Condition Based Maintenance (CBM)
In
Engine Health Management Plus (EHM+)

(From R&D To Sustainment and Vice Versa)

Presented By:
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Presentation Outline

- Maintenance concepts
- Health management capabilities
- U. S. Air Force vision
- DATT
- AFKS R&D/analytical environment
- About SMI

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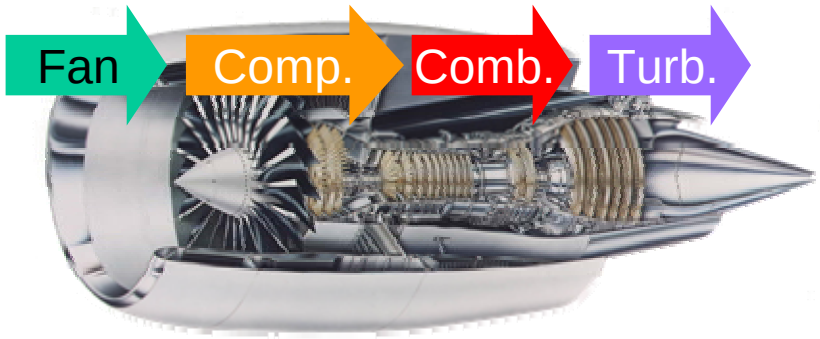
How Maintenance Was Done – An Engine Example

How Engine Works



How Maintenance Works

Photo Courtesy iStockPhoto.com

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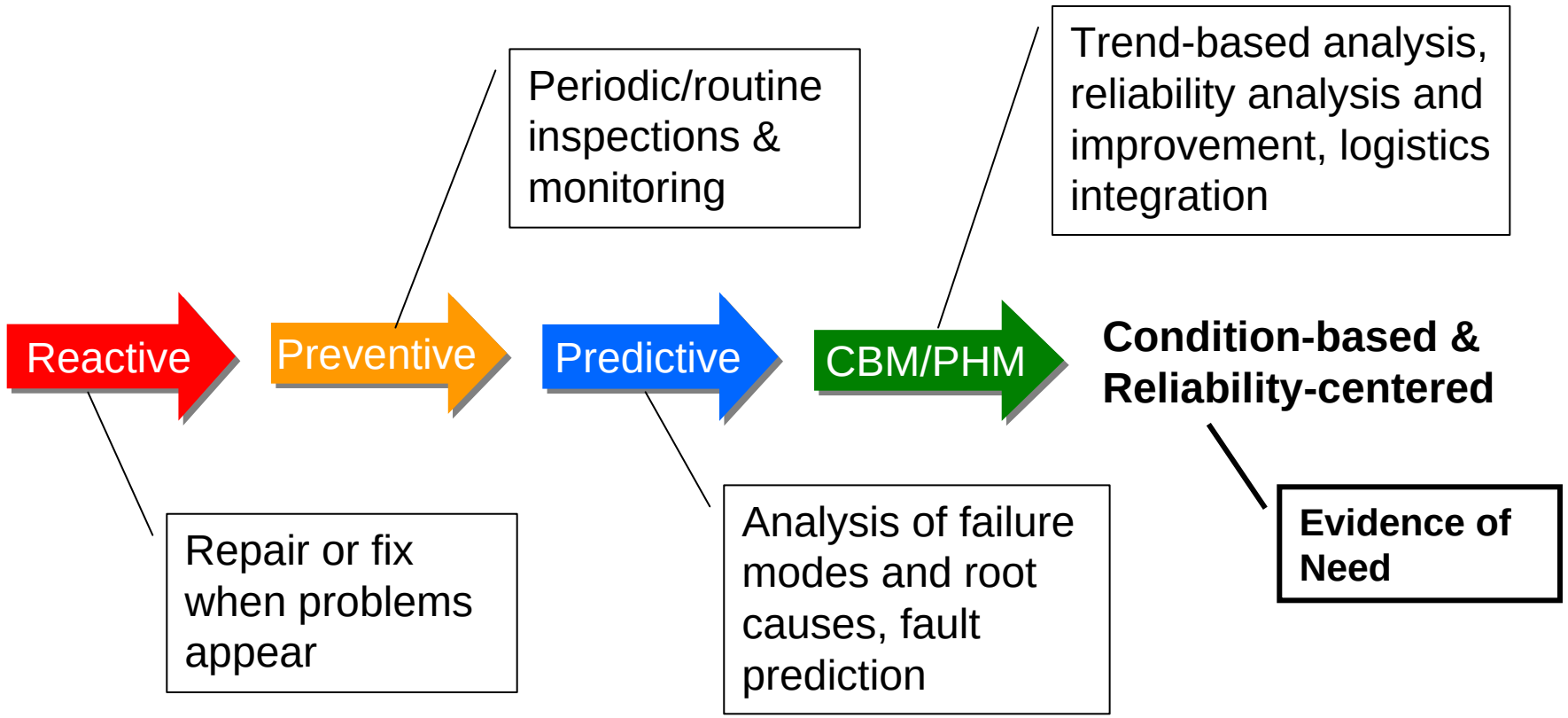
How Maintenance Technology Has Evolved

scientific monitoring inc

Maintenance Evolution



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Health Management Goes Beyond Maintenance

Integration of monitoring, maintenance, supply chain, and operations is the key to maximizing asset availability and logistics efficiency → System/Vehicle Health Management

Operations and Logistics Planning

Equipment or Asset → Control & On-board Monitoring → Off-board Health Management → Maintenance Decision Support → Maint. Work Control

Enterprise Resource Planning/Asset Management

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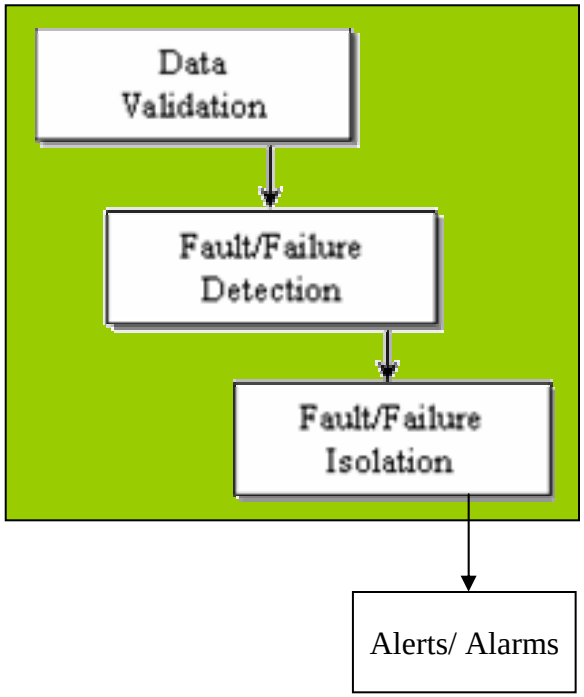
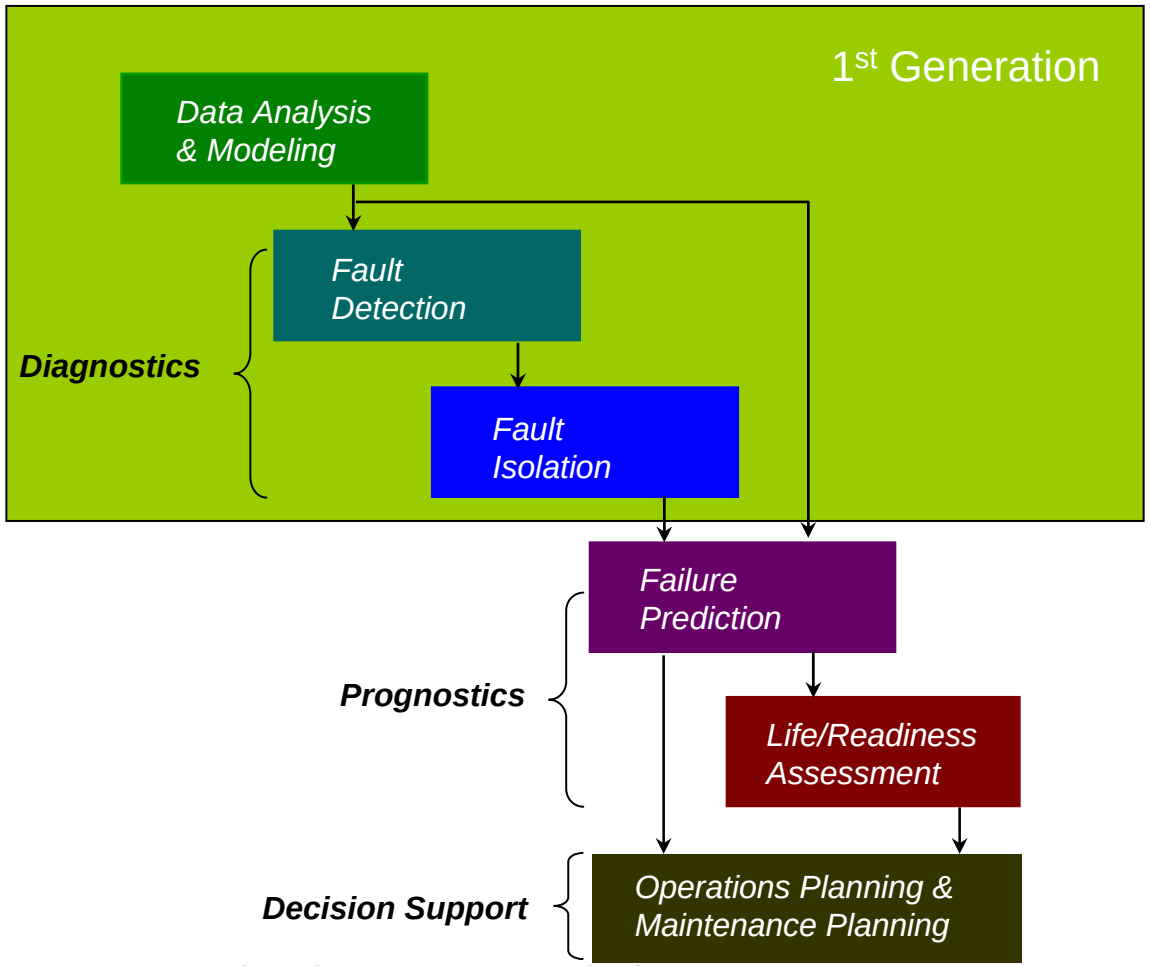
Two Generations of Health Management Capabilities

