The Joint Strike Fighter (JSF) Prognostics and Health Management

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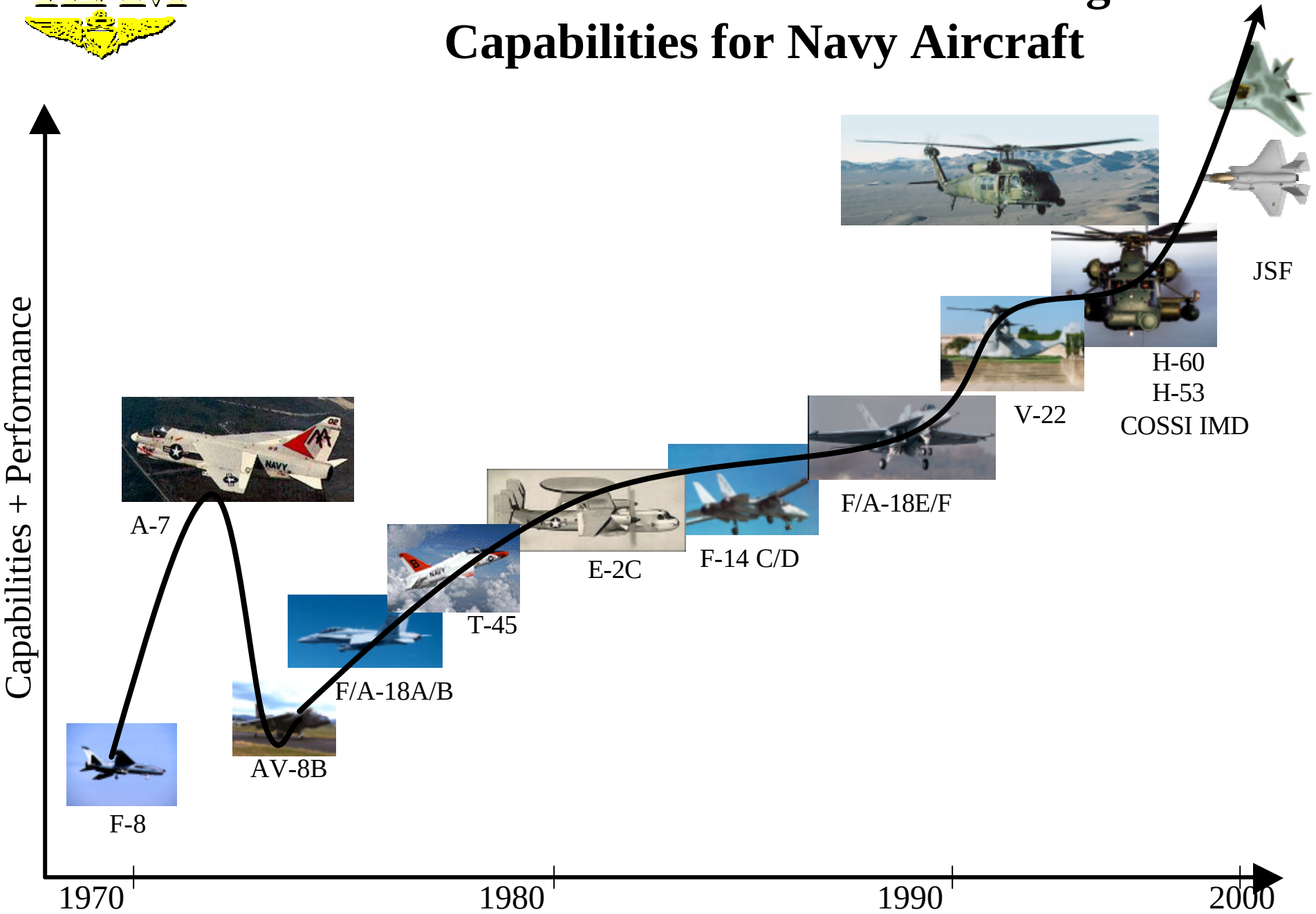
VISION

BE THE MODEL ACQUISITION PROGRAM FOR JOINT SERVICE AND INTERNATIONAL COOPERATION

DEVELOP AND PRODUCE AN AFFORDABLE NEXT GENERATION STRIKE FIGHTER WEAPON SYSTEM AND SUSTAIN IT WORLDWIDE

Relative Evolution of Mechanical Diagnostic Capabilities for Navy Aircraft



A-7E Crusader- Engine Monitoring System (EMS)

