, Industrial Heating**

What is PHM?

- **Definition: The capability to estimate the likelihood of a system failure over some future time interval so that appropriate actions can be taken. A PHM system consists of:**
  - **Raw Data**
    - **Sensor data**
    - **Historical maintenance/failure data**
  - **Diagnostics**
    - **Data fusion**
    - **Data interpretation**
  - **Prognostics**
    - **Predictions**
    - **System "health"**
  - **Health Management**
    - **What should be done**
    - **When should it be done**
- **An extremely accurate, computationally efficient PHM capability is critical to support future aircraft platforms and weapon systems as well as industry needs.**
- **Current technology is probably not mature enough to meet the needs for many weapon systems PHM goals.**

SNL PHM System Architecture



JSF Autonomic Logistics

A comprehensive logistics support environment for the JSF which has these key features:

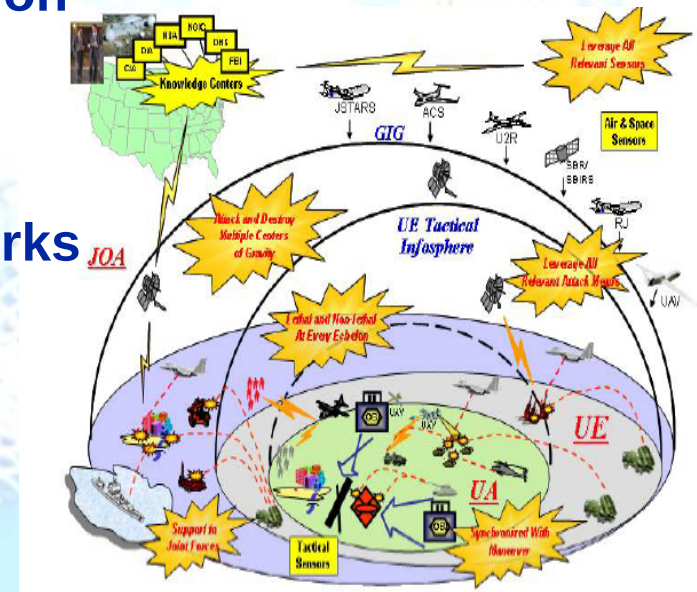
- A highly reliable aircraft which encompasses Prognostics and Health Management
- A technologically enabled maintainer
- A Joint Distributed Information System
- A logistics infrastructure that is sufficiently responsive to support requirements

Army's Future Combat System

FUTURE COMBAT SYSTEMS
FCS
One Team – The Army/DARPA/Industry

Challenging Characteristics of Complex System-of-Systems (SoS) :

- Multiple MOEs/MOPs and System States
- Functional Decomposition of Systems/Platforms
- Large Trade Space Exploration/Optimization
- High-degree of Functional Redundancy
- Extensive Communications & Data Networks
- Large Interdependencies
- Uncertainty Characterization/Propagation
- Diagnostics/Prognostics

