



Prognostics Based Health Assessment System Approaches

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Diagnostic and Prognostic Products and Services
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VSE Corporate Overview

- Established in 1959
- Public company (NASDAQ:VSEC)
- Headquartered in Alexandria, Virginia
- ISO 9001:2000 registered
- Provides worldwide support through diversified engineering, technical, logistics, management, and information technology services to maintain and modernize equipment and systems
- Principal clients are agencies of the U.S. Government and other government prime contractors



Prognostics? What is That?

- Prognostics is an engineering discipline focused on predicting the future condition of a component and/or system of components.
- In most cases, prognostic approaches are based on the analysis of failure modes, detection of early signs of wear, and correlation of these signs with an aging profile (or model).
- Technical approaches to prognostics can be categorized broadly into reliability driven and condition based approaches.
- The VSE approach to Prognostics Based Health Assessment incorporates both reliability and condition based methodologies.



An Example of VSE's Prognostics Based Health Assessment Systems

- ◆ **F/A-18 Automated Maintenance Environment**
 - Integration of system maintenance resources and configuration data and into an integrated system
 - Diagnostics • Prognostics • Health Management
 - Operator Debrief
 - IETMs
 - Life Usage Tracking
 - Asset • Configuration Management / Serial Number Tracking
 - Interfaces to Supply Chain and Maintenance Management Systems



- AME is first instance of a geographically distributed information system that...
 - Supports strategic maintenance planning at
 - Headquarters
 - Each support level
 - Front line tactical maintenance operations
- Open system integrating framework
 - Software backplane that uniquely supports maintenance workflow and the Application Programming Interfaces (APIs) for plug-and-play software
 - Enables continuous use of “best of breed” COTS components
- Generalized APIs that are not system-specific

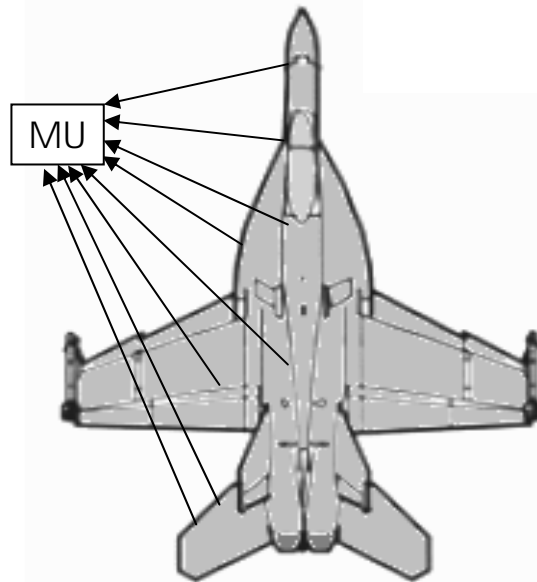


F/A-18 Sensors & Built-in Test (BIT) Provide Foundation

Each individual sub-system has its own diagnostics, BIT or health monitoring capability.

BIT is fully integrated digitally via the primary data bus.

The BIT data is recorded and stored. Data is available by a removable memory storage unit.

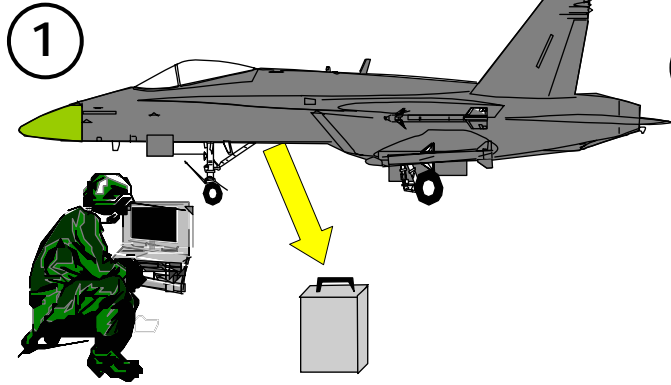


Mechanical, Pneumatics, Hydraulic, Engines, Structure, & Environment Systems are monitored via analog sensors.

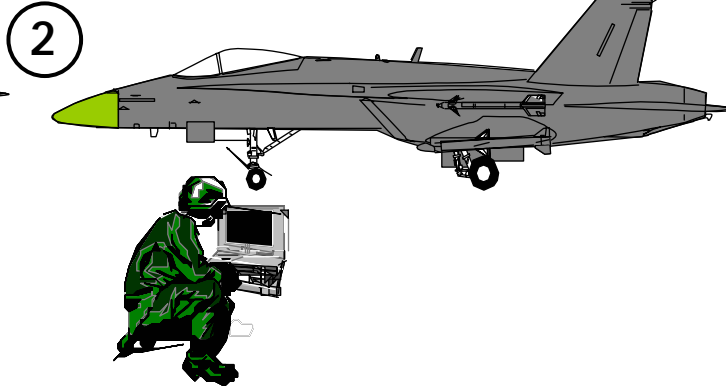
The analog signals are converted to digital and used to verify, monitor, control and ensure optimum system performance.

All BIT, Go/No-Go, and self test data is transmitted via the data bus and recorded to the removable memory unit.

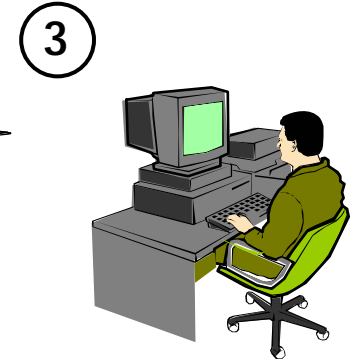
AME Work Flow



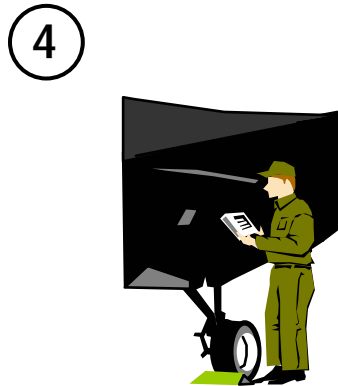
1
Pilot initiates data stripping.