1st Generation – Fault Detection



2nd Generation – Failure Prediction & Accommodation



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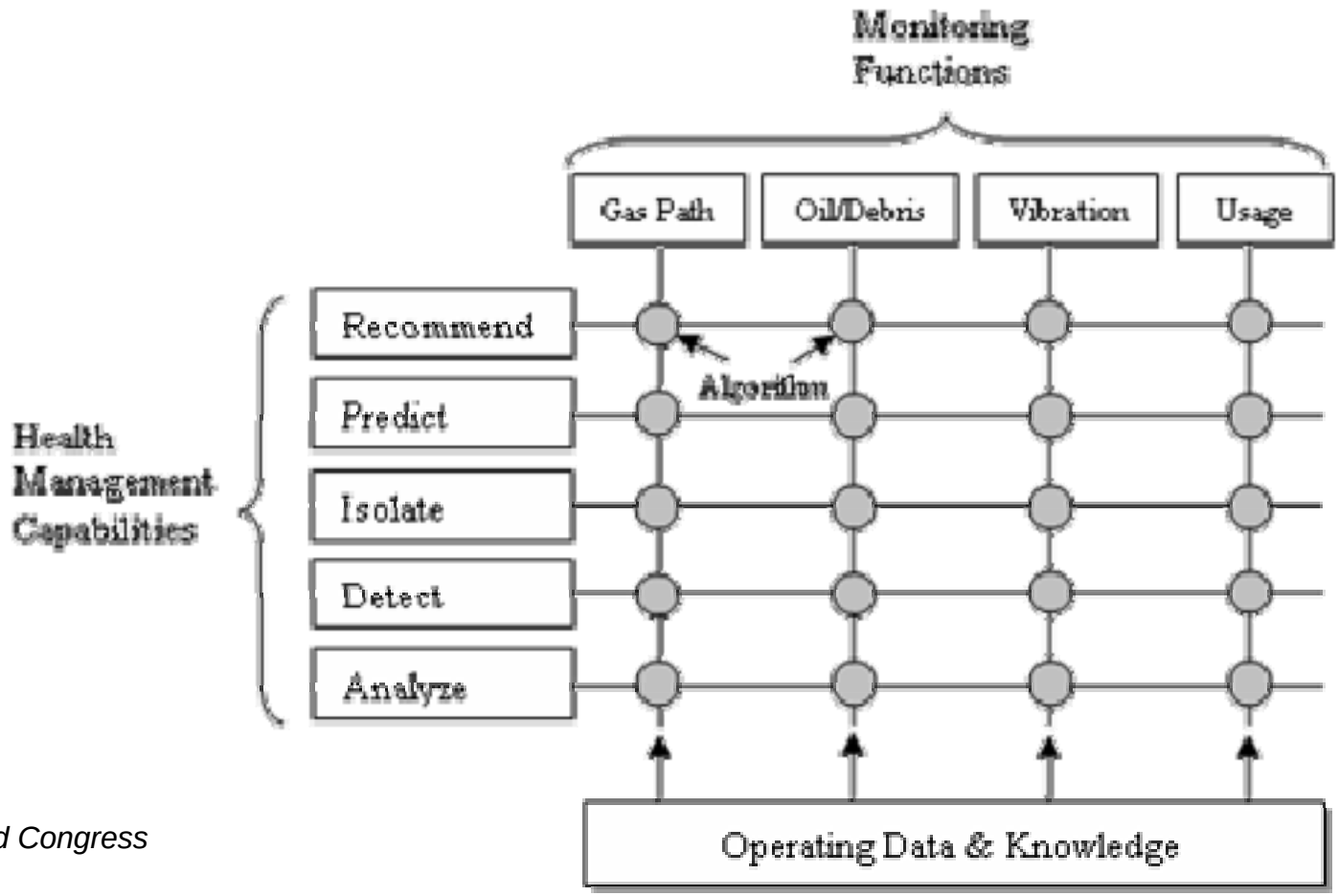
Decomposing Health Management Capabilities

- An aircraft engine example



Jaw, 2005 ASME World Congress

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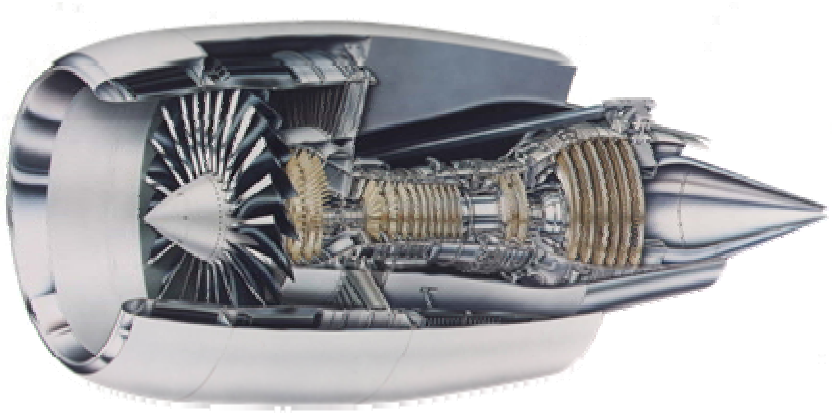
Engine Gas Path Monitoring Algorithm Landscape

Speed	Low	Medium	High
High	Linear Model	Neural Network	Fuzzy Logic Expert System
Medium	Kalman Filter	Hidden Markov Model Hybrid	Nonlinear Est.
Low	Bayesian Th.	Parameter Est.	Genetic Algor.