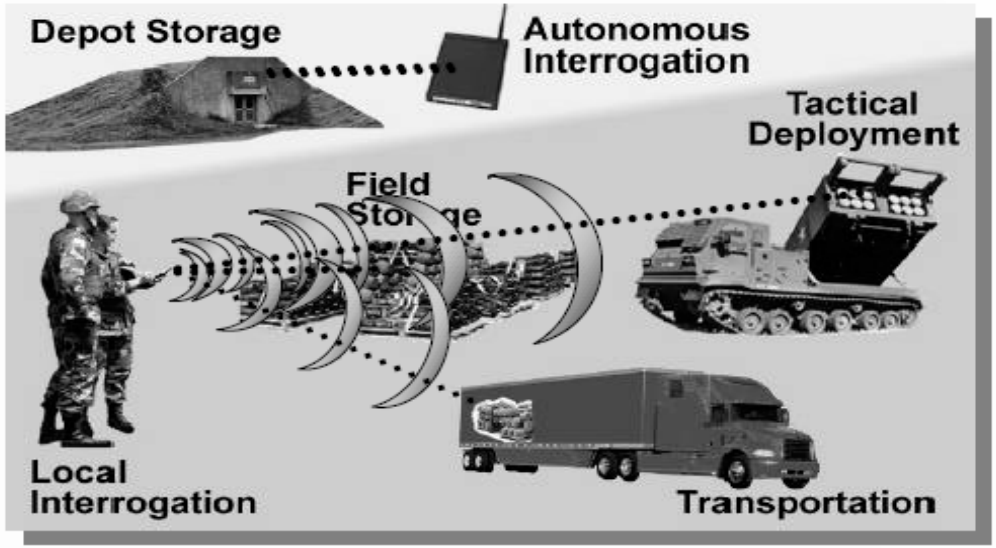


RRAPDS

Remote Readiness Asset Prognostics/Diagnostics System

WARFIGHTER Needs

- Integrated System to Monitor a Weapon's Health/Condition
- Advanced Prognostics/ Diagnostics
- Real-Time Situational Awareness to Anticipate and Accurately Plan Maintenance Requirements
- Low Cost
- Transparent to the Warfighter



TECHNOLOGY Required

- MEMS-Based Sensors and Microchip Technology for Minimum Size and Power Consumption
- Intelligent Power Management for Long Periods of Maintenance-Free Operation
- Prognostics through Artificial Intelligence-Based Decision Tools and Failure Models

A Joint AMCOM-AMRDEC & TACOM-ARDEC Science and Technology Objective (STO)

Mr. Steve Marotta
U.S. Army AMCOM-AMRDEC
Steve.marotta@rdec.redstone.army.mil

Mr. Jim Fedewitz
U.S. Army TACOM-ARDEC
fedewitz@pica.army.mil

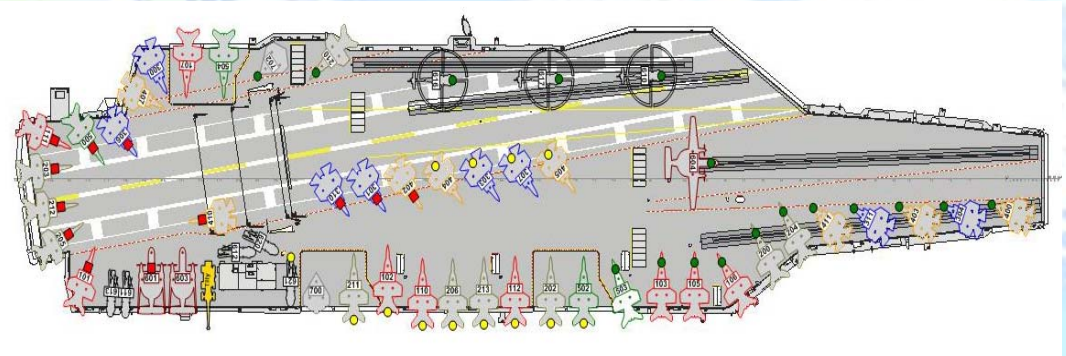
CVN 21 CVW Manpower Study

Independent Review & Analysis of CVN 21 CVW Manpower

Program Objectives

- Analyze current CVW ops, maintenance, support
- Analyze CVN 21 ORD focusing on DRM
- Recommend alternative FY 20 CVW structures, concepts of operation, policies

Enable improved workload distribution including 10-30% manpower reduction while meeting CVN 21 ORD performance parameters



Increase Sortie Generation Rate with Reduced Manpower

DARPA's View of PHM

Idea:

Exploit the fact that materials failure is neither random or unpredictable and provide timely and useful information about the state and future performance of combat systems.

Prediction of evolving damage and failure in high performance DoD assets will revolutionize our management and deployment of combat assets

Technical Challenges:

"From microstructure to throttle settings"

- Demonstrate the predictive nature of coupled materials' failure models in a realistic (complex, dynamic) environments.
- Establish non-invasive interrogation techniques that can be used to enhance the fidelity of the predictions.
- Establish techniques for reducing dimensionality and managing uncertainty in predictions.

