Air Force Needs for SHM

Penn State University
Ben Franklin Center of Excellence in SHM
Inaugural Meeting
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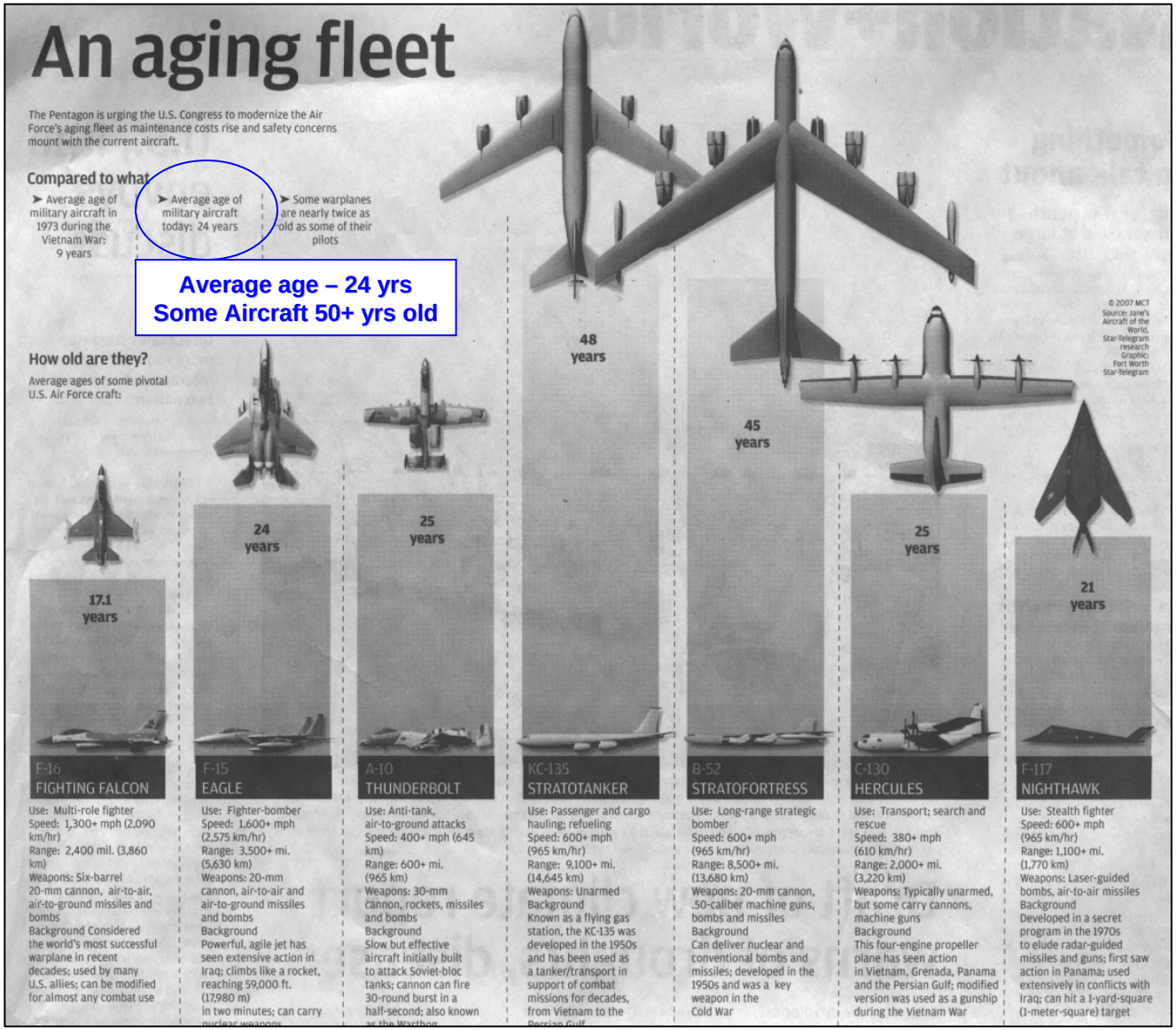
AFRL/MLLP
Air Force Research Laboratory

Presentation Outline

- Motivation for SHM and Integrated/Embedded Sensing
- Air Force Transformation
  - Expeditionary Logistics for the 21st Century : eLog21
  - Condition Based Maintenance : CBM+
  - Focused Long Term Challenge initiatives (FLTCs)
- SHM & Real Time State Awareness of Air Force Systems
  - Past, Present, Future…
- AFRL research initiatives for embedded sensor systems
  - Needs, R&D programs, technical challenges
- Summary

Motivation for SHM & Embedded Sensing



Time and Money

- Aircraft availability
- Aircraft O&S costs
- New vs Old Aircraft

Aging AF Fleet

- More damage
- Increased inspection burdens
- More cost/downtime

NDE and SHM

- More NDE demands
- Inspect more often
- More disassembly
- Remote locations

Air Force Transformation:

eLog21 – Expeditionary Logistics for the 21st Century

- The AF Innovation and Transformation Office (AF/A4I) established in Feb 2003:
  - Role is to develop and implement transformation policy and planning across all the MAJCOMs, Product Centers and ALCs
  - eLog21 is a collection of dozens of AF initiatives
- eLog21 drives change with two goals:
  - 20% increase in equipment availability
  - Reduce Annual O&S Cost by 10% by fiscal year 2011
- Near-term actions with long-term effects

Air Force Transformation:
Condition Based Maintenance+ - an eLog21 Initiative

Paradigm shift from reactive/preventive maintenance to predictive/intelligent logistics and maintenance

- CBM+ enables:
  - Anticipatory, reliability-centered maintenance
  - Reduced logistics footprint and ownership costs
  - Increased operational availability and mission capability
- CBM+ technologies include:
  - Enabling systems for comprehensive systems health awareness
  - Advanced sensors & diagnostics (NDE and embedded SHM)
  - System prognostics & predictive tools