ACCOMPLISHMENTS

- Reduced accident rate due to engine failure 90%
- Reduced Maintenance Man-hour/Flight hour rate 66%
- Overall accident rate reduced 66%
- Saved many airplanes just from vibration and VIGV malfunctions alone
- Still the best operational EMS ever produced
- Monitored all aspects of engine - including ignition and generators/starter
- Ground Station had many helpful hints to Assist Maintenance

CAPABILITIES

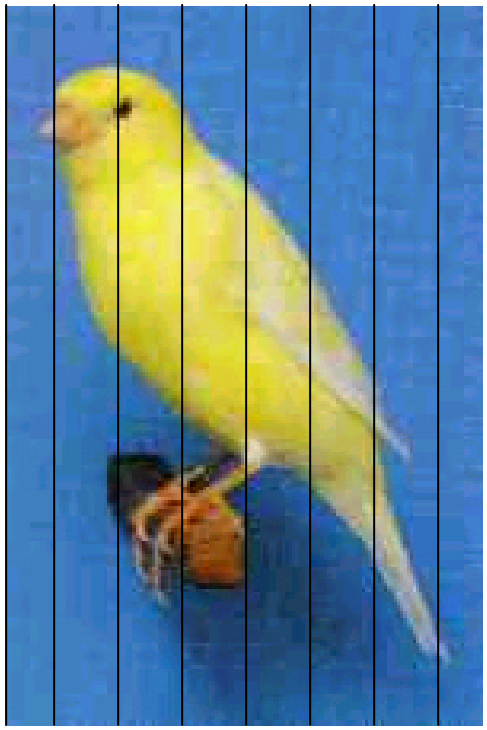
- Constantly Monitored Parameters
  - Detect all engine anomalies
- Superior Ground Station Software
  - Assisted Maintenance in troubleshooting
- Two Vibration Transducers
  - Fore and aft to cover entire engine
- Developed by Engineers on Carriers
  - More knowledgeable than engineers with no post-flight maintenance experience

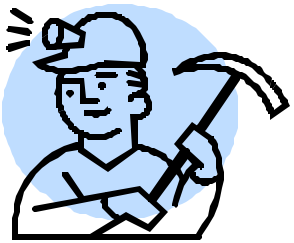
WEAKNESSES

- Recorded LUI's, but program never put into place to take advantage of them
- Old technology

Shift in Condition Monitoring Paradigm

Old Way





New Way

The ability to monitor has been around for a long time, but now we have the technology to really do something with it.