SNL PHM Activities/Programs

Nuclear Power Plant

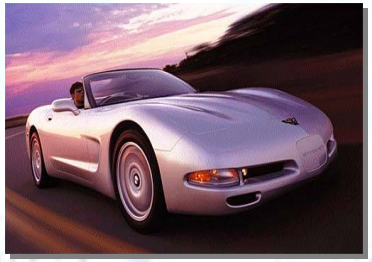
- Nuclear Power Plant
  - Nuclear Energy Research Initiative (NERI), joint program with Penn State, MIT, Duke Engineering, & Westinghouse
  - Introduce PHM to selected power plant equipment

AH-64

- Avionics
  - Potential program with Apache PO
  - Utilize data from Flight Data Recorders

Manufacturing Facility

- Manufacturing Facility
  - DOE funded program
  - Implement PHM in manufacturing facility



Automotive

- Automotive Industry On-Board Diagnostics for Emissions
  - Robust algorithm development for emissions control
  - Pattern recognition and decision algorithms

F-16 ADG

- Flight-critical Systems
  - Implement PHM on Accessory Drive Gearbox
  - Extend replacement intervals

Airborne Laser (ABL)

- Fluid Flow
  - Program with MDA and Industry
  - Implement PHM on fluid flow systems (COIL)

Fundamental PHM R&D supported by Sandia's Laboratory Directed Research and Development (LDRD) facilitates our external programs

PROMIS Program

Sandia National Laboratories

CINCINNATI MACHINE

PROMIS

BOEING

CATERPILLAR

Production Optimization and Manufacturing Information System

API Automated Precision Inc.

Advanced Sensors/Metrology Systems

Knowledge Based Advanced Computer Simulation, Signal Processing, Process Control and Modeling

Communication Technologies LAN, Wireless, Intranet, Internet

PROMIS

Benefits

- Quality and Productivity Improvement
- Optimization of Process Planning , Design and Resources
- Global Enterprise - Virtual Manufacturing
- DOD Supply Chain Integration

Proposed Joint Program w/Honeywell

Honeywell

- Targeting H-53 and H-60 aircraft at Kirtland AFB to perform a pilot project, focusing on vibration analysis
- Use of Honeywell flight data recorder to provide flight parameters to correlate with sensor readings
- Expand program to airframe structures on other platforms