Air Force Transformation:
Focused Long Term Challenges - FLTCs

Air Force Transformation:
Focused Long Term Challenges - FLTCs

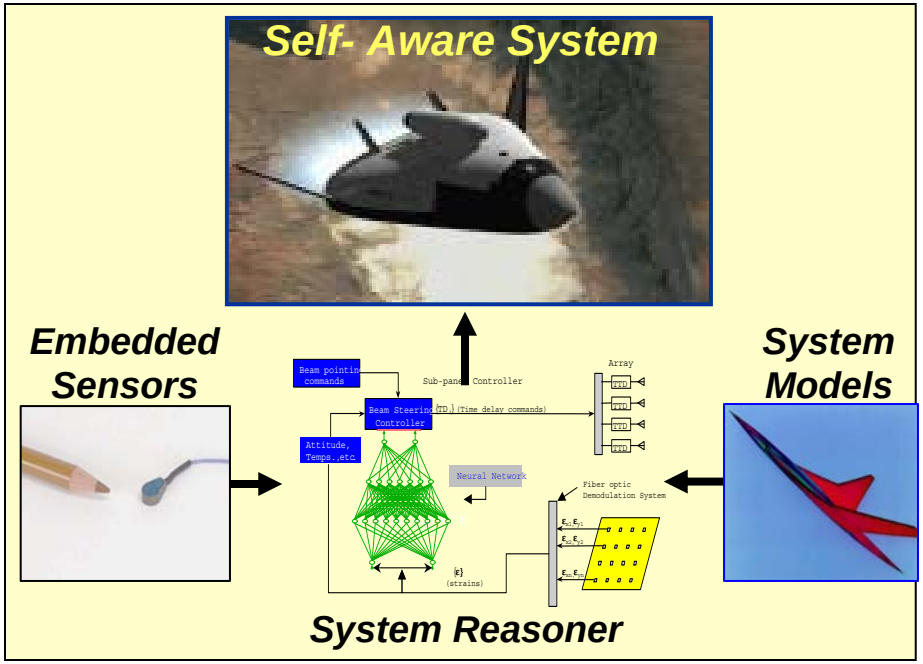
FLTC #8 Attribute 1 - Provide Real-Time State Awareness

MID-TERM DEMONSTRATIONS ***FY***

- **Robust, environmentally relevant, reliable integrated sensor suite** ***2013***
- **Automated usage monitoring and system health analysis in relevant environments** ***2013***
- **Actual system usage profile used to determine individual service intervals** ***2014***

Integrated System Health Management Demo ***2015***

- **Reduce O&S costs by 10%**
- **Increase Mission Capability Rate by 20%**
- **Reduce class A failures by 75%**



FAR-TERM VISION

Integrate real-time state awareness and usage history into AF systems to assess health status for efficient mission and maintenance planning

Air Force Transformation

AF VISION

Through Technology, Eliminate Sustainment As We Know It Today

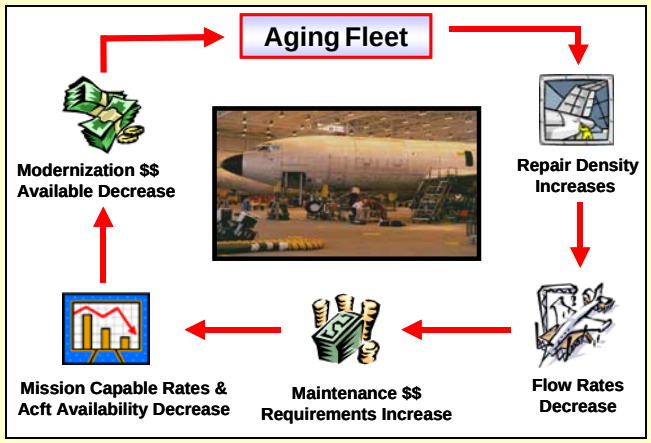
- ✓ **Remove designated intervals for inspections & PDM**
- ✓ **Maintain only *when needed* & *where needed***
- ✓ **Bring sustainment inside the AF Ops decision loop**

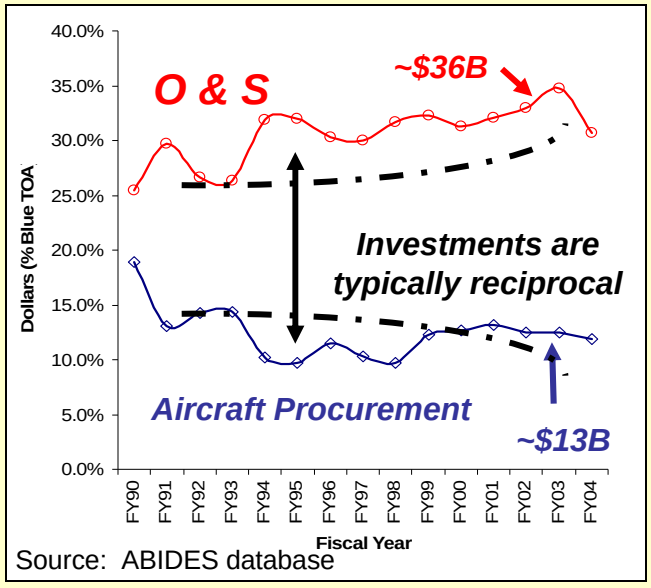
Move From Reactive to Proactive Mindset

SHM & Real Time State Awareness:

Past, Present, Future…

2000





Source: ABIDES database

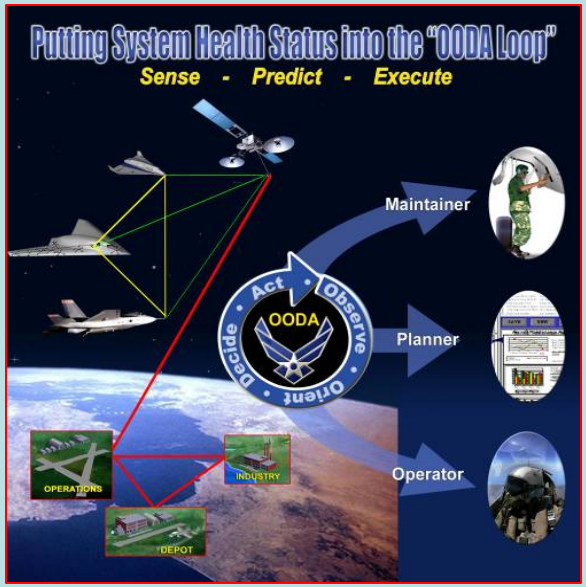
2010

"JSF Prognostics and Health Management**"

- **Requirements for future structural, engine, and stealth health prognostics:**
  - **Integrated structural sensors for strain, temperature, and corrosion**
  - **Engine sensors for system reliability and efficiency improvements**
  - **Embedded antennas and other sensors**
  - **Need identified for demo/implementation by CY 10**

**Joint Strike Fighter - SCIENCE & TECHNOLOGY Priorities Document, June 2003

2030



- Provide maintainer total system health information
- Enable maintenance and mission planners to optimize asset allocations
- Enable operators to assess system capability during the mission

AFRL R&D Initiatives for SHM:

AFRL R&D Programs

Materials/Manufacturing Directorate (AFRL/ML)

- Sensing materials research
- Advanced fabrication methods
- Nondestructive evaluation
- Material failure mechanisms