Current Logistics Structure

High Availability

Ability to Predict Future Health Status

Max Life Usage

MAX SGR

Ability to Anticipate Problems and Req'd Maint Actions

Better FD/FI Efficiency

Quick Turn Around Time

Small Logistics Footprint

No RTOK

Performance Based Maint

Accurate Parts and Life Usage Tracking

Low # of Spares

No False Alarms

Maintenance Mgt

No Surprises

Configuration Tracking

Opportunistic Maintenance

Mission Planning

Short and Responsive Supply Pipeline

No/Limited Secondary Damage

No/Min Inspections

Too Large & Costly

Limit Impact of Quality Control Problems

System Performance Feedback

Immediate Access to all Available Information

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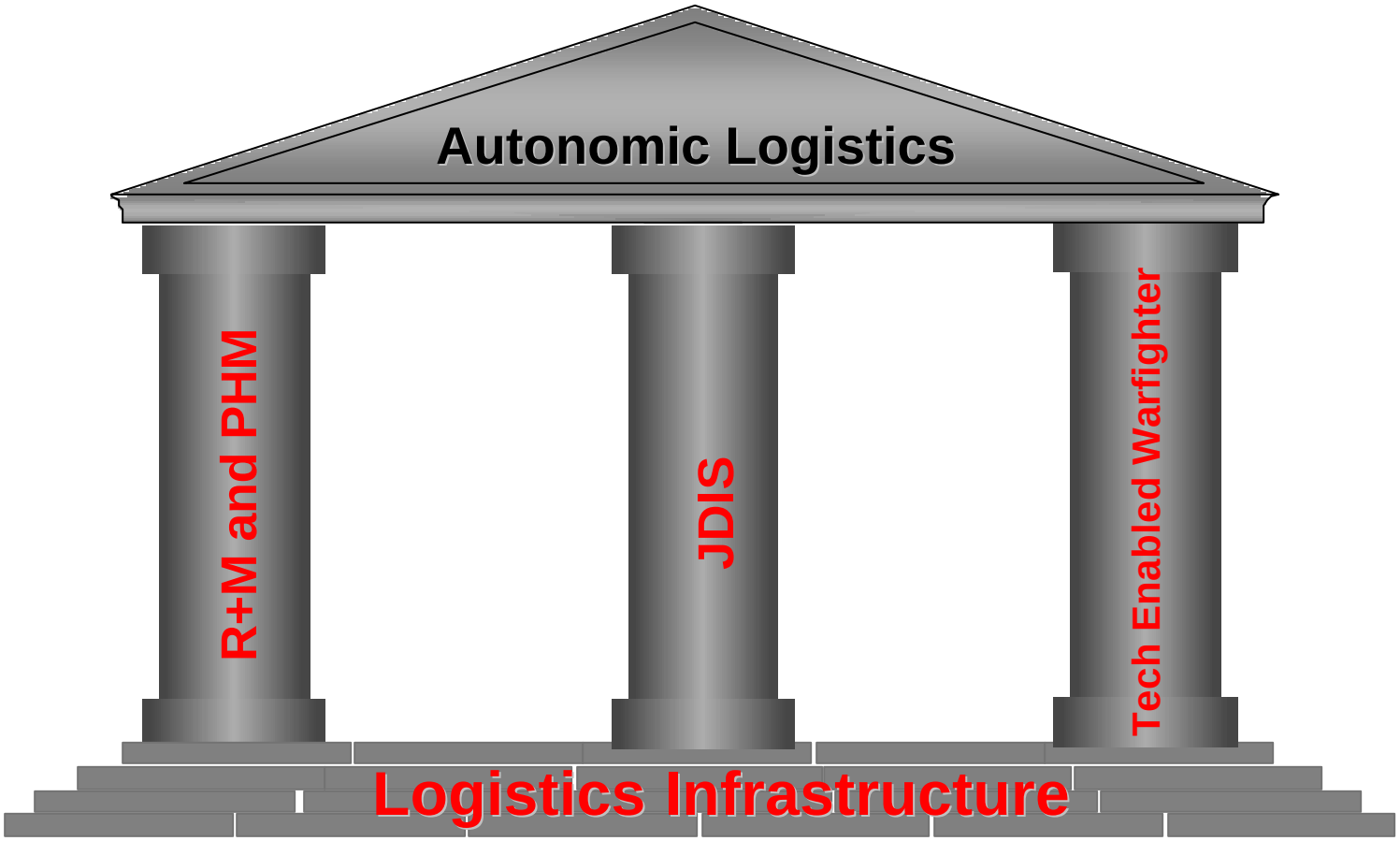
Key Elements of JSF Autonomic Logistics