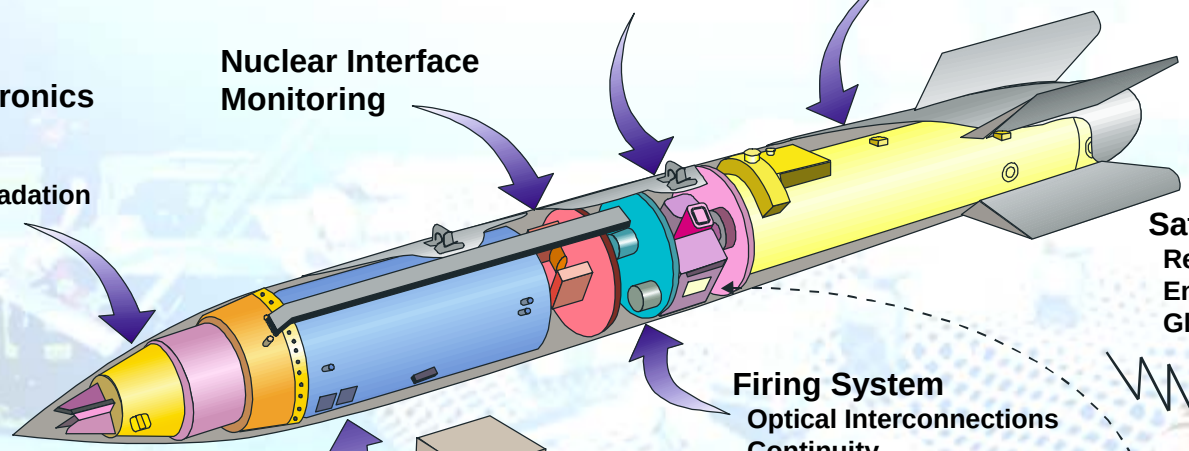
Proposed Joint Program w/Rockwell

- **Sandia and Rockwell Collins are collaborating on meeting the challenges of embedding prognostics on the Lot 12/Block III Apache and migration of a similar capability across the array of Army systems**
  - **Proposed development of a toolkit of prognostic tools that will run within the CAAS/FCS architecture**
    - **Reusable software objects for modeling and assessing remaining useful life of components and subsystems**
    - **Canary devices that physically identify and quantify cumulative environmental damage to provide feedback to the PHM algorithms**
    - **Microsensors that record the life history exposure of systems to provide input to the predictive software**

These tools would be scalable across a wide variety of Army Platforms

"Smart" Weapon Concept Using PHM

Weapons that diagnose and communicate their state of health



“Smart” Missile System Using PHM

Integrated Missile Surveillance, Condition, and Health Monitoring System

- **Develop Integrated Surveillance, Condition and Health Monitoring System for AMRAAM missile system**
  - **Data Logger in missile system would provide info to diagnostic software**
  - **Diagnostic software would provide decision makers with optimal repair & replacement strategy**

What the PHM COE is:

The Prognostics & Health Management (PHM) Center of Excellence (COE) is a Sandia National Laboratories programmatic commitment to use any/all its capabilities in a multi-year, multi-party effort to advance PHM technology solutions.

Why the PHM COE:

- Supports Sandia National Laboratories and DOE's Nuclear Weapons Stockpile Stewardship mission
  - For example, the Advanced Simulation Computing (ASC) Program supported our initial needs assessments within the PHM community
- Congress recognized excellence in the National Laboratories and directed Technology Transfer as a means of leveraging R&D funds within the federal government and U.S. private sectors
  - Cooperative Research & Development Agreements (CRADA's)
- PHM is a difficult and widely shared problem, and needs the combined efforts of both industry & government

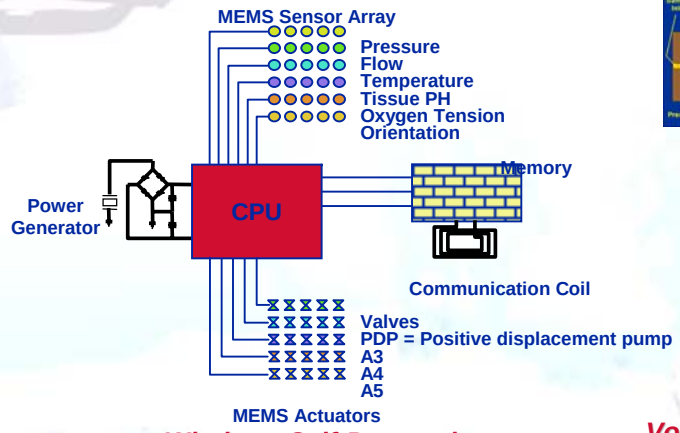
Why Sandia?

- Sandia's mission is to deliver technology solutions for the most challenging problems that threaten our nation's security and economic competitiveness. Our unparalleled resources, science and technology base, facilities, and existing PHM programs, combined with our partnership responsibilities and contracting mechanisms, uniquely position us for establishing the Center of Excellence.
- Sandia offers:
- One stop service
  - The only R&D organization that can address and integrate all areas of PHM technology
    - Machinery
    - Structures
    - Electronics
    - Data
    - Sensors
    - Algorithms
- Honest Broker
  - Non-competitive with US industry
  - Accessible to PHM technology users and developmers
  - Motivations are US national security and economic competitiveness vs corporate profit

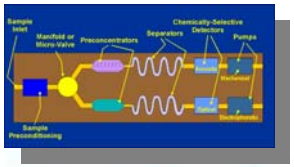
Sandia Technologies Support PHM

Technologies for SNL's NW's Enhanced Surveillance & Life Extension Programs

- **Modeling & Simulation**
  - Predictive analyses
  - Sensitivity/Uncertainty analyses
  - Optimization analyses
- **Microsensor Development**
  - Fiber-optic chemical sensors
  - Integrated/Micromachine Sensors
  - Micromachine Ion Mobility Spectrometer
  - Wireless, self-powered sensors
- **Life Prediction Algorithms**
  - Fuzzy Logic
  - Neural networks, Bayesian networks
  - Genetic Algorithms
  - Bayesian updating
- **Electronics Quality/Reliability Center**
  - Failure analysis
  - Burn-in elimination & testing
  - Life prediction
- **Materials Aging**
  - Life extension
  - Reliability predictions