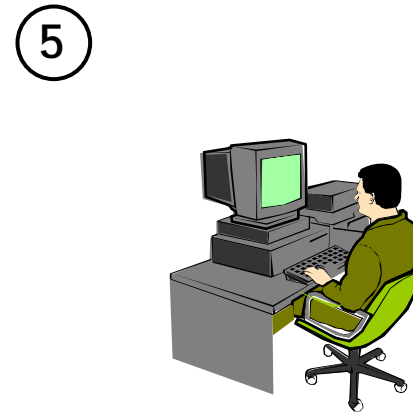
2
Pilot performs debrief.



3
Work Center Supervisor assign tasks.



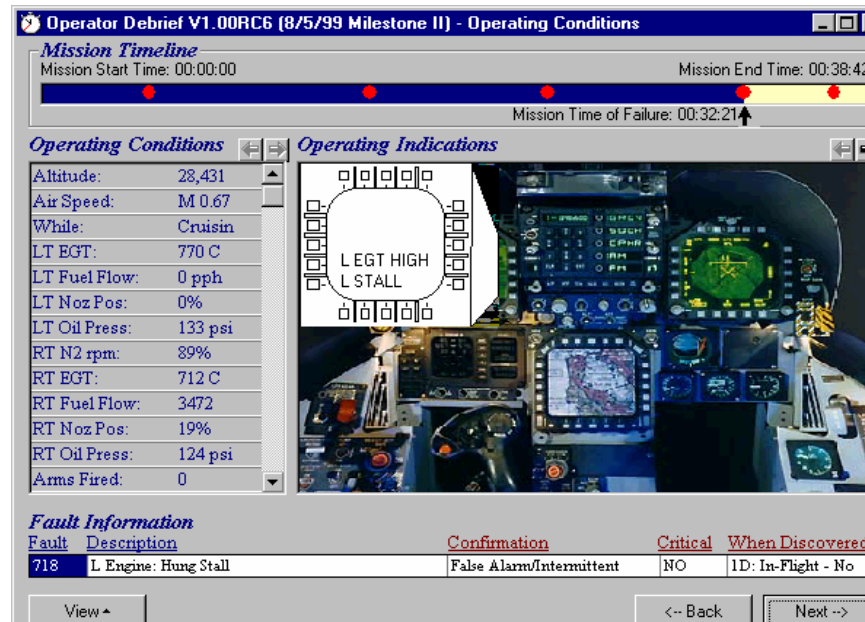
4
Technician performs repair procedure using IETM.



5
Materiel Control transfers item to Supply / I-level

Debrief Logs any Additional Discrepancies

- The pilot reviews the faults identified by the expert system and adds any other discrepancies



Operator Debrief V1.00RC6 (8/5/99 Milestone II) - Operating Conditions

Mission Timeline
 Mission Start Time: 00:00:00 Mission End Time: 00:38:42
 Mission Time of Failure: 00:32:21↑

Operating Conditions

Altitude:	28,431
Air Speed:	M 0.67
While:	Cruisin
LT EGT:	770 C
LT Fuel Flow:	0 pph
LT Noz Pos:	0%
LT Oil Press:	133 psi
RT N2 rpm:	89%
RT EGT:	712 C
RT Fuel Flow:	3472
RT Noz Pos:	19%
RT Oil Press:	124 psi
Arms Fired:	0

Operating Indications

LEFT HIGH
L STALL

Fault Information

Fault	Description	Confirmation	Critical	When Discovered
718	L Engine: Hung Stall	False Alarm/Intermittent	NO	1D: In-Flight - No