Complexity

Y. G. Li, 2002
L. Jaw, 2005



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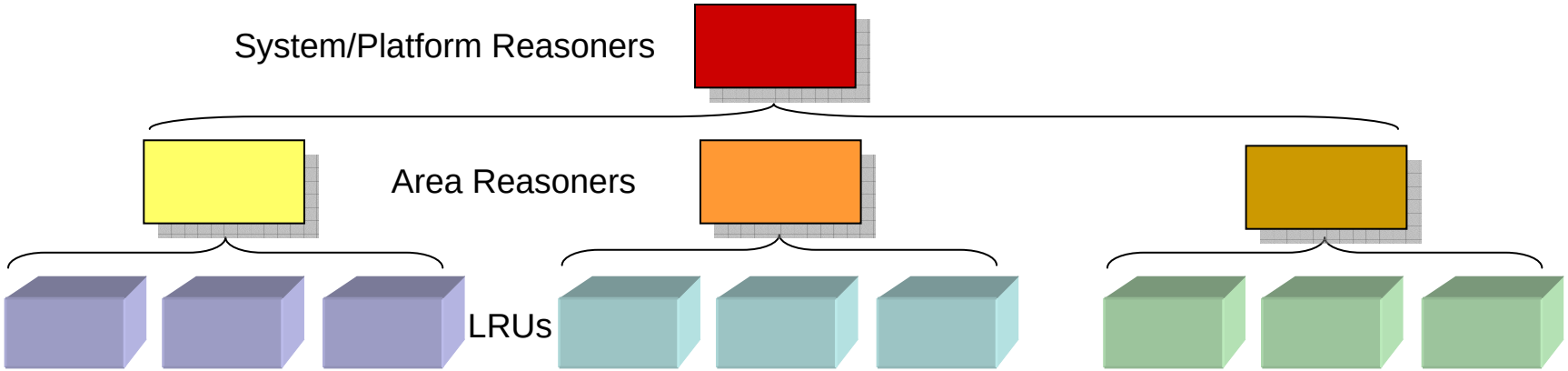
Two Perspectives of Health Management

- System integrators
  - Integrated system fault isolation
  - Availability & readiness



- Component/LRU suppliers
  - Diagnostics
  - Prognostics

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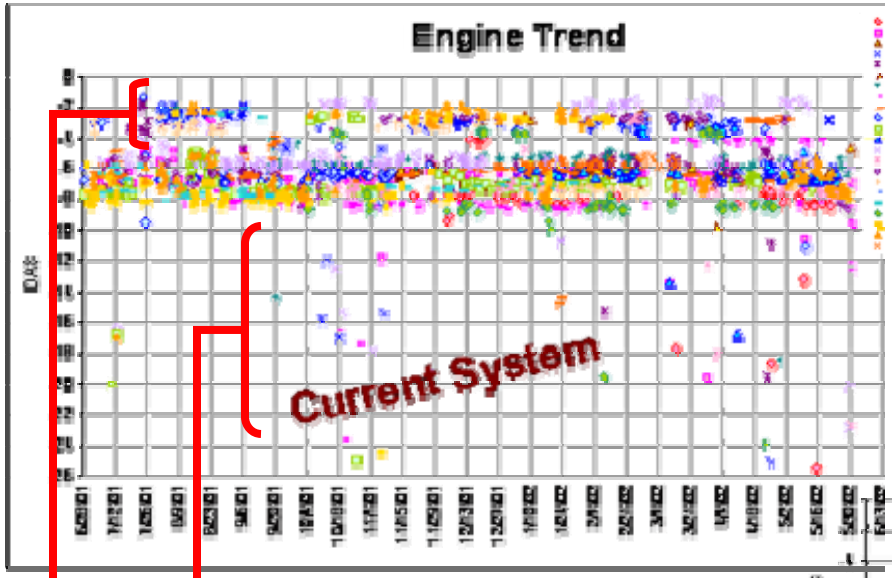
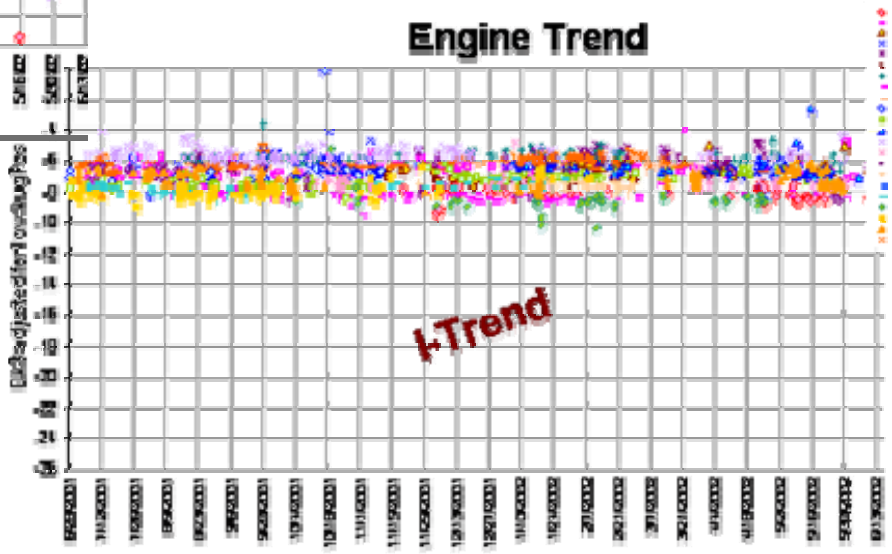
Health Management Starts with Data Analysis & Trending



Reducing data scatter or variability is the key to diagnostic success!



'Outliers' – with valid reasons for variation

Valid alarms mixed in with outliers

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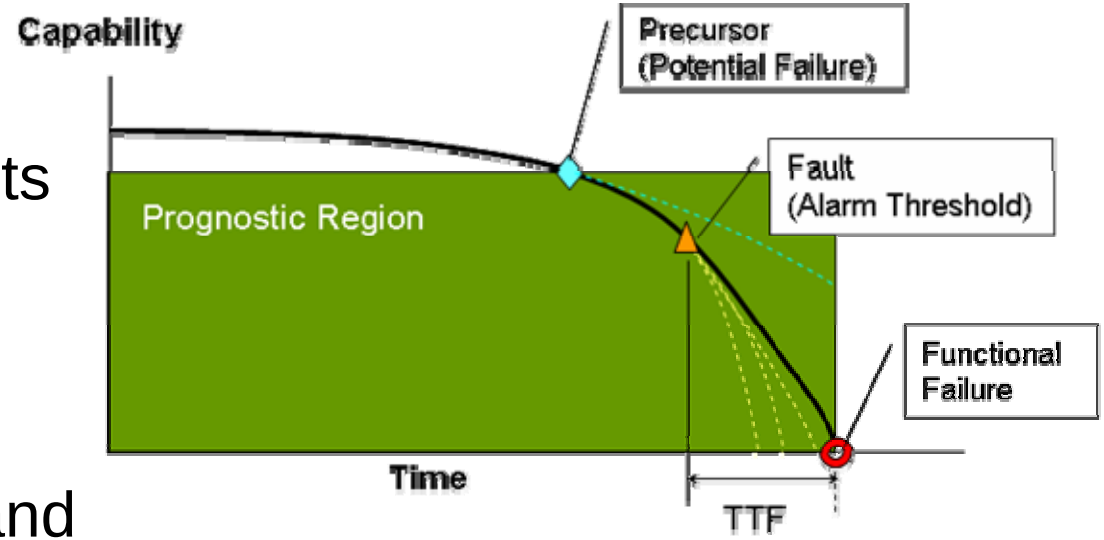
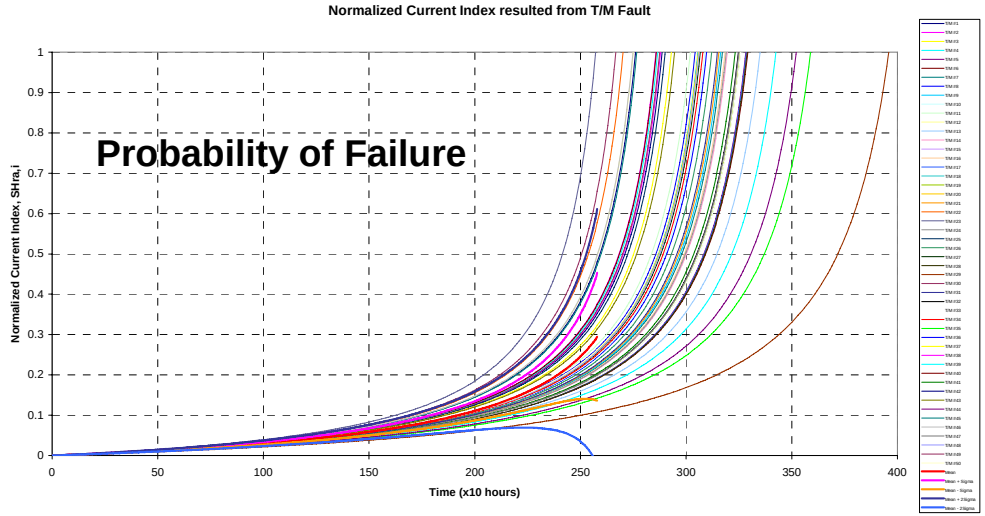
Health Management Ends with Failure/Life Prediction & Logistics