Affordable, Survivable, Maintainable, Supportable

Operationally Available and Lethal

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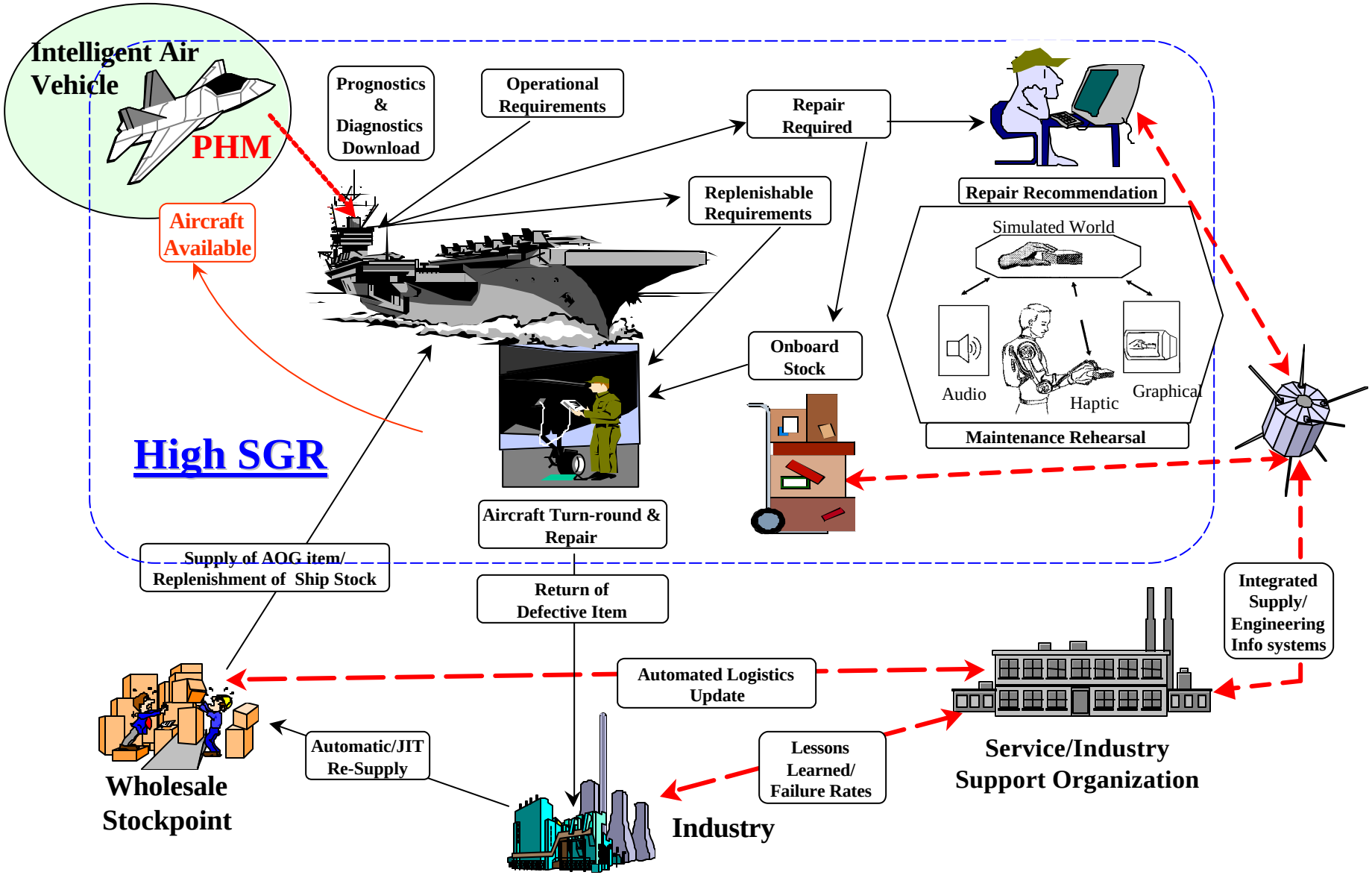
Autonomic Logistics Structure



Prognostics and Health Management

- **Why Did We Choose This Technology?**
  - Enable Autonomic Logistics
  - Enhance Flight Safety
    - Single Engine Aircraft, Must Have Dual Engine Reliability
  - Increase Sortie Generation Rate
  - Eliminate False Alarms
  - Eliminate CND's and RTOK's
  - Reduce Life Cycle Costs
  - Maximize PHM Benefit from Limited Specialized Sensors
  - Take Max Advantage of the "Smart" Digital Aircraft

Natural Evolution of Legacy Diagnostic Capabilities Coupled with the Added Functions, Capabilities, and Benefits offered by New Technologies

Prognostics and Health Management

What is it?

- **Diagnostics – is the process of determining the state of a component to perform its function(s)**

- **Prognostics – is predictive diagnostics which includes determining the remaining life or time span of proper operation of a component**

- **Health Management – is the capability to make appropriate decisions about maintenance actions based on diagnostics/prognostics information, available resources and operational demand.**

PHM turns ‘Bad Actors’ or ‘Intermittents’ into scheduled maintenance without affecting the success of the Mission

Goals of PHM

- **Enhance Mission Reliability and Aircraft Safety**
- **Reduce Maintenance Manpower, Spares, and Repair Costs**
- **Eliminate Scheduled Inspections**
- **Maximize Lead Time For Maintenance and Parts Procurement**
- **Automatically Isolate Faults to 1 LRC**
- **Eliminate CNDs and RTOKs**
- **Provide Real Time Notification of an Upcoming Maintenance Event at all Levels of the JSF Logistics Chain**
- **Catch Potentially Catastrophic Failures *Before* They Occur**
- **Detect Incipient Faults and Monitor Until Just Prior to Failure**
- **Opportunistic Maintenance Reduces A/C Down Time**

Some Facets of Diagnostics and PHM

- Fault Detection
- Fault Isolation
- Advanced Diagnostics
- Predictive Prognostics
- Useful Life Remaining Predictions
- Component Life Tracking
- Performance Degradation Trending
- Warranty Guarantee Tracking - Enabling New Business Practices
- Selective Fault Reporting
  - Only tells pilot what NEEDS to be known immediately
  - Informs Maintenance of the rest
- Aids in Decision Making & Resource Management
- Fault Accommodation
- Information Fusion and Reasoners
- Information Management
  - Right info to right people at right time