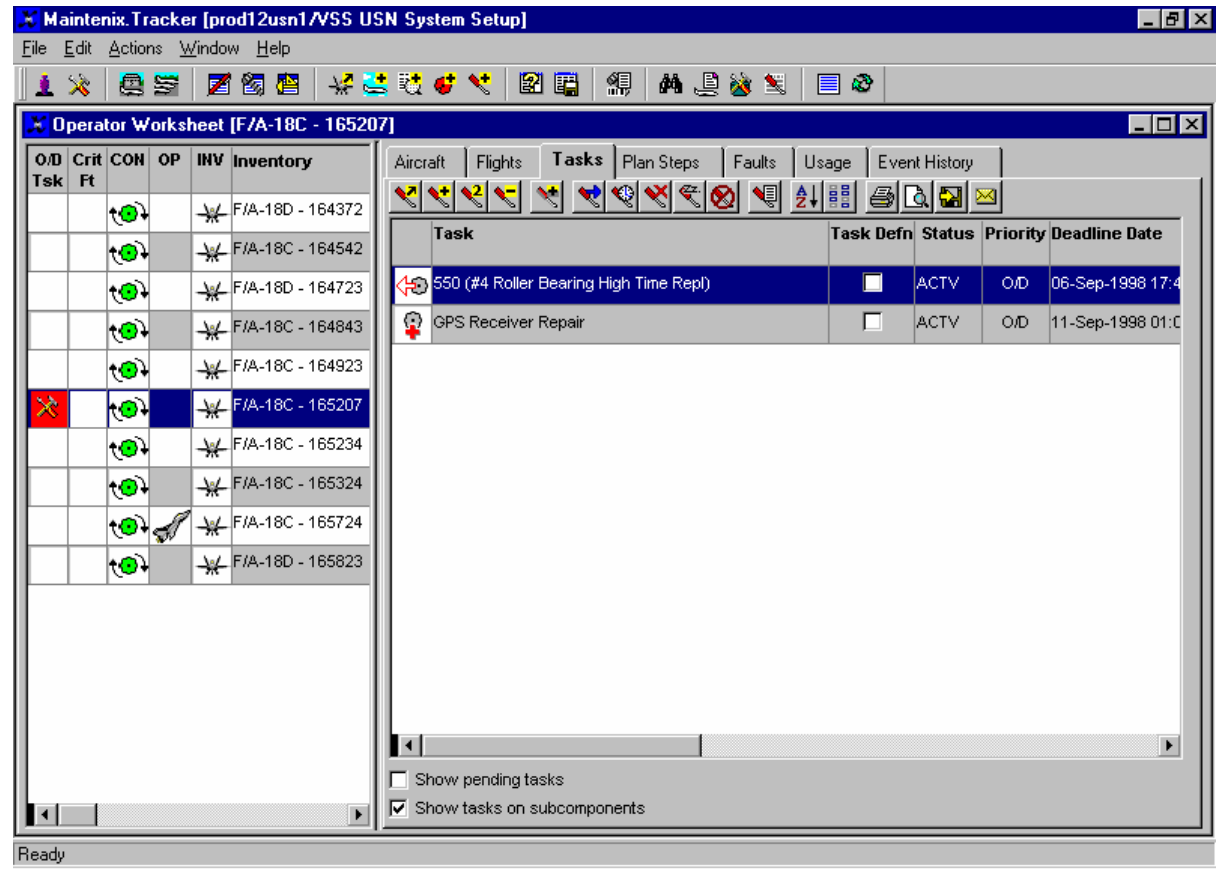
View ▲ <- Back Next ->

- Maintenance tasks are passed to Maintenance Management Database



Maintenance Alerted to Aircraft Caution

- The aircraft is shown with overdue tasks
- The maintenance tasks are shown
 - Debrief task is to repair GPS receiver (*Condition Based*)
 - The LUI increase has caused an engine turbine to go 'high-time', requiring an engine removal (*Reliability Based*)



Maintenix Tracker [prod12usn1/VSS USN System Setup]

File Edit Actions Window Help

Operator Worksheet [F/A-18C - 165207]

O/D Tsk	Crit Ft	CON	OP	INV	Inventory
					F/A-18D - 164372
					F/A-18C - 164542
					F/A-18D - 164723
					F/A-18C - 164843
					F/A-18C - 164923
					F/A-18C - 165207
					F/A-18C - 165234
					F/A-18C - 165324
					F/A-18C - 165724
					F/A-18D - 165823

Task Details:

Task	Task Defn	Status	Priority	Deadline Date
550 (#4 Roller Bearing High Time Repl)		ACTV	O/D	06-Sep-1998 17:4
GPS Receiver Repair		ACTV	O/D	11-Sep-1998 01:0

Show pending tasks
 Show tasks on subcomponents

Ready



Identify Maintenance Tasks

- System shows all upcoming work for the squadron to Maintenance Control
 - Work can be sorted to facilitate planning
- Maintenance Control initiates maintenance actions based on the identified tasks

Maintenix Tracker [prod12usn1/VSS USN System Setup]

File Actions Window Help

Task Worksheet

Retrieve

Row Limit: 1000

Search By:

Inventory: Root Inventory: Assembly: BOM:

Work: Labour Skill: Work Type:

Assigned To: Plan Step:

HR: Work Dept:

Task: Historical Tasks

Task Class: Status:

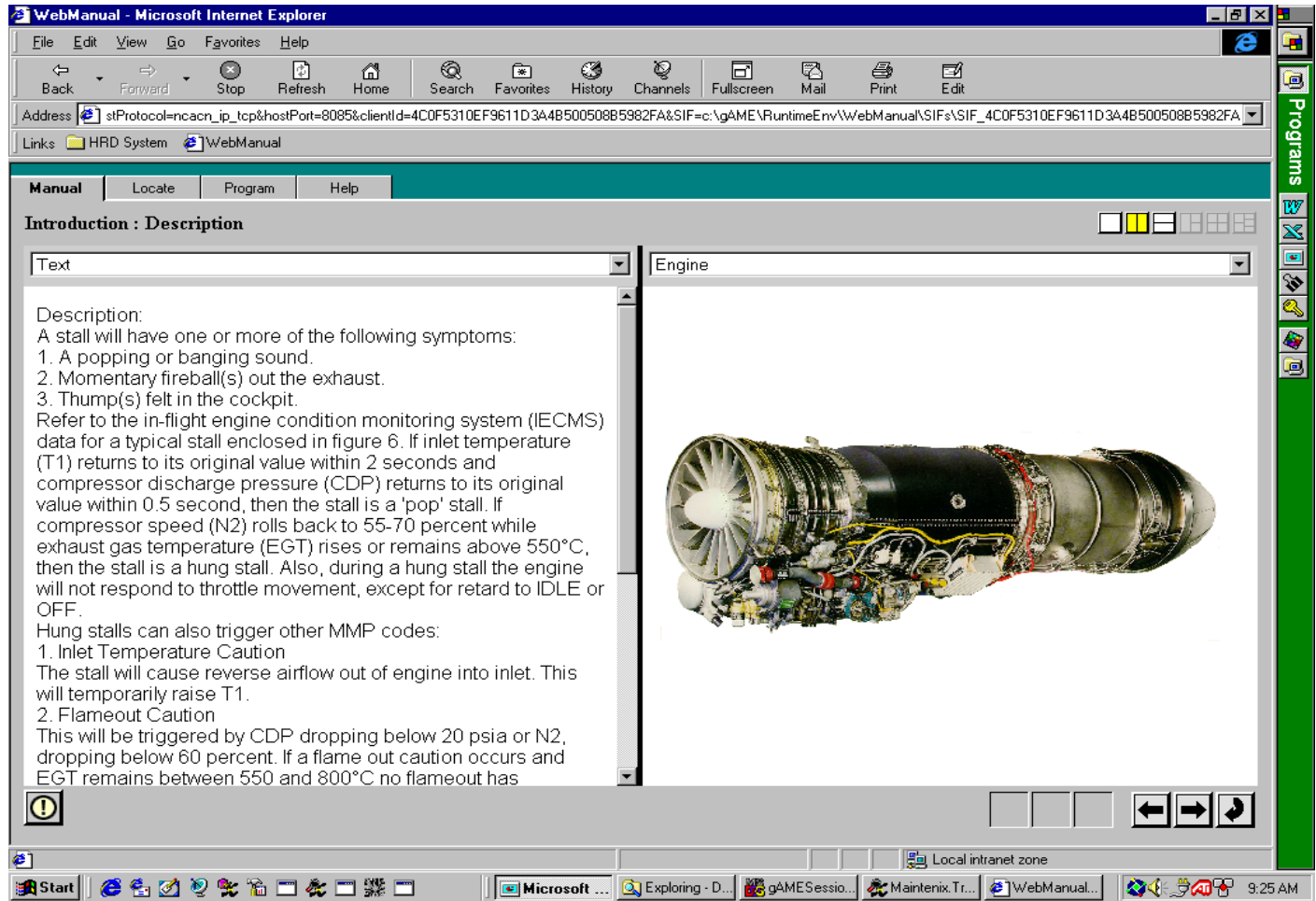
Task	Task Defn	Status	Priority	Deadline Date	Main Usage Until Deadline	Usage Until Deadline	Assembly	BOM
215 (Stg 1 Fan Blade Set High-Time Rep)	<input checked="" type="checkbox"/>	ACTV	LOW	10/21/98 18:36:40	40.0hour(AFH)	40.0LUI(ELCF)	TXC	274
GPS Receiver Repair	<input type="checkbox"/>	ACTV	O/D	9/11/98 01:00:00	-0.7hour(AFH)	-0.7day(CDY)	AMAF	AM
21 Day Inspection	<input type="checkbox"/>	ACTV	NONE	9/15/98 00:00:00	3.2hour(AFH)	3.2day(CDY)	AMAG	AM
030000C (30 Hour Special Engine Inspe)	<input checked="" type="checkbox"/>	ACTV	LOW	10/11/98 18:36:40	30.0hour(AFH)	30.0hour(AFH)	AMAF	27
550 (#4 Roller Bearing High Time Repl)	<input type="checkbox"/>	ACTV	O/D	9/6/98 18:36:40	-5.0hour(AFH)	-5.0hour(EOT)	TXC	27
550 (#4 Roller Bearing High Time Repl)	<input type="checkbox"/>	ACTV	O/D	9/6/98 18:36:40	-5.0hour(AFH)	-5.0hour(EOT)	TXC	274
Remove Engine	<input type="checkbox"/>	ACTV	HIGH				AMAF	27

9 Rows Retrieved

Start Workspace at Mxl ... Exploring - Lui Microsoft PowerPoi... **Maintenix Trac...** 6:41 PM



- The maintainer takes the PEDD/PMA out to the aircraft and uses the IETMs while executing the maintenance tasks



WebManual - Microsoft Internet Explorer

File Edit View Go Favorites Help

Back Forward Stop Refresh Home Search Favorites History Channels Fullscreen Mail Print Edit

Address stProtocol=ncacn_ip_tcp&hostPort=8085&clientId=4C0F5310EF9611D3A4B500508B5982FA&SIF=c:\gAME\RuntimeEnv\WebManual\SIFs\SIF_4C0F5310EF9611D3A4B500508B5982FA

Links HRD System WebManual

Manual Locate Program Help

Introduction : Description

Text Engine

Description:
 A stall will have one or more of the following symptoms:
 1. A popping or banging sound.
 2. Momentary fireball(s) out the exhaust.
 3. Thump(s) felt in the cockpit.
 Refer to the in-flight engine condition monitoring system (IECMS) data for a typical stall enclosed in figure 6. If inlet temperature (T1) returns to its original value within 2 seconds and compressor discharge pressure (CDP) returns to its original value within 0.5 second, then the stall is a 'pop' stall. If compressor speed (N2) rolls back to 55-70 percent while exhaust gas temperature (EGT) rises or remains above 550°C, then the stall is a hung stall. Also, during a hung stall the engine will not respond to throttle movement, except for retard to IDLE or OFF.
 Hung stalls can also trigger other MMP codes:
 1. Inlet Temperature Caution
 The stall will cause reverse airflow out of engine into inlet. This will temporarily raise T1.
 2. Flameout Caution
 This will be triggered by CDP dropping below 20 psia or N2, dropping below 60 percent. If a flame out caution occurs and EGT remains between 550 and 800°C no flameout has

Local intranet zone

Start Microsoft ... Exploring - D... gAMESessio... Maintenix.Tr... WebManual... 9:25 AM



Aircraft Status is updated

- The PEDD/PMA upload installed the new engine in the aircraft logset
- The Status Board now shows the aircraft as ready to fly