- Accurate prediction of failures or in-flight events
- Accurate estimate of time-to-failure and remaining life
- Recommendations for maintenance/logistics and operations
- Prognostic capabilities:
  - Today → "macroscopic" prediction
  - Future → "microscopic prediction





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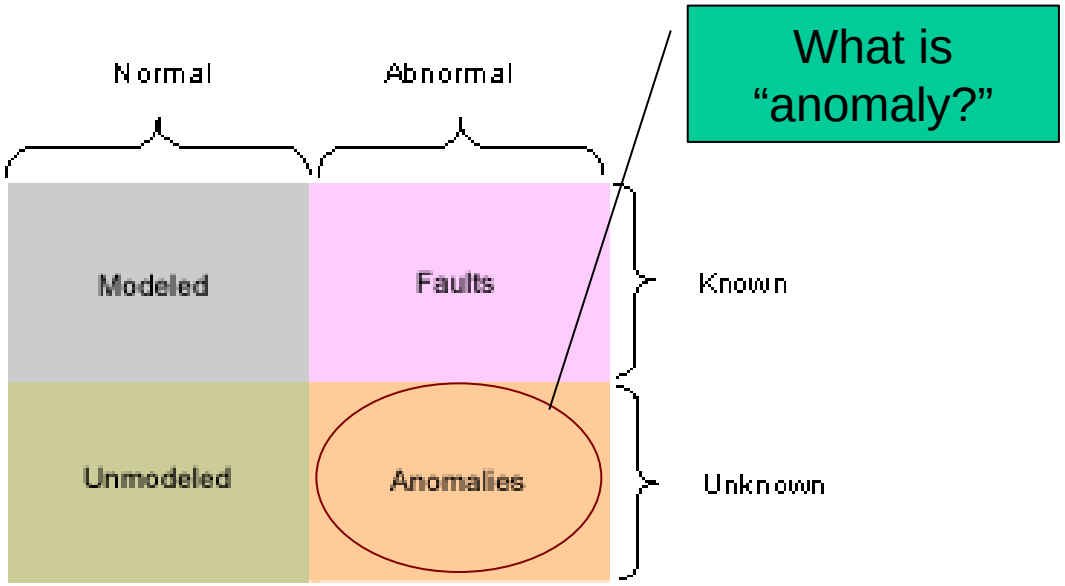
Discerning Noise, Precursor, and Anomaly

- Noise is “global” but precursor is “local”
- Precursor can be:
  - True detectable sign of early stage of a failure
  - Anomaly
- We can solve this problem by defining “anomaly” as an *unknown* (or intermittent) *abnormal* condition



Jaw, 2005 ASME World Congress

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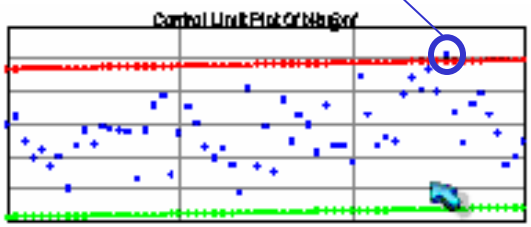
Unified Framework to Represent Diagnostic & Prognostic Problems

- Diagnostics:

$$z(t) = y(t) + v(t) > \gamma$$

$$\hat{x}_d(t) > \varepsilon$$

Exceeding threshold



- Prognostics

$$z(t + T_{tf}) = y(t + T_{tf}) + v(t + T_{tf}) > \varsigma$$

$$\hat{x}_d(t + T_{tf}) > \xi$$

T_{tf} = Time Delay or Prognostic Horizon

Degradation State Variable

Jaw, 2006 ASME World Congress

- The problem – threshold exceedance and state variable estimation

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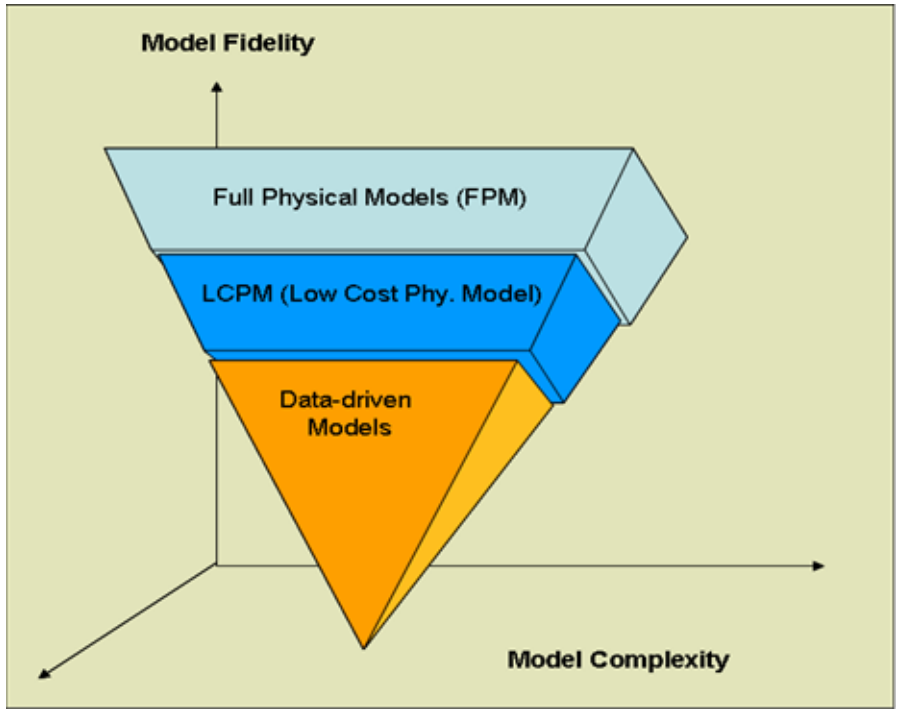
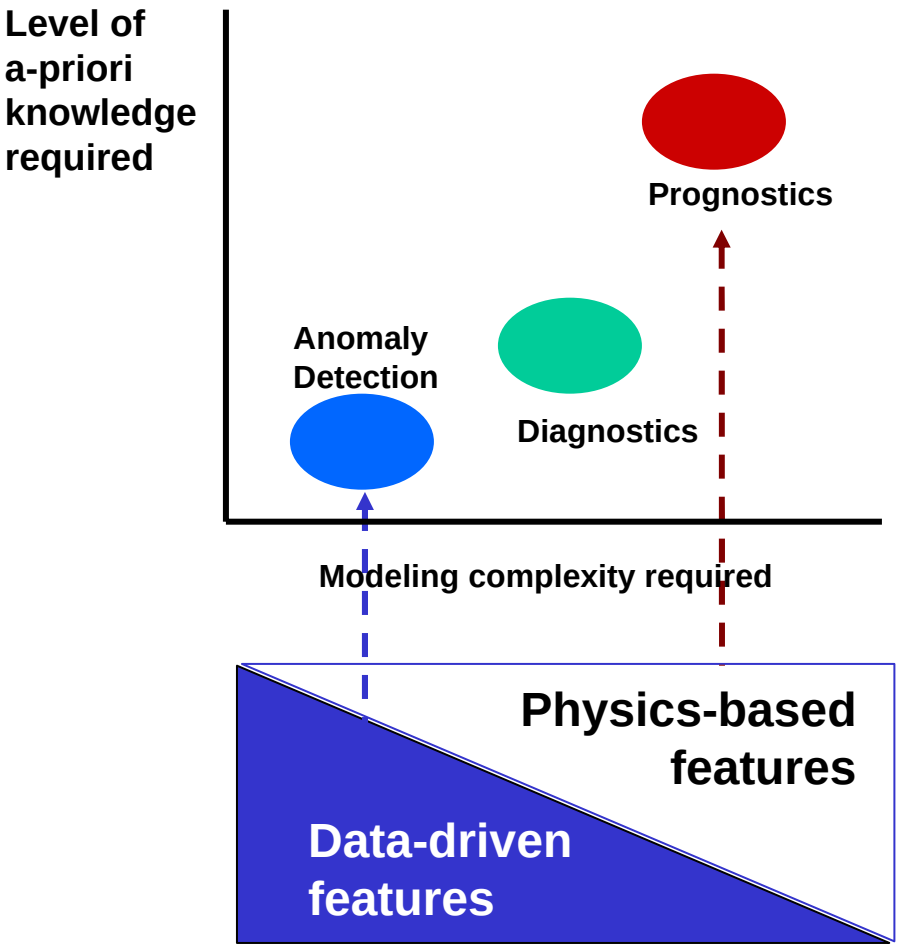
SMI's Hybrid & Scalable Modeling Approach