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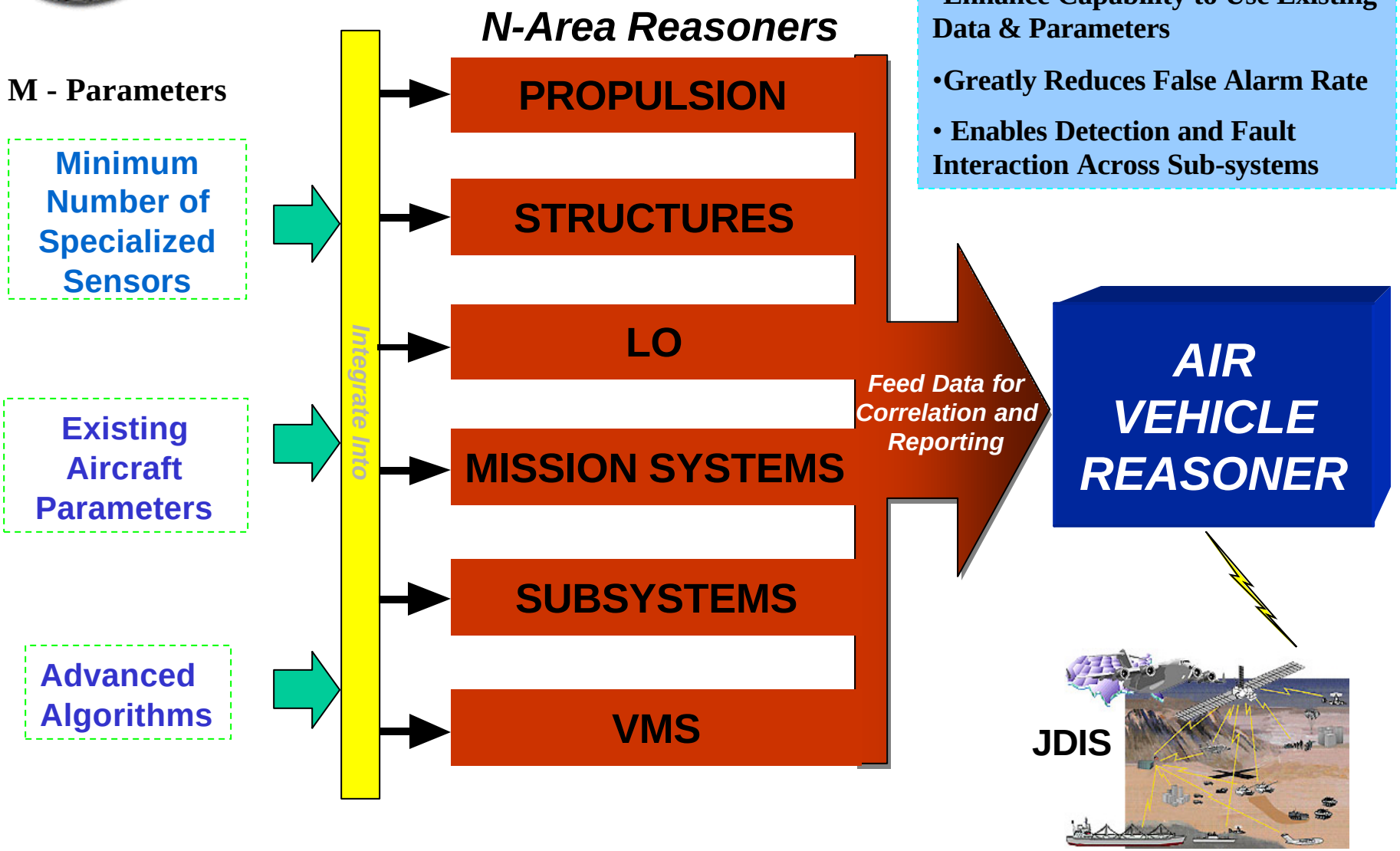
PHM Architecture

Reasoner Approach Benefits:

- Enables Use of Few Specialized Sensors
- Enhance Capability to Use Existing Data & Parameters
- Greatly Reduces False Alarm Rate
- Enables Detection and Fault Interaction Across Sub-systems