Air Vehicles Directorate (AFRL/VA)

- Sensor insertion into aircraft structures
- Sensor system testing
- Aircraft system failure modes
- Wireless sensing

Human Effectiveness Directorate (AFRL/HE)

- Human factors/system interface research

Space Vehicles Directorate (AFRL/VS)

- Sensors for harsh environments
- Spacecraft system failure modes

Propulsion Directorate (AFRL/PR)

- Sensor insertion into engines
- Sensor system testing
- Engine system failure modes
- Sensor energy/power research
- Sensors for harsh environments

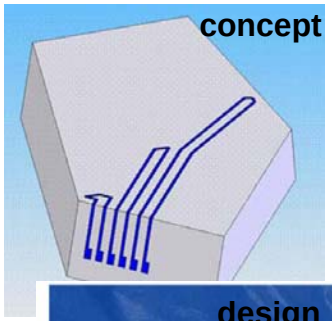
Sensors Directorate (AFRL/SN)

- Sensor development
- Wireless sensing
- Sensor energy/power research

Information Directorate (AFRL/IF)

- Sensor data collection/storage
- Data interpretation/decisions

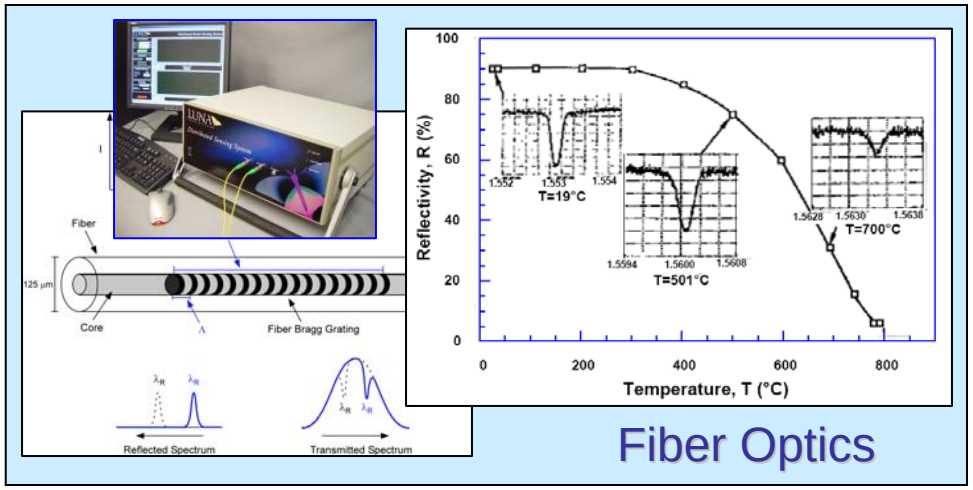
AFRL R&D Initiatives for SHM:
Technology Needs



- Embedded sensor development
  - Extensions of current technologies/methods
  - Revolutionary materials and sensing concepts
- Embedded Sensor System Evaluation
  - Standardized performance T&E
  - ISHM System Durability and survivability
- Physics of failure and sensor/sensing physics
- Complex geometry Aerospace sensing problems
- Rational strategies for SHM implementation
- Data management and infrastructure development

AFRL R&D Initiatives for SHM:
Embedded Sensor Development

Extensions of Current Technologies/Methods

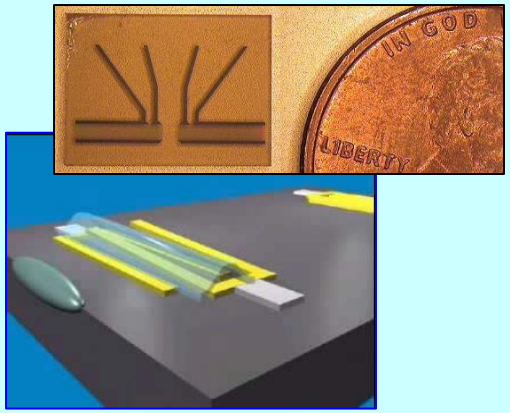


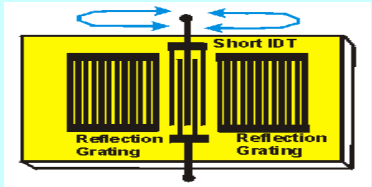
Fiber Optics

SHM Considerations for Aircraft

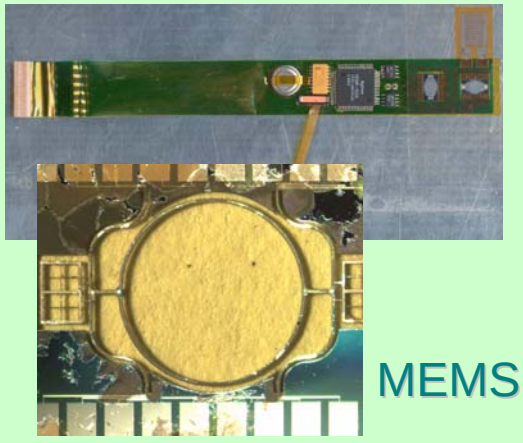
- Miniature, lightweight, nonintrusive
- Flexible, conformable
- Reliable, robust, durable
- Easy installed, removed, repaired
- Autonomous, wireless, self-powered
- Inexpensive