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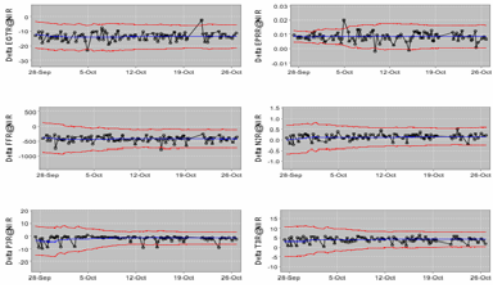
Health Management Needs A Flexible Software Architecture

User Interface
(Web, Existing Enterprise UI, Application interface)

- Trending
- Alerting
- Watchlist



Sensor & Aircraft Data Interfaces

XML or parsed text

CBM Tool Suite

XML or Sockets

Maintenance Control Software

CBM Database

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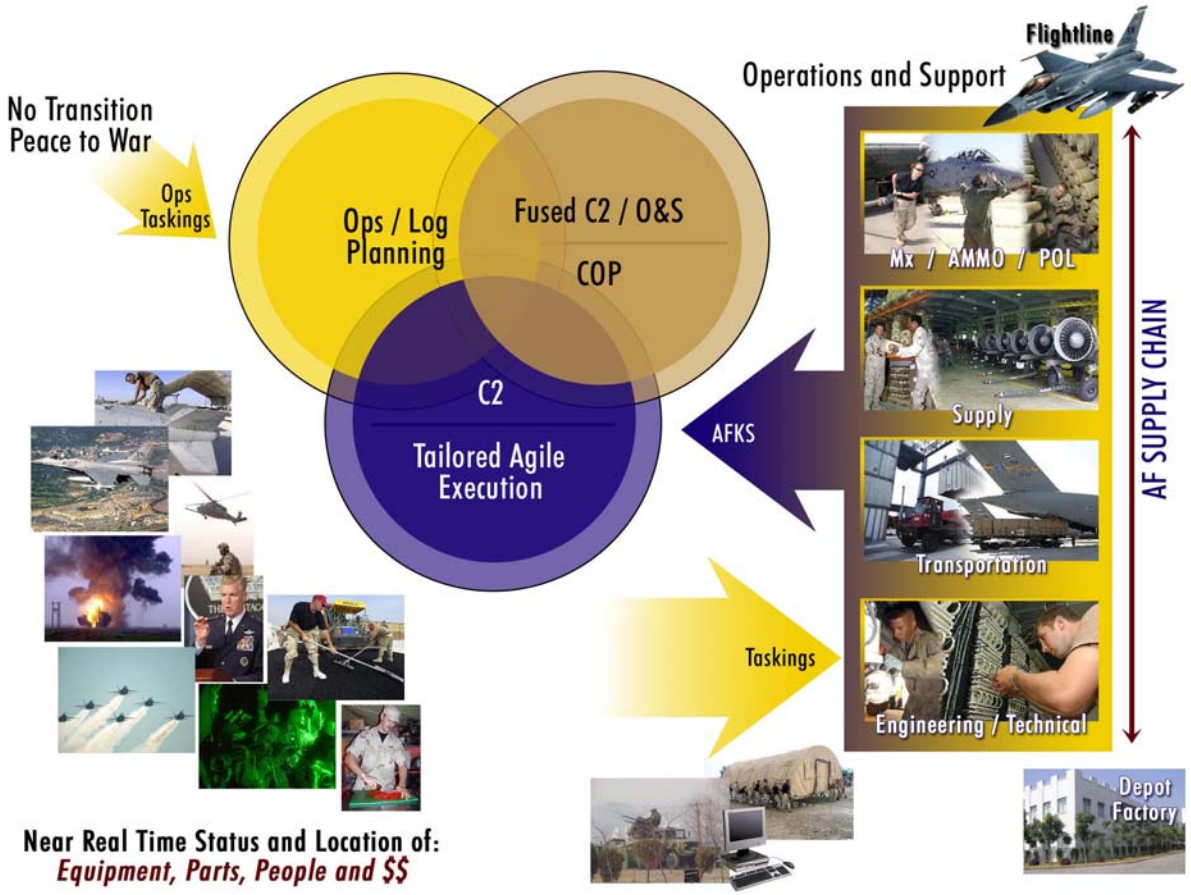
Air Force Information Technology Vision

- Air Force Vision: COP (Common Operational Picture)
  - Single access point to horizontally and vertically integrated data across the enterprise
  - Support Airmen in their decision making process
  - Timely access to all cross-functional and cross-domain data that is customizable and can be tailored to each user's needs



Reference: Air Force Common Operational Picture, USAF COP Team, 25 April 2005

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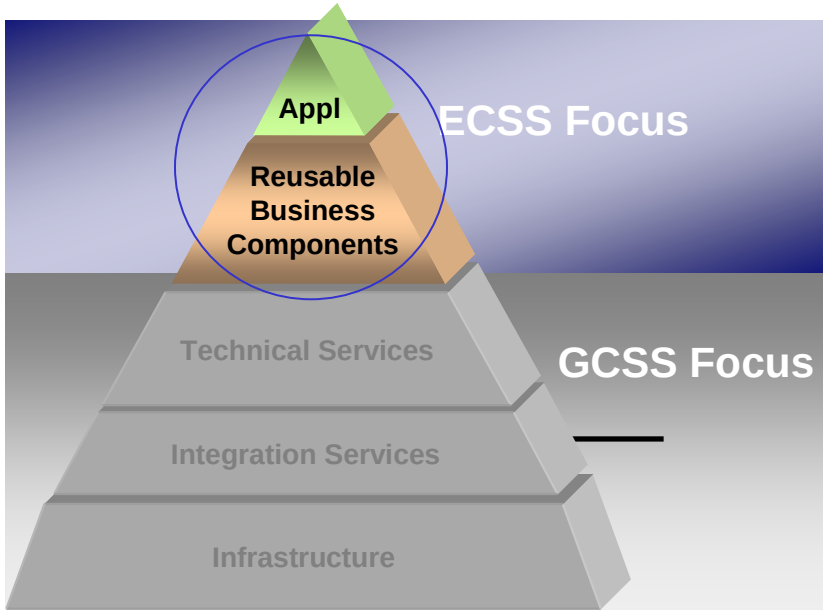
COP-enabling Capabilities

- Network-centric
- Service-oriented
- Enterprise management
- Business intelligence
- **Logistics transformation**:
  - **Expeditionary Combat Support System (ECSS):**
    - Improve war-fighter capability by transforming AF Logistics' business processes:
    - Establish real-time modernized information system