PHM is Designed into the Air Vehicle

- **Reflected in ORD and JMS Requirements**
- **Reaches across the entire airframe**
  - **Mission Systems**
    - **FD/FI – In flight reconfiguration**
  - **Structures**
    - **Intelligent Load Monitoring**
  - **Propulsion**
    - **Dual engine safety with single engine**
  - **VMS**
    - **Electronics Prognostics**
  - **Subsystems**
    - **Hydraulics**
    - **Fuel System**
    - **Electric Power System**
    - **APU**
    - **Drive Shafts**
    - **Etc…**

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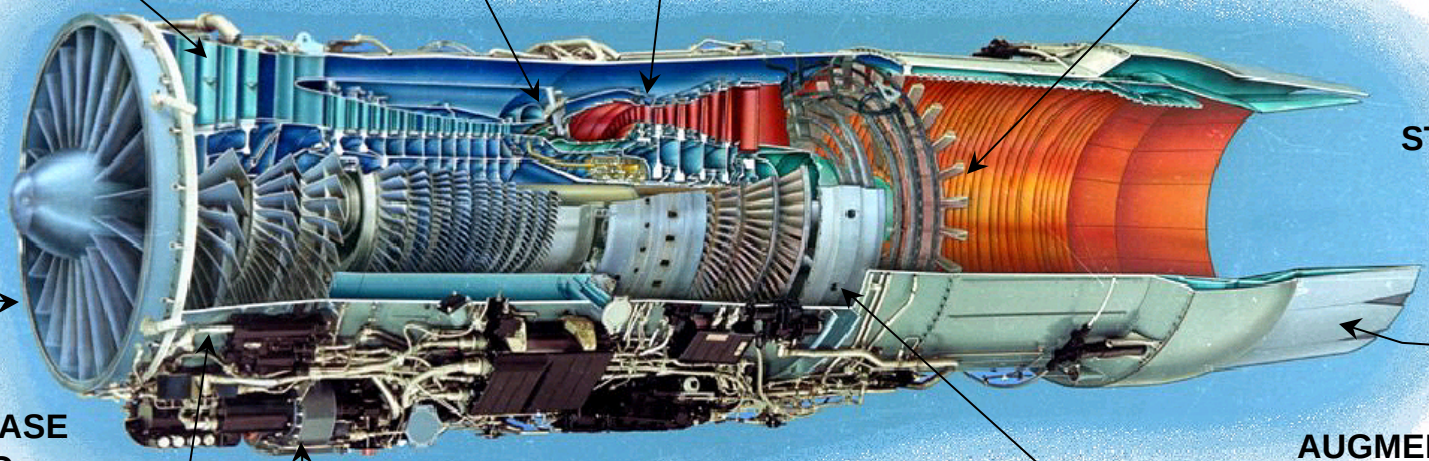
F100 Seeded Fault Engine Test Plan



FAN 1st ROTOR TIP/TE CRACKS
(ECS,BVM8X,AFD,IDMS, EDMS,VIBES,RLI,SWAN)

OVERFLOWING / BLOCKED FUEL NOZZLE
(EDMS,VIBES, RLI,SWAN)

COMBUSTOR/HPT EROSION
(EDMS)

HOT SHUTDOWN & BOWED ROTOR START ATTEMPT
(EDMS,VIBES, RLI,SWAN)

AUGMENTOR GUTTER FAILURE
(EDMS)

LPT BLADE RUB
(EDMS,VIBES RLI,SWAN)

NOZZLE STATIC STRUCTURE FAILURE
(PZT)

FOD/DOD
(AFD,IDMS, EDMS,ECS, VIBES, RLI,SWAN)

VAPOR PHASE COKING
(OCM, EODM,EBM)

AUGMENTOR FUEL DISTRIBUTION VARIATION
(EDMS)

BULK OIL DEGRADATION
(OCM, EODM,EBM)

GEARBOX FAILURE
(VIBES,RLI,SWAN)

#1 CARBON SEAL FAILURE/CONTAMINATION
(ODM, EODM,OCM, EBM,VIBES,RLI,SWAN)

#5 BEARING ASSEMBLY FAILURE
(ODM,EODM,EBM, VIBES,RLI,SWAN)

#1 BEARING FAILURE
(ODM,EODM,EBM VIBES,RLI,SWAN)

#1 COMPARTMENT FIRE
(OCM, EODM,EBM)