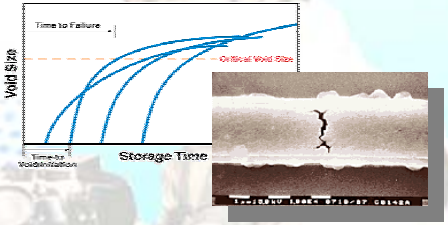


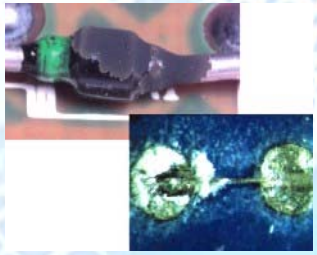
Wireless, Self-Powered MEMS Sensor & Actuator



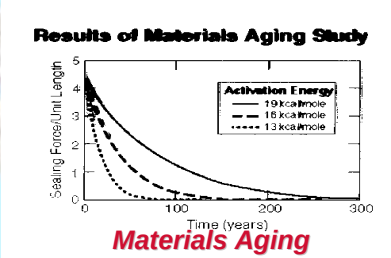
MEMS Technology

Void Growth Analysis





Corrosion Analysis



Materials Aging

The PHM COE Scope:

PHM Center of Excellence goals are to advance PHM state-of-the-art through IEEE standards (or other relevant standardized metrics), a centralized information systems infrastructure, technology analysis and development, and technology test and validation. Technology transfer will be achieved through cooperative R&D and IP licensing to industry and academia.

- Information systems development capabilities will include:
  - An infrastructure to collect and store sensor data
  - A warehouse for integration with related data such as materials, maintenance, aging, or other test data
  - Tools to view, analyze, and make predictions
- Technology analysis and development will include:
  - Sensor development and validation
  - Algorithm development and validation
  - Fault data source for diagnostic and prognostic technique development
  - Alpha and beta test facility for sensors, algorithms, diagnostics, and prognostics techniques
  - Integrated training for field practitioners and technicians using data and algorithms
- Technology test and validation facility will include:
  - Machinery system test facility
  - Fluid diagnostics and prognostics test facility - oil debris and hydraulic fluid particle analysis
  - Structural diagnostics and prognostics system test facility
  - Electrical and electronic systems diagnostics and prognostics

The PHM COE Mission

Develop and make available to the PHM developer and user communities a comprehensive research, development, and experimental institution for advancing economic competitiveness. Center operations will focus on helping companies develop proprietary PHM tools and will facilitate collaboration with other researchers in the development of shared tools.

To meet the above mission and enhance the ability of PHM Programs to respond to, not only weapons systems requirements in performance, safety, reliability, and sustainability, but to all systems using this type of technology, the PHM COE will:

- **Maintain a data repository including alpha and beta test diagnostic and prognostic data sets, a comprehensive data set for every test conducted at the facility, and a comprehensive lessons learned library of field data**
- **Provide the data needed for developers and users to intelligently select PHM technologies for new PHM development and application**
- **Support the development and V&V standards and guidance for machinery, structures, electronics, and software**
- **Perform as an honest broker for diagnostic and prognostic technology selection, development, and V&V**
- **Develop and license SNL PHM IP to industry**

The PHM COE Vision:

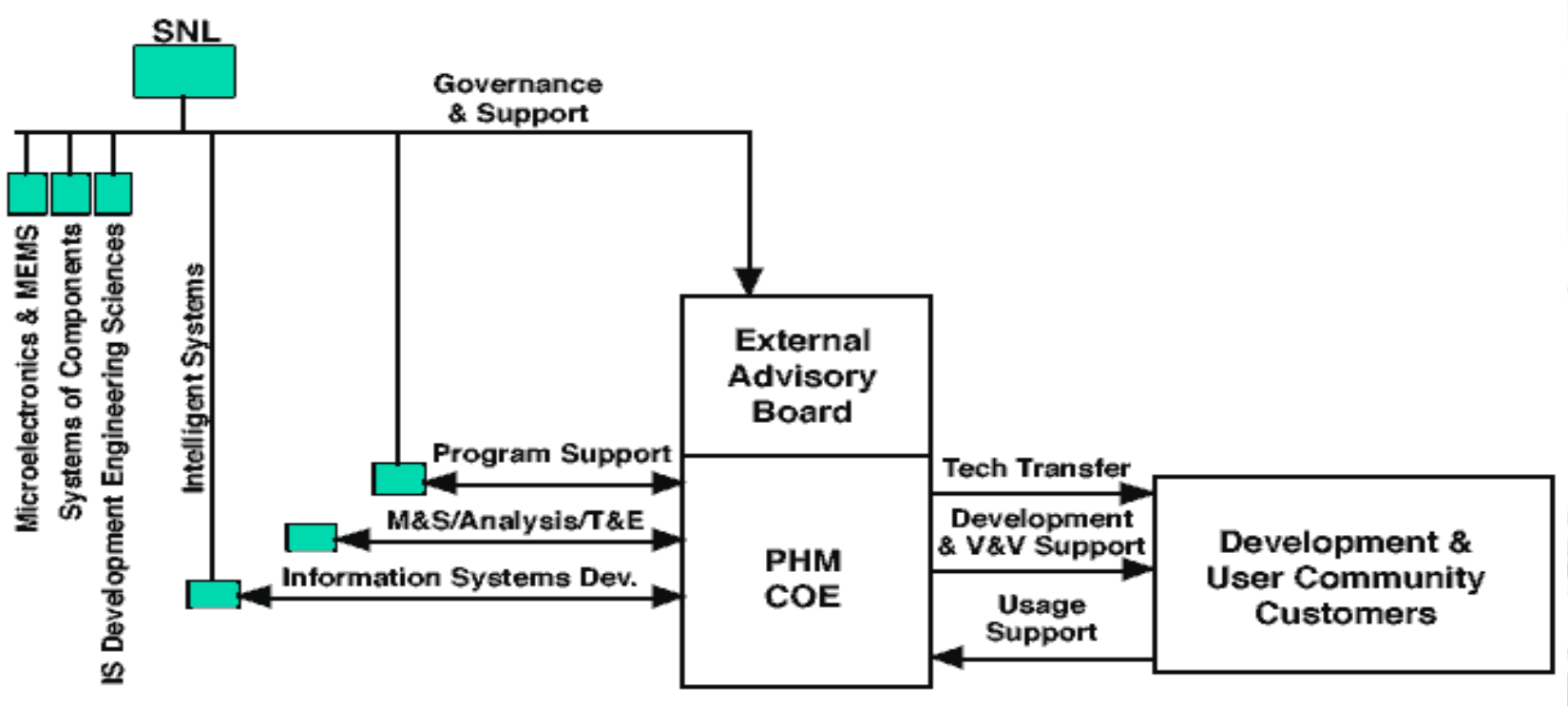
Sandia is establishing, in collaboration with the DoD, Industry, and Academia, the PHM Center of Excellence, which will have both technology development and technology test and validation capabilities.

Our vision is a world class facility dedicated to conducting experimental analysis and relevant research, through comprehensive science-based modeling, simulation, and experimentation.

How the PHM COE will Operate:

An advisory board will be established and will be composed from organizations within Sandia and external organizations from government, military, industry, academia, and professional societies with specific interest in prognostic and diagnostic technology.

The following figure shows a Notional COE Organizational Concept illustrating how the COE Board and operations might be set up.



The PHM COE-When?

The PHM COE will commence operation no later than April 1, 2005. The COE anticipates operations for 5-10 years, depending on challenges the COE is asked to solve.