Delay-Line SAW





Resonator SAW

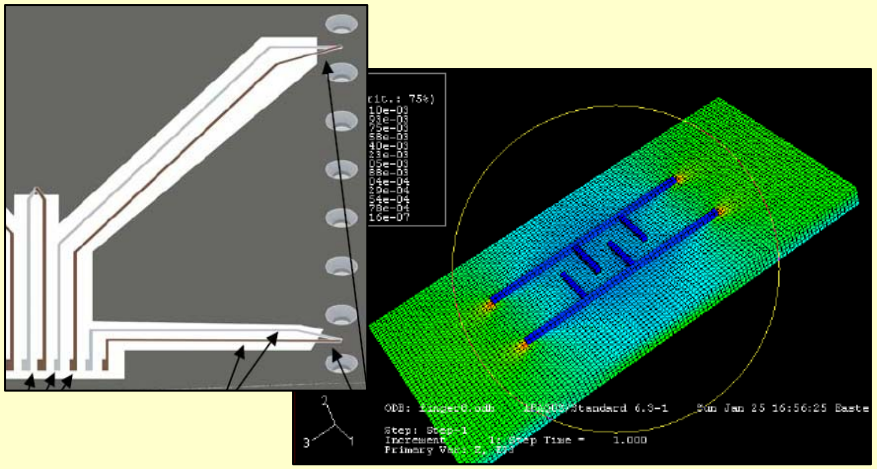


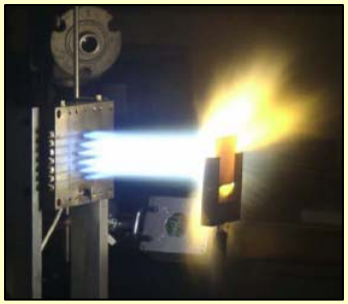
MEMS

Piezo

AFRL R&D Initiatives for SHM:
Embedded Sensor Development

Revolutionary Materials and Sensing Concepts

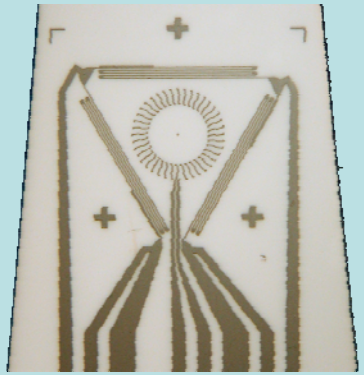


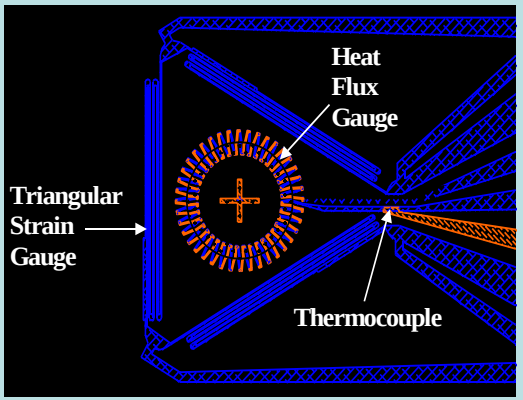


Plasma Spray Sensors

SHM Considerations for Aerospace

- Extreme environments sensors
- Multi-functional sensing
- Fully-integrated
- Wide-area, global sensing
- Self-sensing, self-aware systems





Multi-Functional Thin Film TaN Sensor

AFRL R&D Initiatives for SHM:

Physics of Failure & Sensor/Sensing Physics

Prognosis - Predict future capability (or health) based on knowledge of current state and the intended future usage

Quantified Health/Damage State

State Awareness - Sensors/Diagnostics

Failure physics, damage evolution, predictive models

Prognosis

Database: Mission History, Maintenance, Life Extension and Design

SHM Opportunities:

- Predict future capability based on damage state + anticipated usage + damage evolution models
- Capability management by tail number
- Manage assets based upon actual usage
- Optimized maintenance
- Maximize availability
- Insure safe operation
- Adaptive asset allocation

AF (ALC, MAJCOM, OEMs)