BULK OIL CONTAMINATION
(OCM, EODM, EBM,EBM,ODM)

purple *- primary sensor*
green *- secondary sensor*

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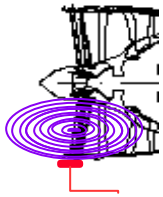
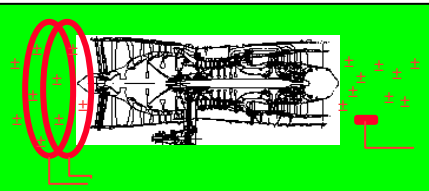
PHM Technologies Evaluated During CDP

- Boarded
- Under development
- Not boarded



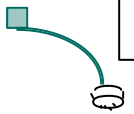
Acoustic FOD Detector (AFD)

Eddy Current Blade Sensor (ECS)
GDATS

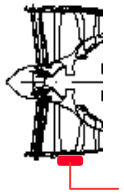


Ingested Debris Monitoring System (IDMS)

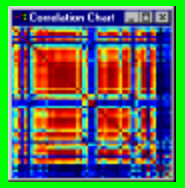
Engine Distress Monitoring System (EDMS)
Stewart Hughes Ltd



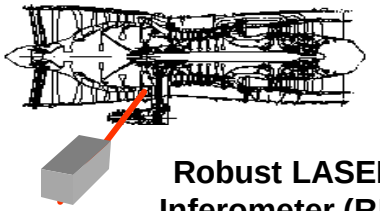
Piezoceramic Patch Crack Detection (PZT)
UTRC



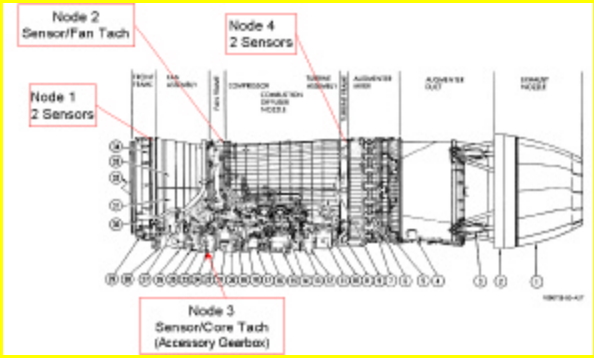
Blade Vibration Meter (BVM8X)
Hood Technology



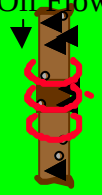
Beacon-Based Exception Analysis for Maintenance (BEAM) JPL



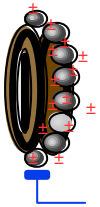
Robust LASER Inferometer (RLI)
Epoch Engineering



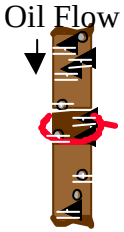
MEMS Sensors



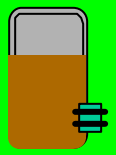
F119 Oil Debris Monitor (ODM)
GasTOPS



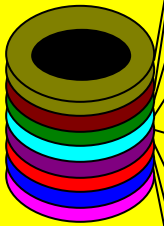
Electrostatic Bearing Monitor (EBM)
ExperTech



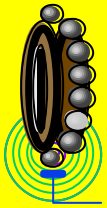
Electrostatic Oil Debris Monitor (EODM)
ExperTech / SHL



Oil Condition Monitor (OCM)
UDRI



ICHM



Stress Wave Analysis (SWAN)
DME

PHM Redefines Design Criteria

- **Old**
  - **Safety and Supportability are a Function of Reliability, Redundancy, and the Support Concept ~ *Ensures***
- **New**
  - **Safety and Supportability are a Function of Reliability, Redundancy, PHM Capabilities, and the New Support Concept ~ *Drives***