Maintenix Tracker [prod12usn1/VSS USN System Setup]

File Edit Actions Window Help

Operator Worksheet [F/A-18C - 165207]

O/D Tsk	Crit Ft	CON	OP	INV	Inventory
					F/A-18C - 164542
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					F/A-18C - 165207
					F/A-18C - 165234
					F/A-18C - 165324
					F/A-18C - 165724
					F/A-18D - 164372
					F/A-18D - 164723
					F/A-18D - 165823

Aircraft | Flights | Tasks | Plan Steps | Faults | Usage | Event History

Aircraft Details

Registration: 165207

Carrier Name: US Navy

Country: USA (United States of America)

Airworthiness Code: Private

Aircraft Status

Condition: EVC (Serviceable)

Operating:

Complete

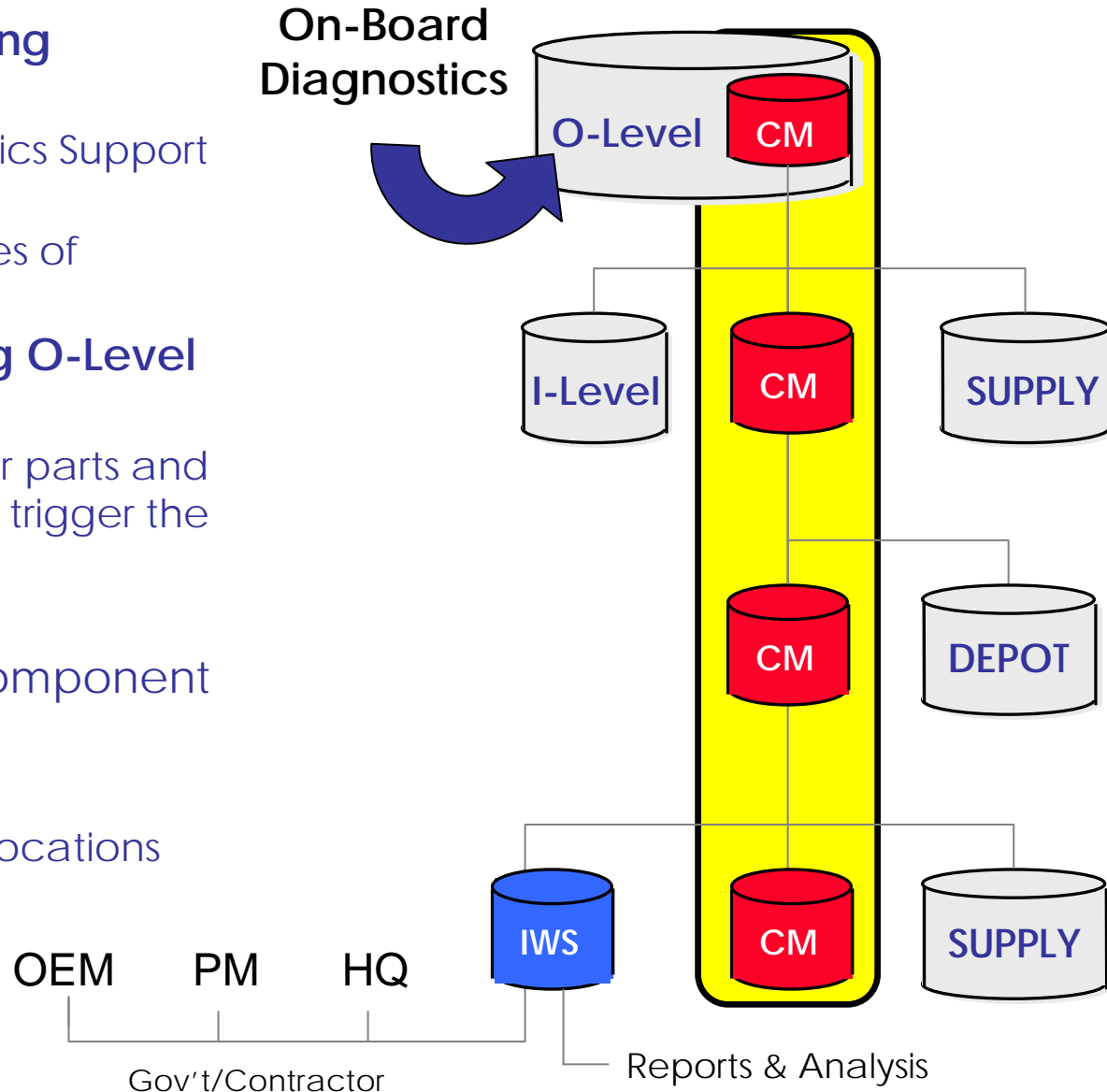
Aircraft Comments:

Refresh the operator worksheet window



AME Vertical Integration

- ◆ **Integrated environment linking maintenance and OEMs**
 - Accurate feedback to Logistics Support re: fleet status
 - Rapid and accurate deliveries of Maintenance Plan updates
- ◆ **Total Asset Visibility including O-Level activities**
 - PM can 'see' the demand for parts and other resources and properly trigger the Supply Chain
- ◆ **Modular components**
 - Can rapidly install on a component by component basis
- ◆ **Deployable**
 - Can fully operate in remote locations with no operational impact
 - 24/7 Global User Support



● Increased Operational Availability

- IT-related improvements have increased F/A-18 Readiness by 8%
- Significantly improved understanding of current status
- Improved maintenance efficiency via comprehensive and accurate diagnostics
- Ability to capture and use status information for maintenance and supply actions
- Improved supply chain management based on knowledge of in-field demand for resources
- Provides timely & accurate data for logistics analysis