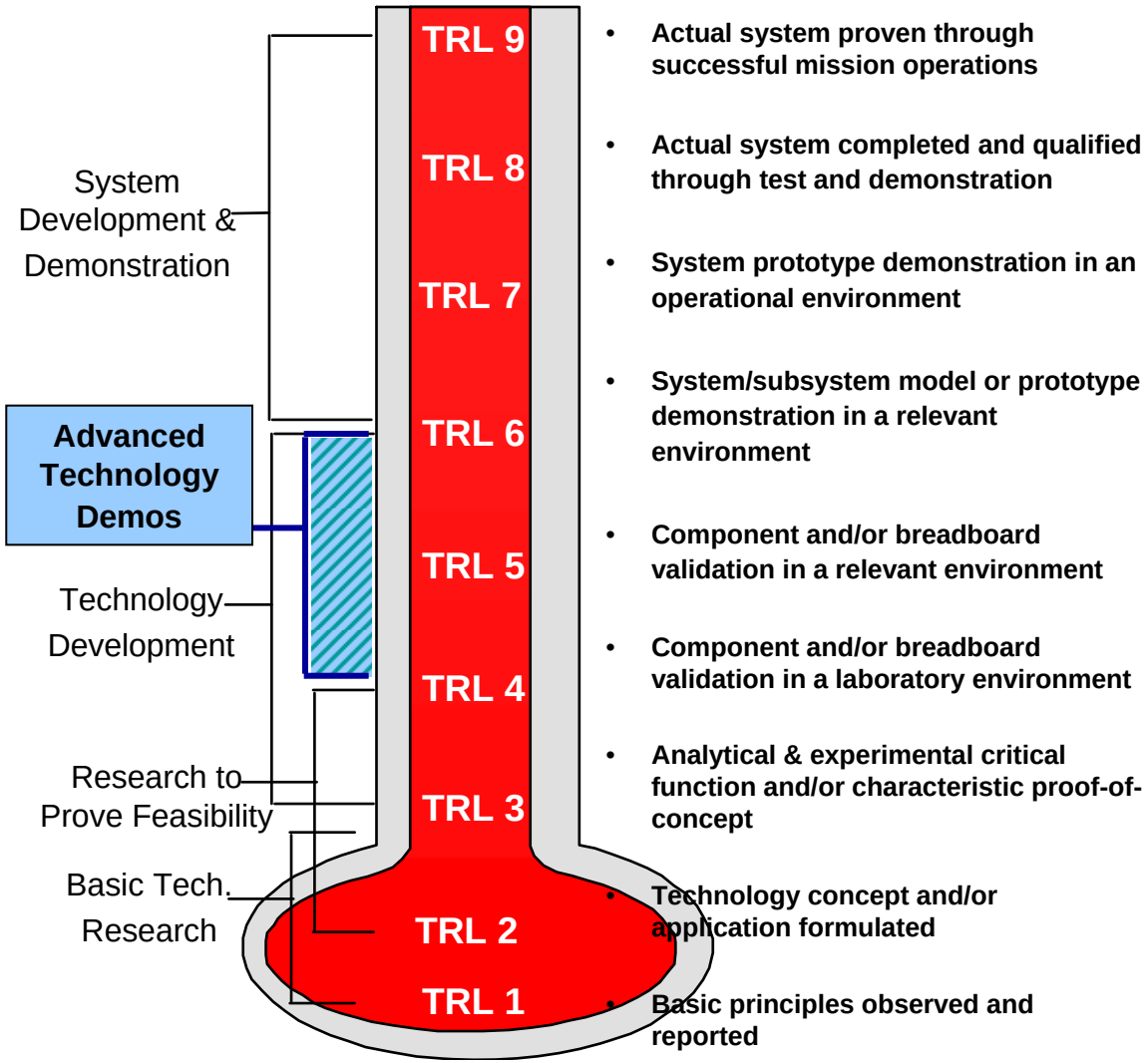
AFRL

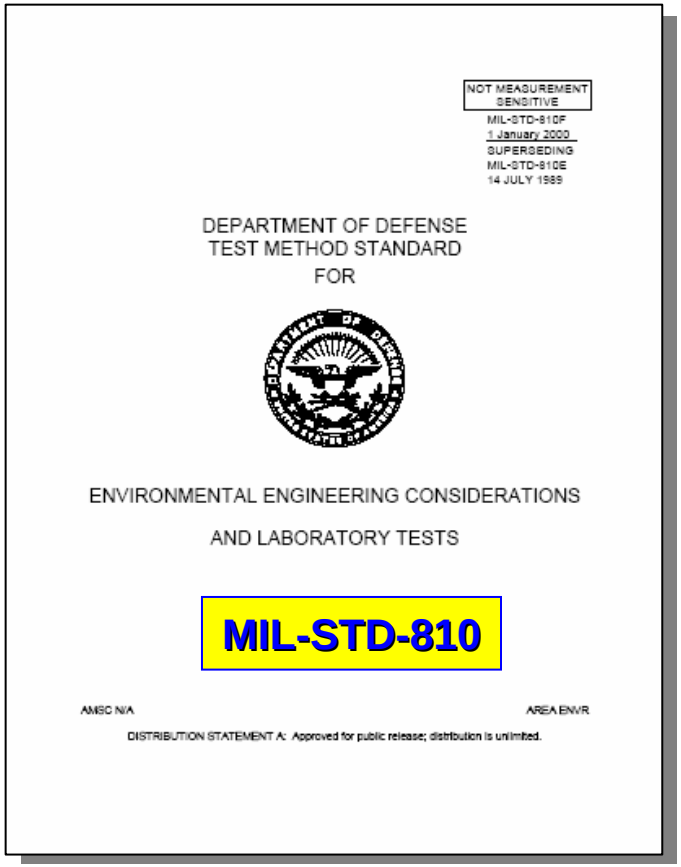
DARPA

AFRL R&D Initiatives for SHM:

Embedded Sensor System Evaluation

Standardized Testing & Evaluation




NOT MEASUREMENT SENSITIVE
MIL-STD-810F
1 January 2000
SUPERSEDING
MIL-STD-810E
14 JULY 1989

DEPARTMENT OF DEFENSE
TEST METHOD STANDARD
FOR

ENVIRONMENTAL ENGINEERING CONSIDERATIONS

AND LABORATORY TESTS

MIL-STD-810

AMSC N/A AREA ENVR

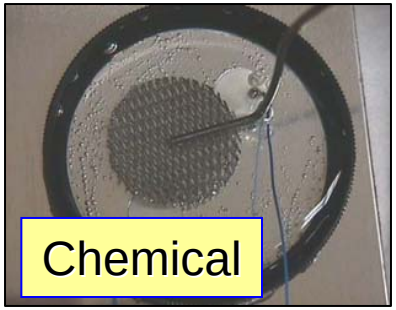
DISTRIBUTION STATEMENT A: Approved for public release; distribution is unlimited.

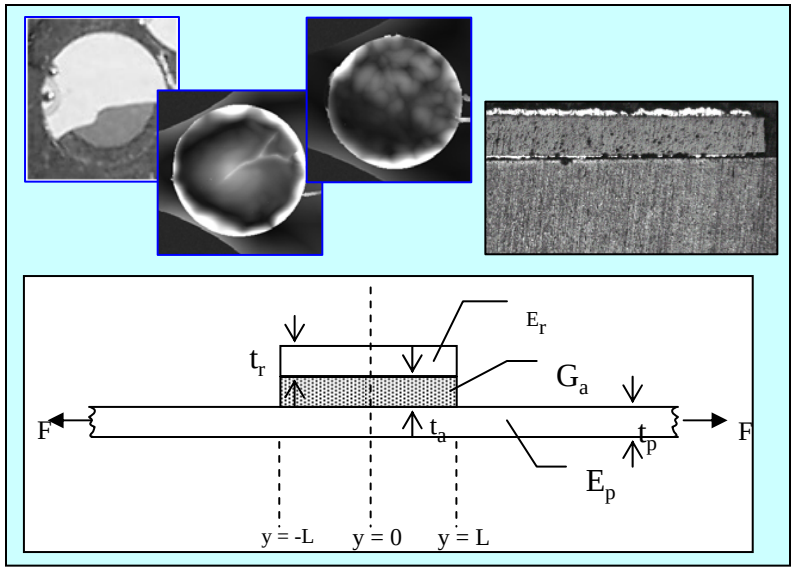
- **Accelerated Lab Testing**
- **Flying SHM testbed**
- **STIC, Flight Qualified**

AFRL R&D Initiatives for SHM:

Standardized Test & Evaluation

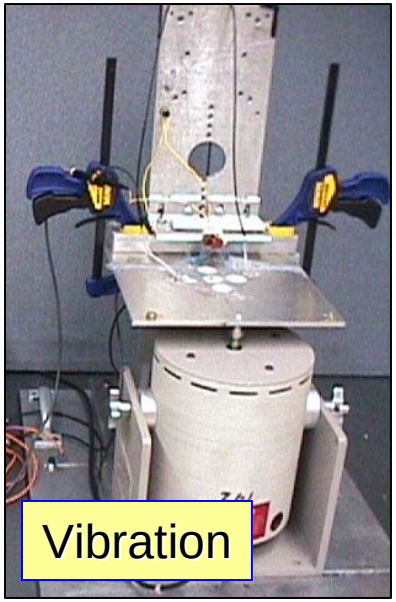
SHM Durability and Survivability





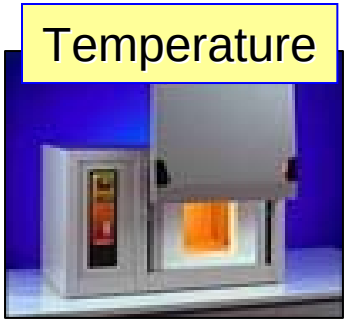
SHM Durability Issues

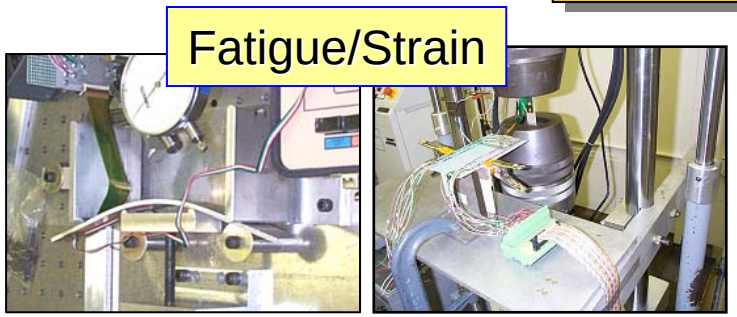
- Sensor damage
- Sensor degradation
- Sensor drift
- Auxiliary systems