Reference: ECSS Overview, Col. William Cox

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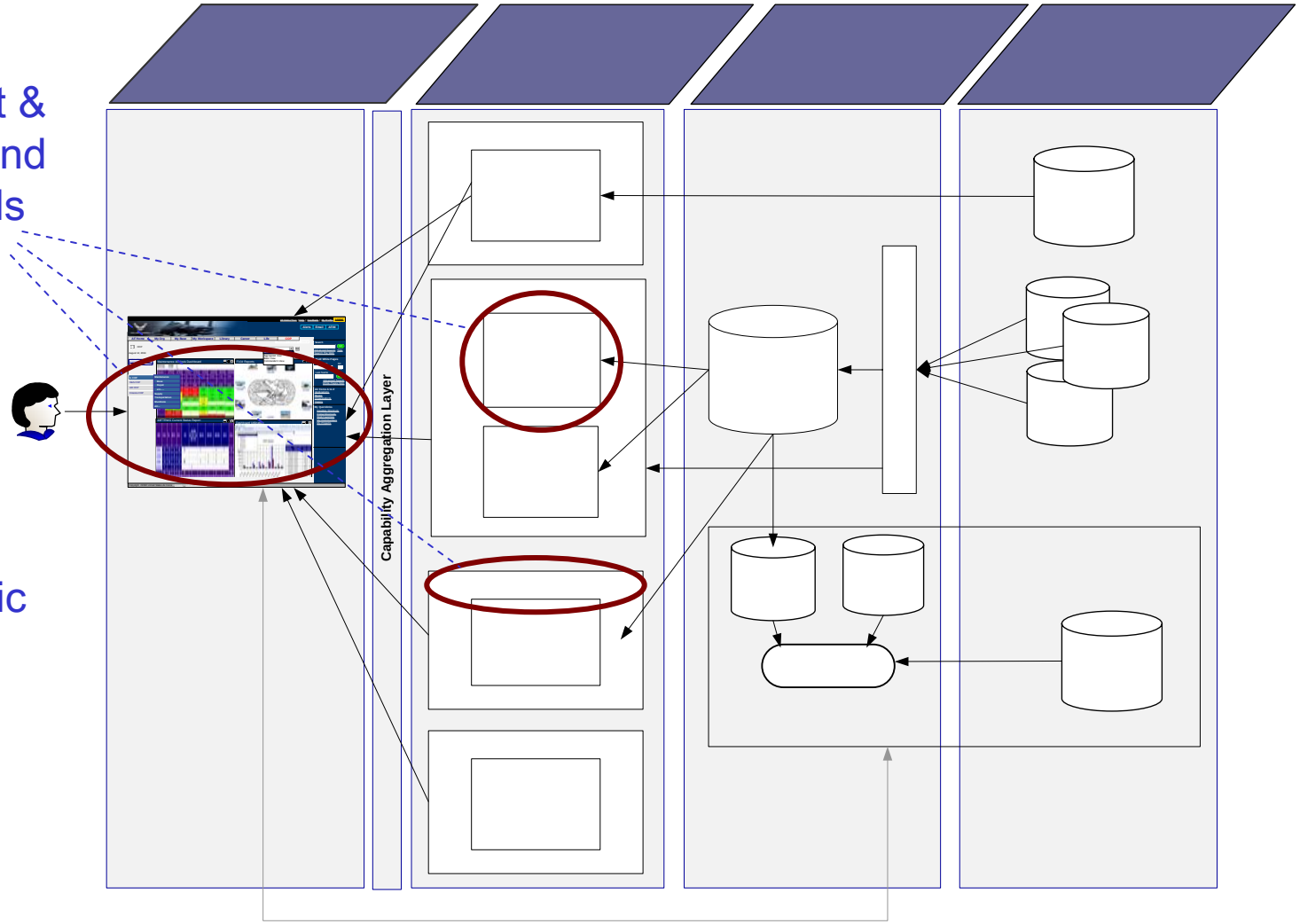
DATT Supports COP & ECSS

DATT provides Decision Support & Common "Feel and Look" for all levels of maintenance (O, I & D)



DATT: Diagnostic Analysis and Trending Tools

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DATT Is an Analysis & Reporting Software for Health Management

- DATT consists of two parts:
  - Architecture/framework:
    - **Open-system**: applicable to engine data, ground equipment data, test cell data, oil data, usage/life data, and vibration data
    - **Plug-and-play**: integrated framework for all analytical tools
  - Algorithms:
    - **Basic engine monitoring capabilities**: Diagnostics, Analysis, Trending, and Alert
    - **More advanced capabilities**: Prognostics, Availability/Readiness Assessment, Removal and Workscope Planning
- DATT is enabling CBM and RCM goals:
  - More accurate and effective management of engine system health than conventional monitoring tools
  - A component of the National Security System (NSS) EHM+ software

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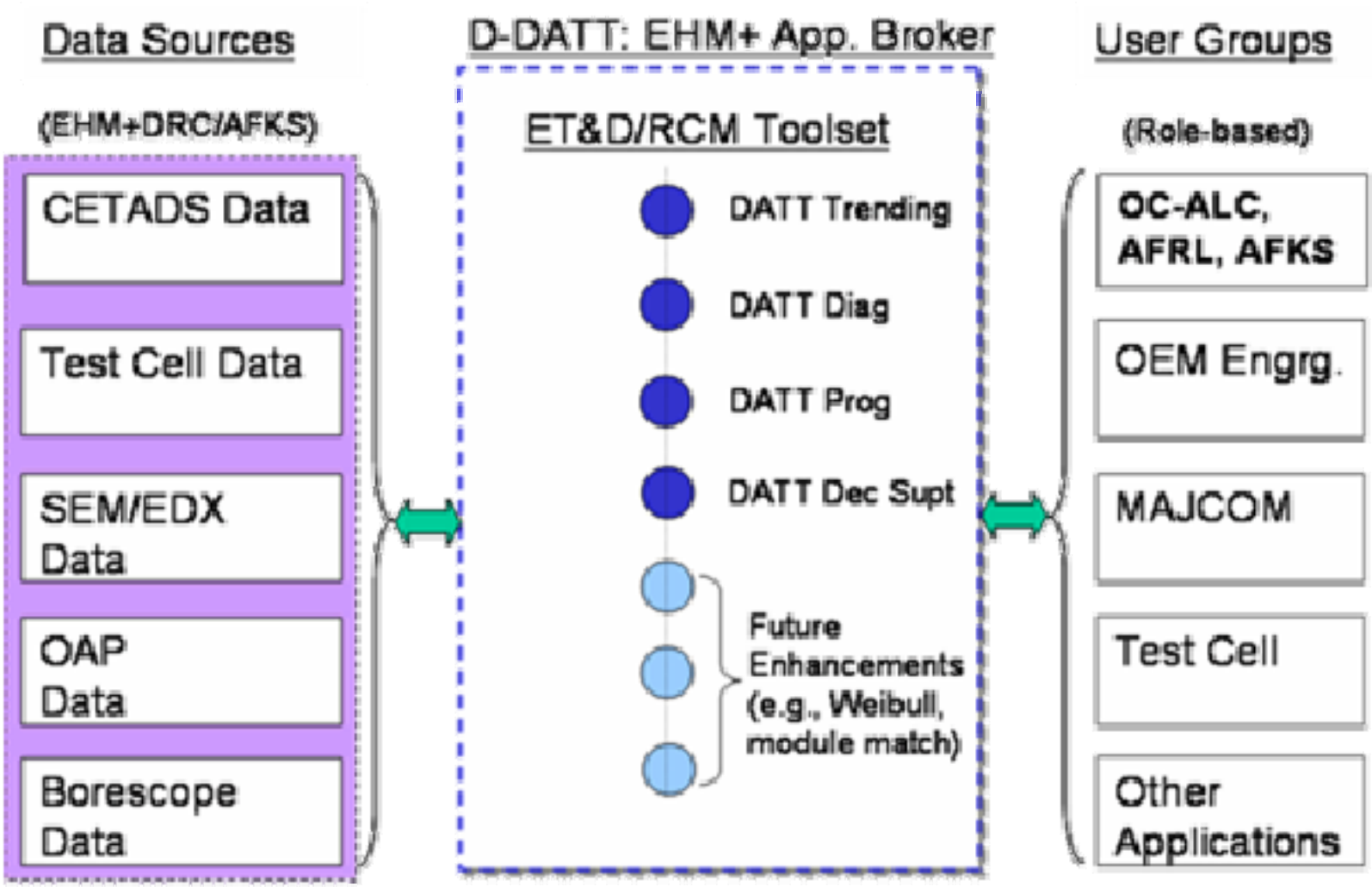
DATT Provides Analytical "Bridge" between Data and Users