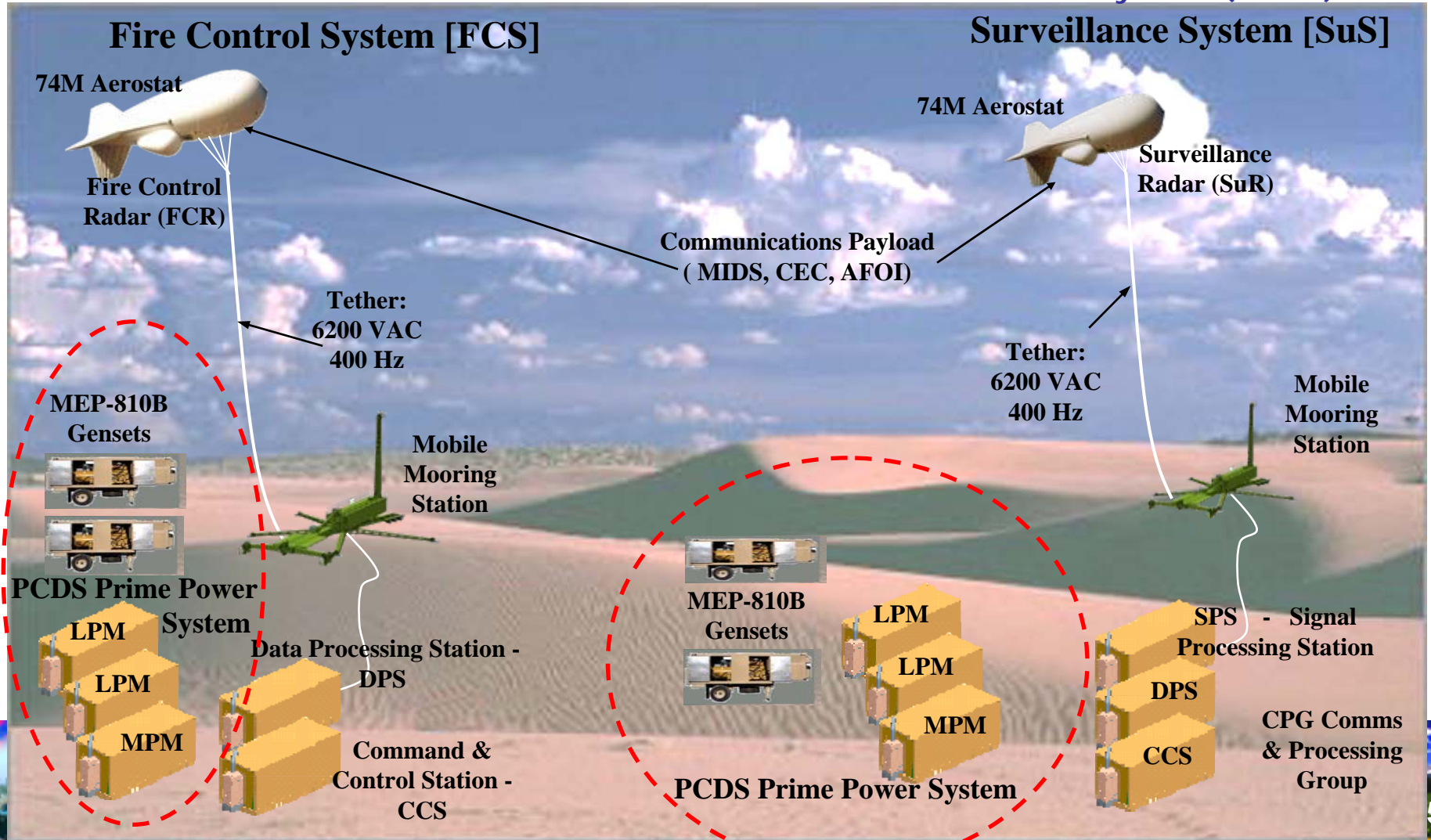
● At Reduced Cost

- More than \$1B cost savings over the past decade
- More efficient maintenance labor execution
- Improved asset utilization
- Significantly fewer good or unknown items floating through supply