SHM Opportunities

- Packaging
- Materials
- Design/models
- Integration

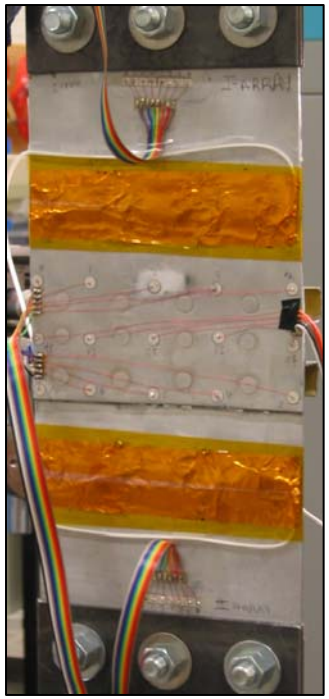




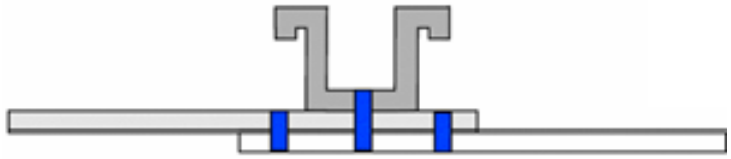
AFRL R&D Initiatives for SHM:

Complex Geometry Aerospace Sensing

Considerable SHM Opportunities for Aircraft Joints

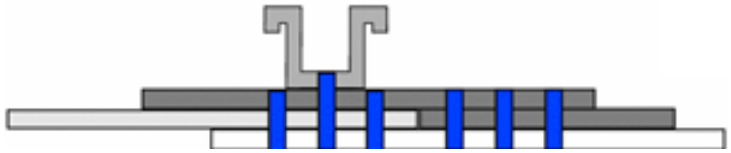


Two-layered lap-splice

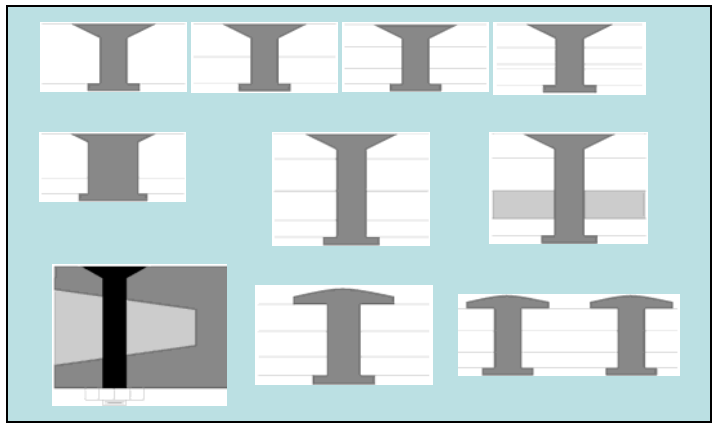


Two-layered lap-splice with reinforcing stringer

Three-layered butt-splice



Two-layered lap-splice with reinforcing stringer and tear straps



Aircraft Joint Complexities:

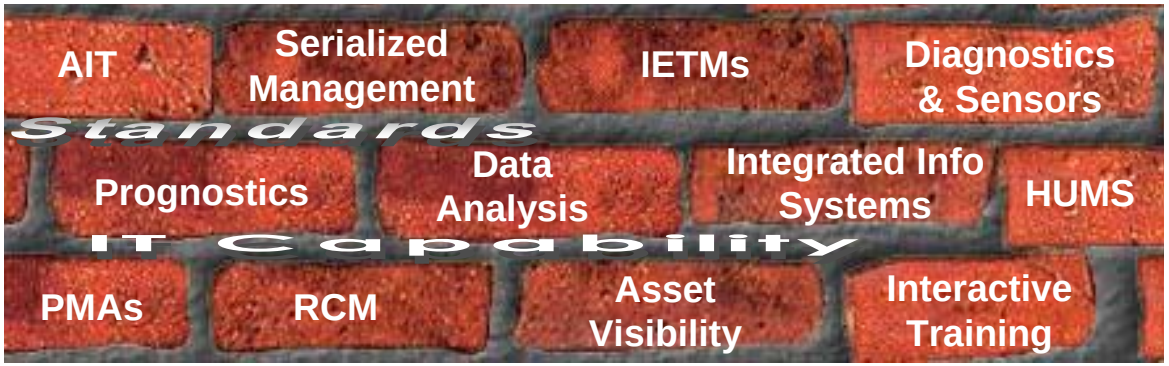
- Variable joint structures
- Variable thicknesses
- Variable fasteners
- Multi-layer systems
- Multi-material systems

AFRL R&D Initiatives for SHM:

Rational Strategies for SHM Implementation

SHM Implementation:

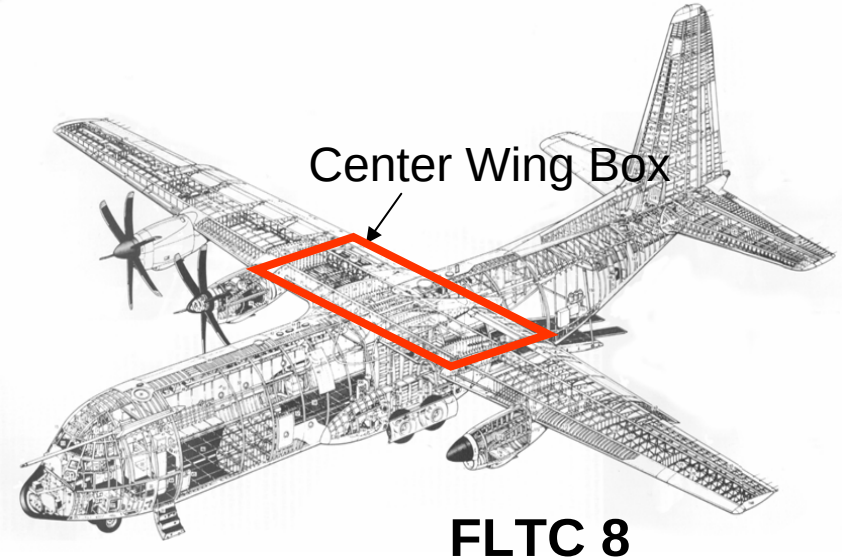
- in new systems during acquisition/design
- in legacy systems *where applicable* and *cost effective*