Autonomic Logistics Enables a Paradigm Shift

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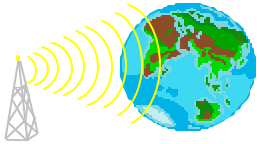
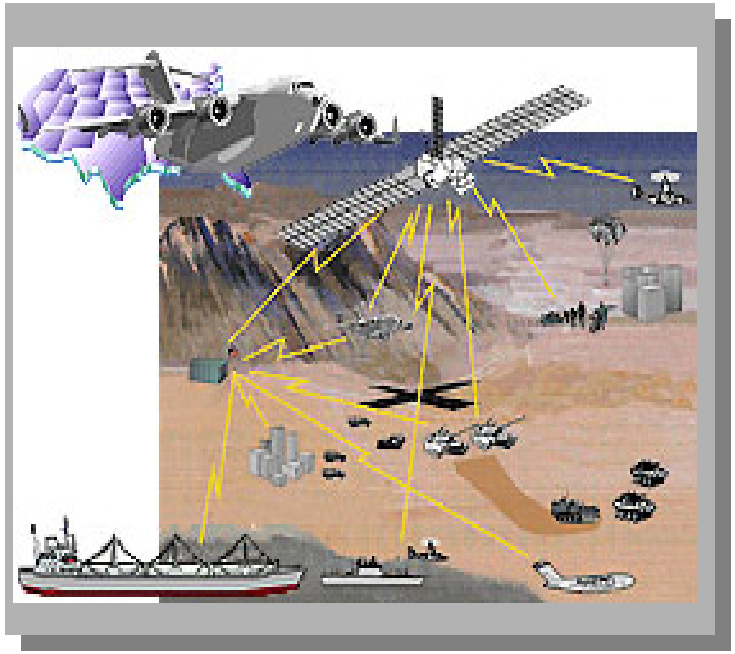
Joint Distributed Information System (JDIS)



Communications
- Web enabled
- Radio Frequency
- Infrared/Ultraviolet
- SATCOM
- Databurst Mayday (Black Box Data)



Database Management
- Safety
- Mission Ops
- Configuration Management
- Status Updates
- Schedule Adjustments
- General Maintenance Actions
- Analyze Health of Aircraft
- Population
- Provide Interactive Electronic Technical Manual (IETM) Knowledge

Maintenance Management
- Web Interfaces
- Maintainer Identification
- Automatic Record of repairs
- Compatibility with legacy systems

Intelligent, Connected Logistics Infrastructure

Some Facets of JDIS

- Mission Planning
  - Accommodates for unexpected maintenance actions
- Automatic Ordering of Spares
  - Avoids lengthy down time
- Bookkeeping of parts by serial number
  - Notice trends with a particular part
  - Notice trends with a particular operating condition
  - Detect Design Defects
- Full Asset Visibility Across Fleet
- Parts Life Tracking
  - Allows users to know actual condition of fleet

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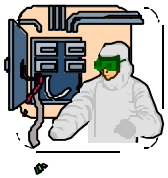
Technologically Enabled Warfighter



Training Continuum
Distributed Simulation/
Mission rehearsal

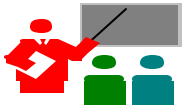
Virtual Reality Haptic Feedback

Interactive Electronic
Technical Manuals

MSAP JSFPO MxITL WSC's

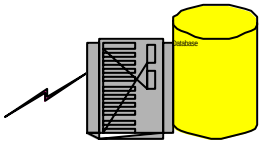
Maintainer in the Loop

Embedded
Simulation



Electronic
Classroom

On-Line Support



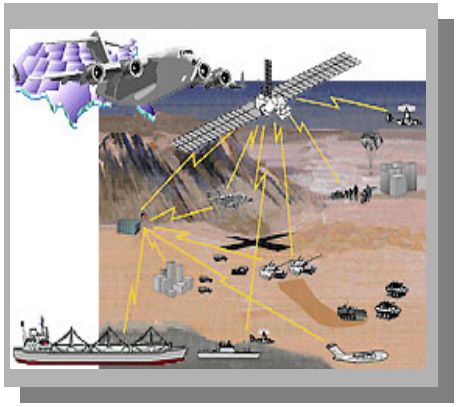
On-Line Maintenance
Technical Manuals

Technician Enhanced With Technology

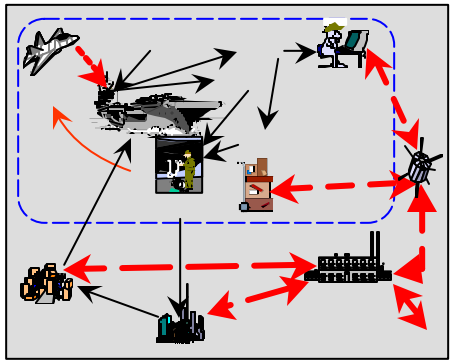
Autonomic Logistics Summary

Intelligent Air Vehicle

Technologically Enabled Warfighter



Joint Distributed Information System



Autonomic Logistics

By 2020, the JSF will comprise 75% of US Tactical Aircraft

Affordability is the only option

AUTONOMIC LOGISTICS WILL DELIVER

JOINT STRIKE FIGHTER

The Next Generation Strike Fighter