Another Example of VSE's Prognostics Based Health Assessment Systems

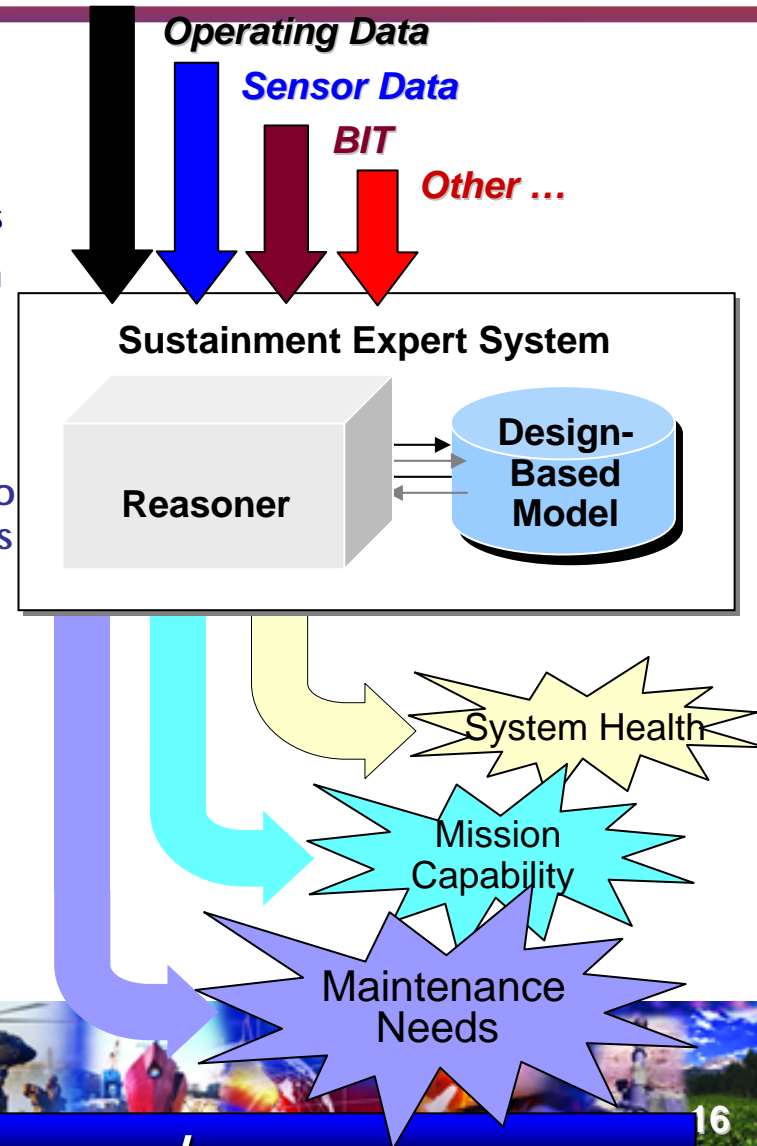
Joint Land Attack Cruise Missile Defense Elevated Netted Sensor System (JLENS)



Prognostics Framework Reasoning

Expert System using Model-Based Reasoning

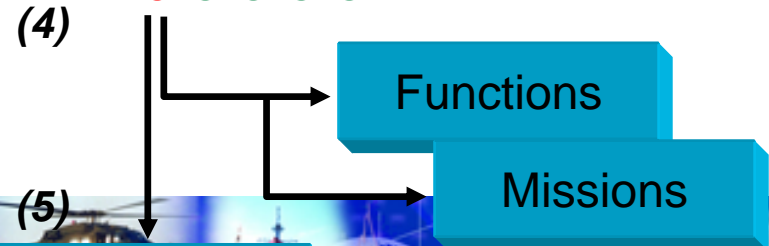
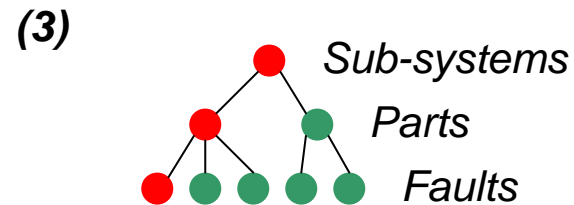
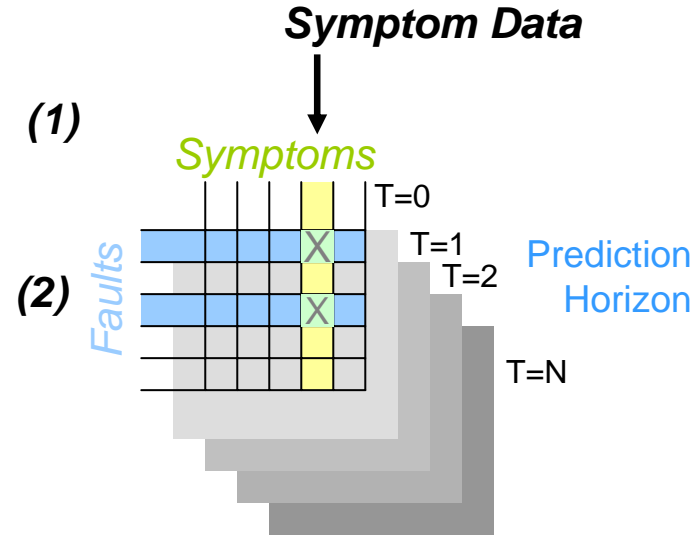
- Uses design-based model for diagnostics/prognostics
- Is deterministic model using “first principles” of design
- Reasons by dynamically interpreting the inference of data
- Reads streams of data from variety of sources
- ☑ Interprets sensors, built-in test and operational data; to assess system health, predict, detect and isolate faults
- ☑ Results in health monitoring, diagnostics *and* prognostics
- ☑ Can be embedded (on-line, real-time) or off-line
- ☑ Can be used on existing or new systems
- ☑ Replaces traditional fault/logic tree