Traditional field eddy current Probes

Advanced on-board / depot / ield sensing

NDE + SHM



FLTC 8

Product 8.1.1.1

Structural Integrity Demonstration - 2015

AFRL R&D Initiatives for SHM:

Rational Strategies for SHM Implementation

Classes of SHM Window Problems

1. **Surface-breaking flaws:**
   a. Deterministic damage
   b. Localized damage
   c. Accessible structures
2. **Sub-surface flaws at fastener sites in horizontal (single, multi-layered) structures:**
   a. Deterministic/localized damage
   b. Access from an outer layer
3. **Sub-surface flaws in vertical risers with limited access**
4. **Sub-surface flaws with uncertain location in complex structural joints**
   a. Flaws under bushings
   b. Complex joints w/ uncertain flaw growth

Examples:

C-130 Rainbow Fitting
F-15 Pylon

C-130 Hat Section
A-10 WS 23
B-1B Lower Wing Skin
B-52 Span-wise Splice

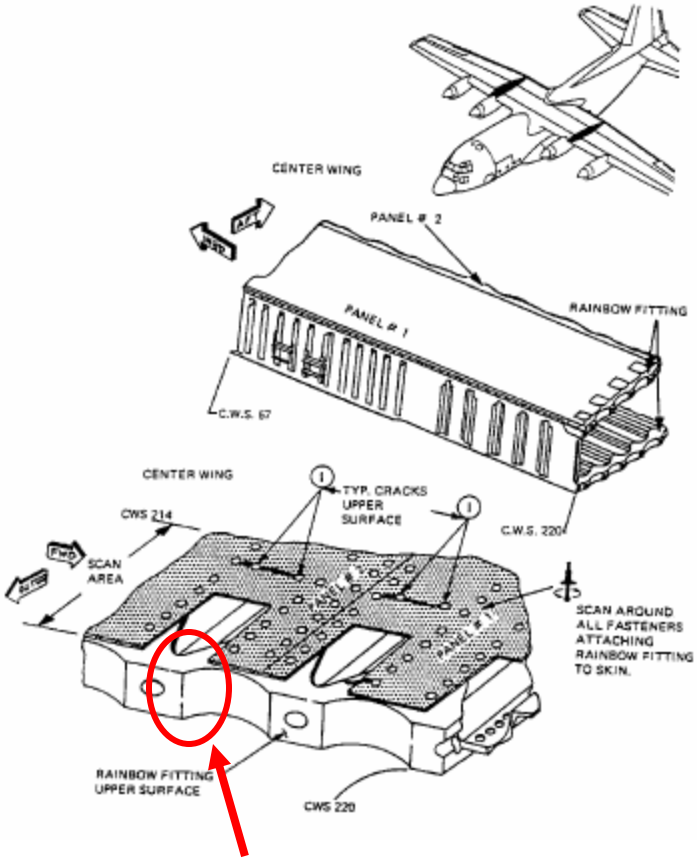
C-130 Beam Cap
A-10 Fuel Vent

A-10 WS 23 Bushed
B-1B WCT
C-130 Center Wing Box

AFRL R&D Initiatives for SHM:

Complex Geometry Aerospace Sensing

Class 1: C-130 Rainbow Fitting Cracking

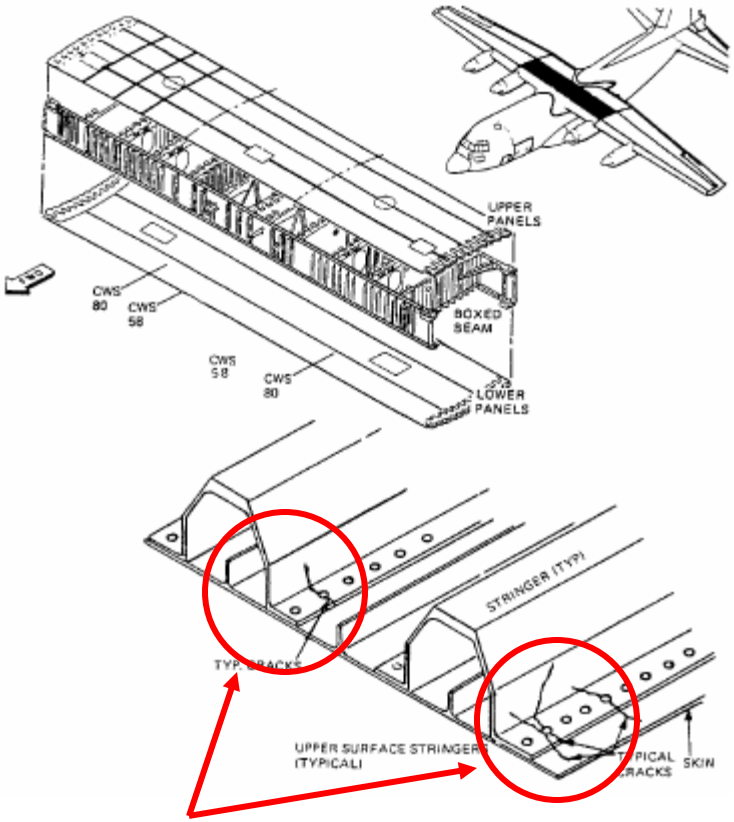


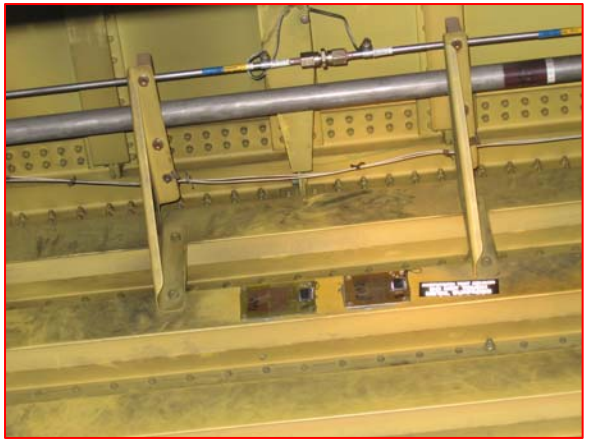
Deterministic, localized thru-crack in lug-bolt nodes

AFRL R&D Initiatives for SHM:

Complex Geometry Aerospace Sensing

Class 4: C-130 Center Wing Box

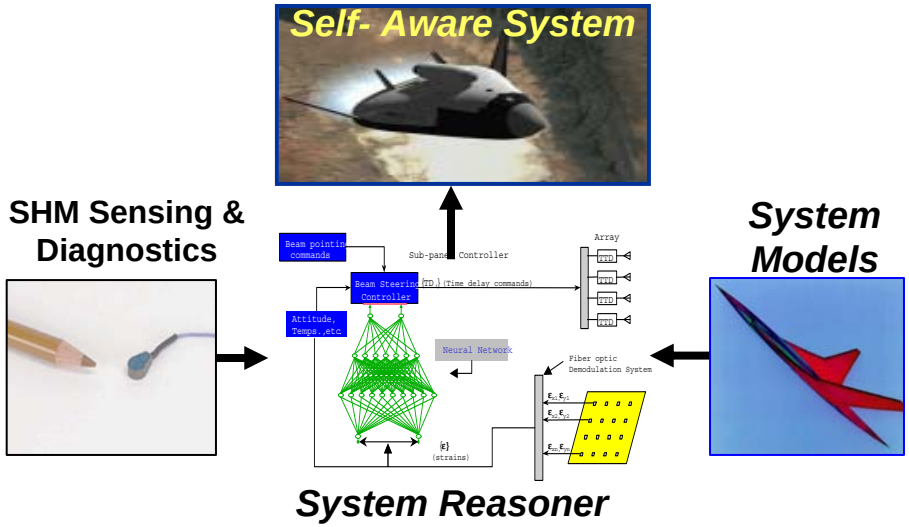




Non-deterministic, widespread cracks in multi-layer, complex joints

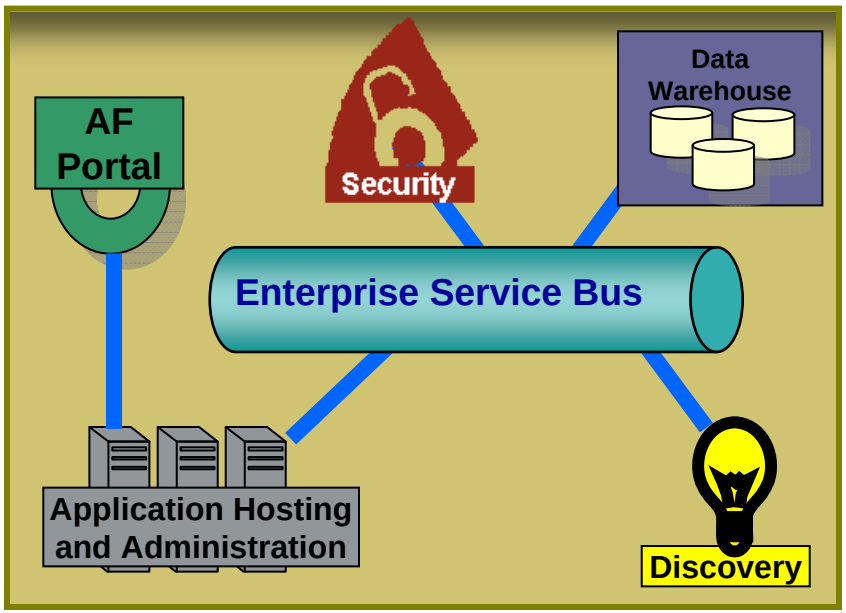
AFRL R&D Initiatives for SHM:

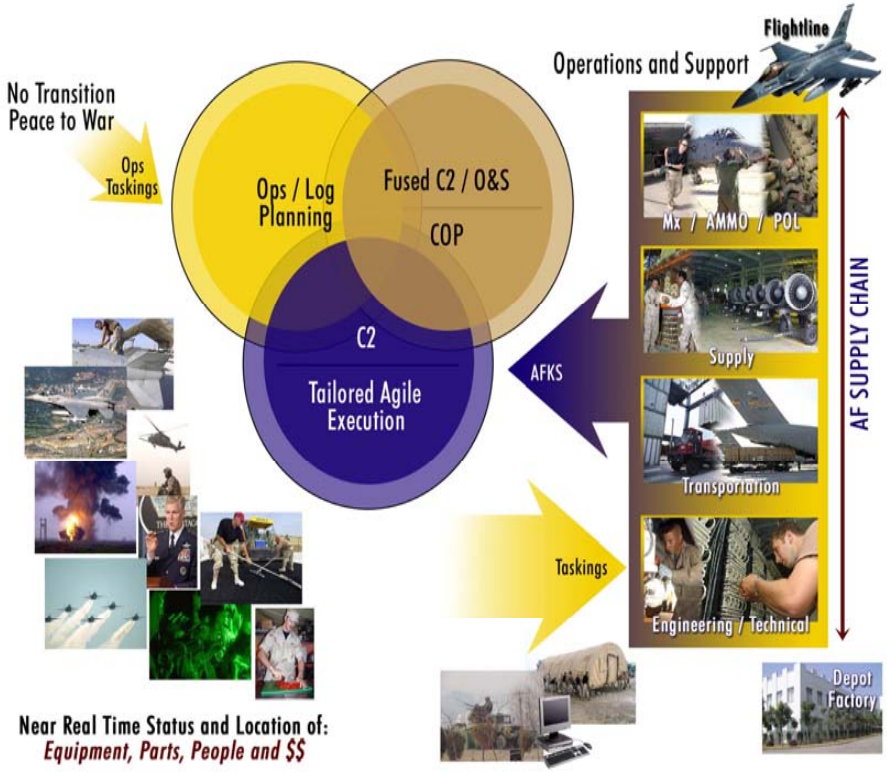
Data Management and SHM Infrastructure



SHM Infrastructure

- Technical interfacing
- Physical interfacing
- Operational interfacing





AFRL R&D Initiatives for SHM:

SHM Technical Challenges

- Robust and capable embedded sensor network development, optimization, calibration, and validation
- Extreme long-life requirements for SHM sensors
- Physics-based system diagnostic model development
- Understanding sensing system dynamics in varied operational environments and configurations
- Assimilation of embedded sensing systems with host system, and data from on-board, off-board, and system models
- Data acquisition architecture to collect, process and manage health data for system diagnoses and prognoses

Summary

- U.S. Air Force need for Integrated/Embedded Sensing
  - Time/money, aging fleet, growing problem
- Recent Air Force Transformation Activities:
  - Expeditionary Logistics for the 21st Century : eLog21
  - Condition Based Maintenance : CBM+
  - Focused Long Term Challenges (FLTCs)
  - Identified needs, requirements, and opportunities… 5-10 years
- SHM & Real Time State Awareness
  - Real aircraft systems – complex geometries, damage, environments
    - Classes of problems
  - Durable, validated, qualified SHM systems
  - Meaningful systems with proven benefit and payoff