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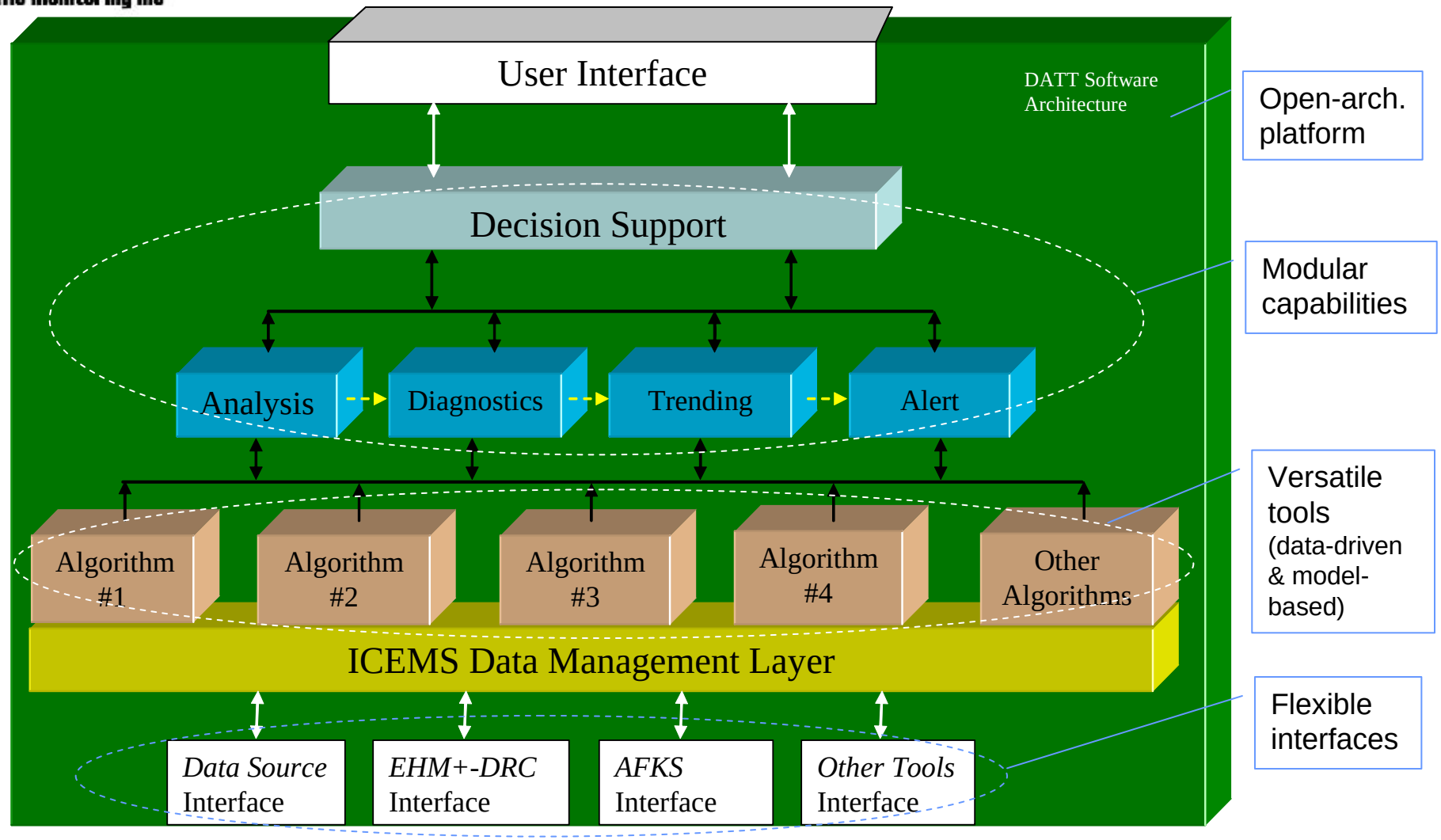
DATT Open Architecture Supports EHM+ Capabilities Plug-and-Play



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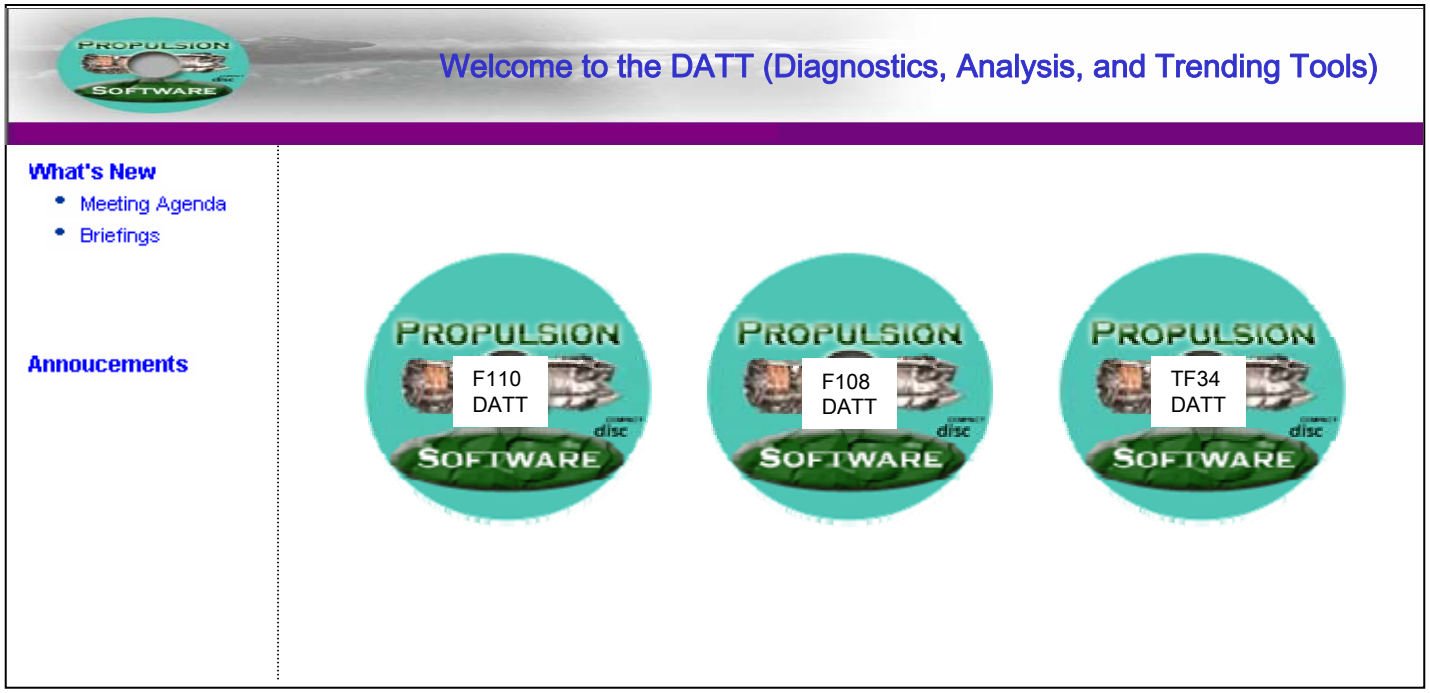
Notional DATT Framework for Multiple Engine TMS

- DATT common features will support all engine TMS (Type Model Series)
- DATT uses engine-specific features to perform health management functions and capabilities



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DATT Is a Technology Transition Success Story

- Technology originated as an Air Force Research Lab. (AFRL) SBIR project aimed at enhancing engine health management capabilities

	Stage \ Calendar Year	'97	'98	'99	'00	'01	'02
	SBIR Phase I: Feasibility						
F100	SBIR Phase II: Exploratory Dev.						
F100	Phase II Enhancement: Adv. Dev.						
F110	Field Demo on F110 @ Cannon						

- DATT is being fielded by OC-ALC! (Contract started in 2005)

From Lab. to Field

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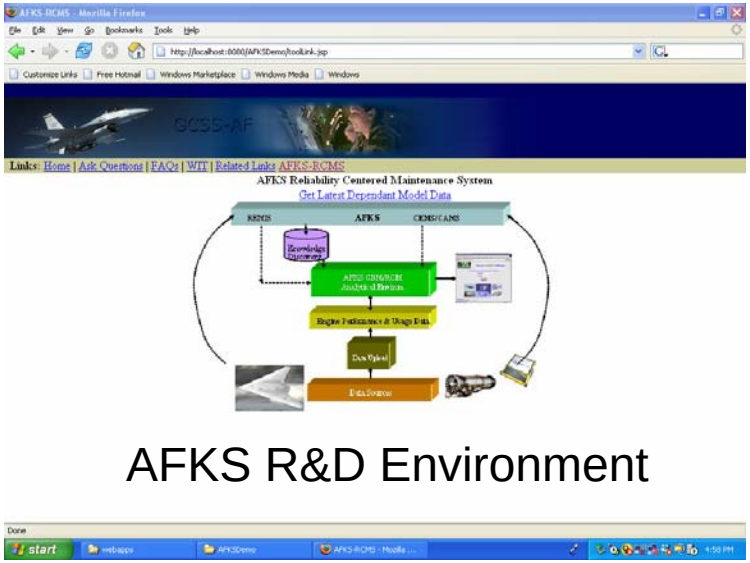
DATT Is Also a Catalyst for Feeding Field Experience Back to R&D

- DATT is the “blue print” for the AFKS (Air Force Knowledge Services) R&D environment to be used by AFRL to facilitate health management technology development and maturation

From Field to Lab.



AFKS R&D Environment

DATT for Sustainment

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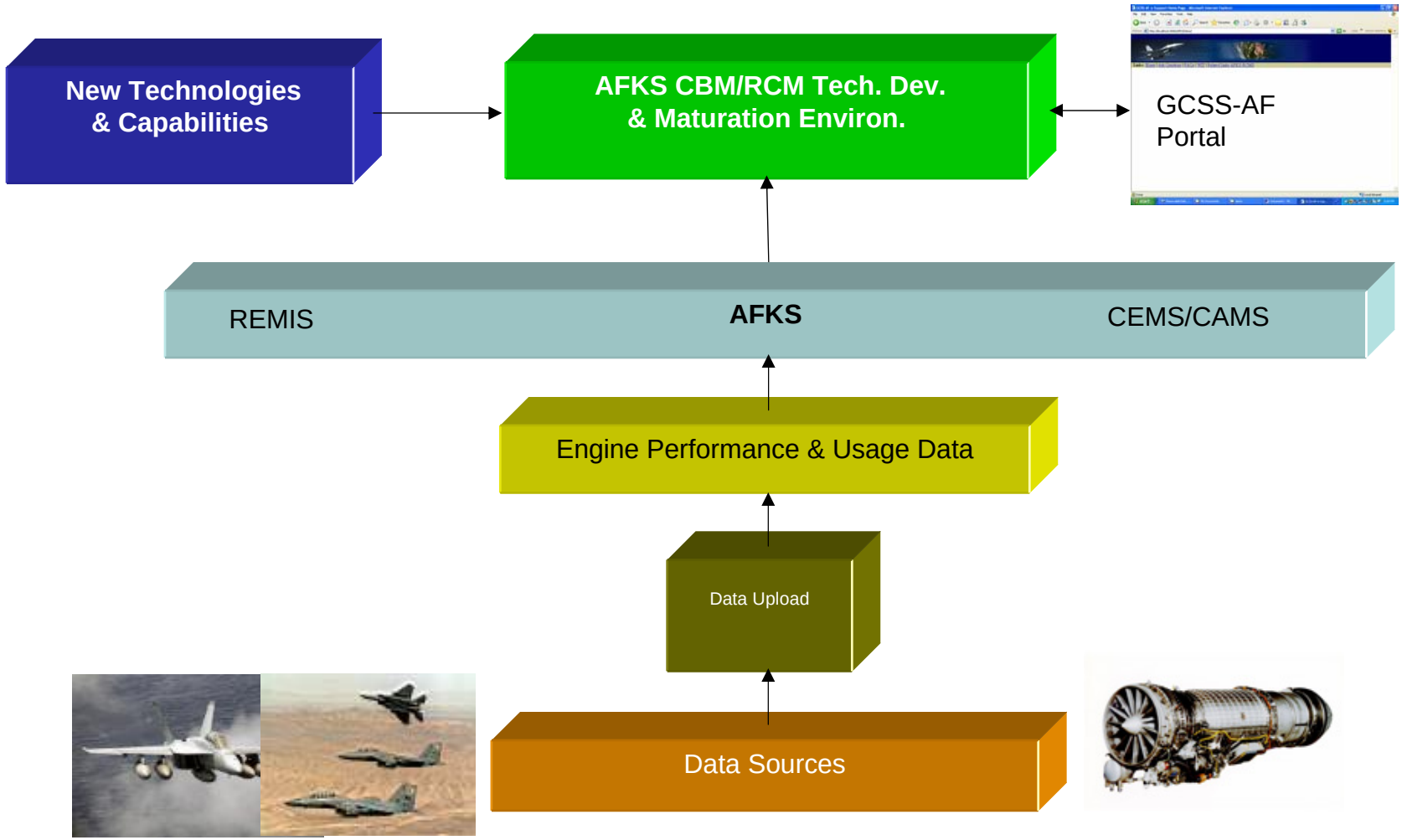
Fully Developed AFKS R&D Environment Will Support ECSS



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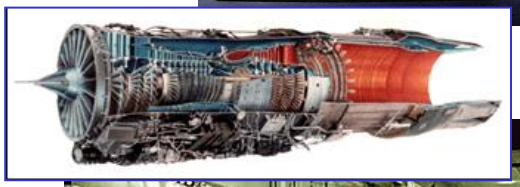
SMI Background

- Founded in 1993 as a consulting and R&D company in adaptive controls & system health management
- Received numerous national awards:
  - 2000 Small Business Award for Excellence
  - 2001 Tibbetts Award as an outstanding R&D company
  - 2002 NASA Achievement Award
- Recognized as the leader in condition monitoring and predictive maintenance:
  - Boeing has selected SMI as a partner for Boeing Airplane Health Management (AHM)
  - USAF has selected SMI to enhance its Engine Health Management (EHM) software
- Over 10 awarded and pending patents
- Located in Scottsdale, Arizona with satellite offices in California and Ohio

SBA Administrat
Award for Exce



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Our Technologies

Open-architecture CBM software platform

ICEMS™

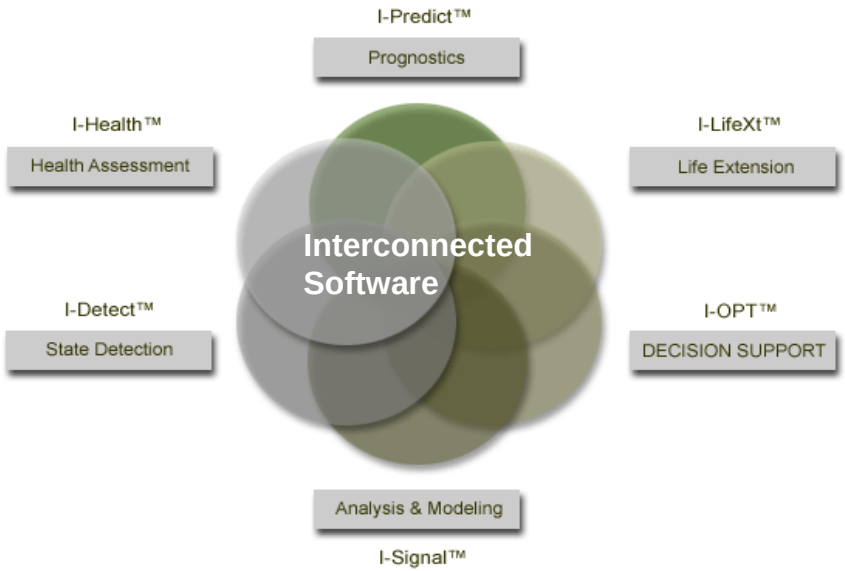
&

I-Trend™

DATT

AFKS

Commercial front-end software for trending, diagnostics & prognostics



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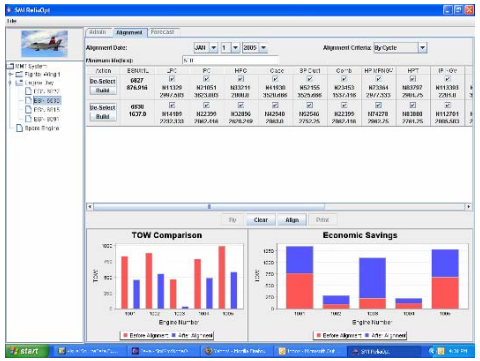
Our Technology Applications



Reliability Centered Maintenance

Asset optimization & work scope planning for engine & SRUs

Test Bench

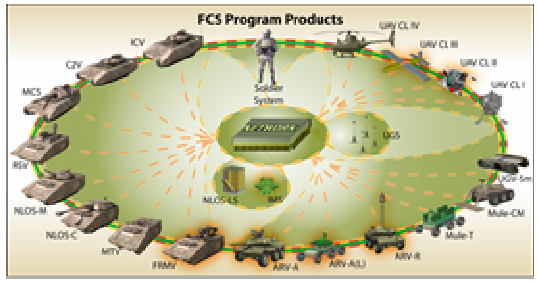
V&V and PHM life cycle maturation

USAF NSS-EHM+ DATT

Next generation engine trending, diagnostics, prognostics, and decision support software

Boeing AHM

Airplane Health Management for fault forwarding, alerting, and prognostics



US Army Future Combat Systems

Integrated system fault isolation & mission readiness assessment

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About the Presenter

Link Jaw is the founder and the president of Scientific Monitoring, Inc.. He has more than 25 years of experience in the aerospace industry. Before founding SMI in 1993, he worked in the engine performance and the control system design departments for Honeywell Engines & Systems (formerly Garrett Turbine Engine Co.) from 1983 to 1993. He was a real-time system engineer for Singer Link Flight Simulation and FlightSafety International from 1980 to 1983.

Link Jaw received a Ph. D. in Aeronautics and Astronautics from Stanford University in 1991, an M. S. from The University of Michigan in 1980. He has published papers in the Journal of Engineering for Gas Turbines and Power and at the conferences of American Society of Mechanical Engineer (ASME), American Institute of Aeronautics and Astronautics (AIAA), International Electrical and Electronic Engineering (IEEE), and International Society of Air Breathing Engines (ISABE).

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