An Information Driven Approach

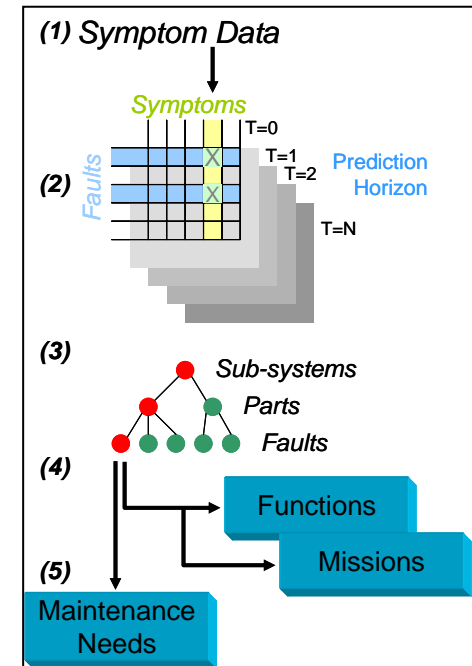
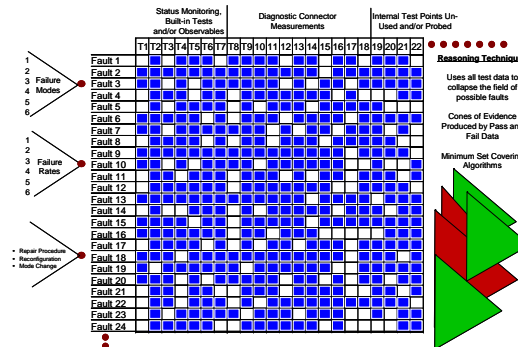
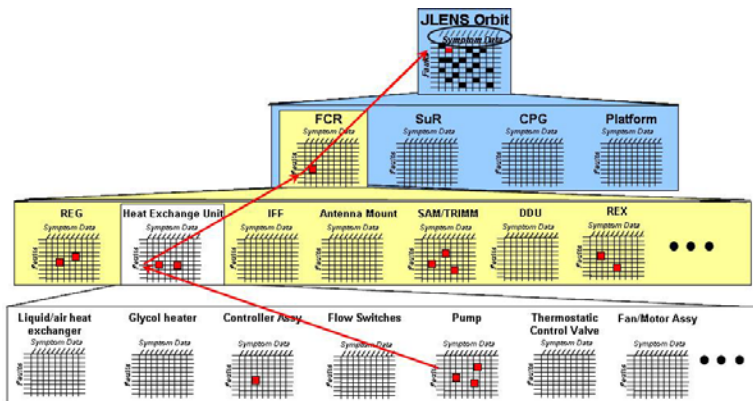
Achieving Design-Base Comprehension

1. Accept operational data, sensor, BIT and parametric data as symptoms
2. Apply reasoning algorithms to predict & diagnose the implication of out of tolerance symptoms on each future time point defined in the model
3. Identify the components and sub-systems affected by predicted failures - **sub-system health**
4. Identify the functions and missions affected by predicted failures - **mission readiness**
5. Identify the repair actions needed - **anticipatory maintenance**



Diagnostic/Prognostic Reasoning

- Build a System Model to reflect system hierarchy
- Map fault propagation and test coverage in a Fault/Symptom matrix
- Correlate actual test data with faults across system hierarchy (*Intelligent Reasoner*)



DESIGN DATA

- Definition of Parts, Faults, Failure Modes, Failure Rates, Tests, Interconnectivity and Test Coverage

SYSTEM DATA MANAGEMENT

- Input Data Definition & Characterization
- Prediction Horizons

TEST/SENSOR DATA

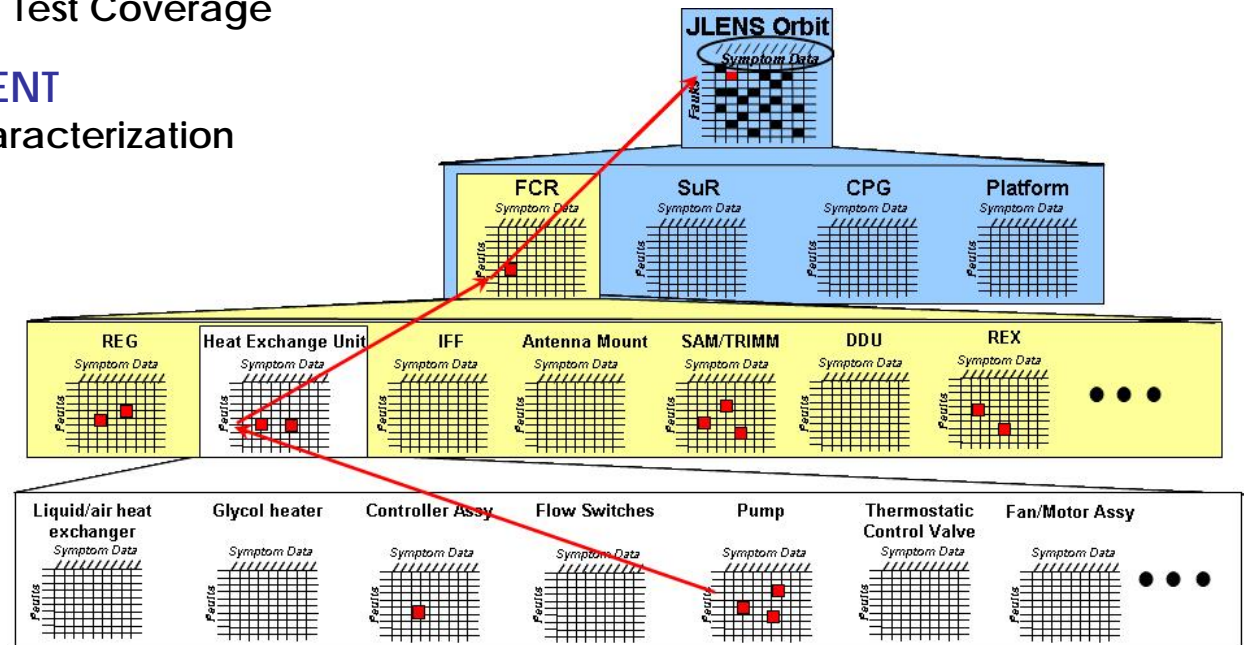
- BIT Inputs & Mapping
- Sensor Data & Mapping

HEALTH MANAGEMENT

- Detection Algorithms
- Diagnostic Coverage
- System Stress Factors
- Prediction Algorithms
- Fault Criticality
- Input Data Processing & Filtering
- Confidence Factors

MISSION SUPPORT

- Mission Profile
- Function Correlation to Mission Phases
- Function Criticality to Mission
- Immediate Operator Actions

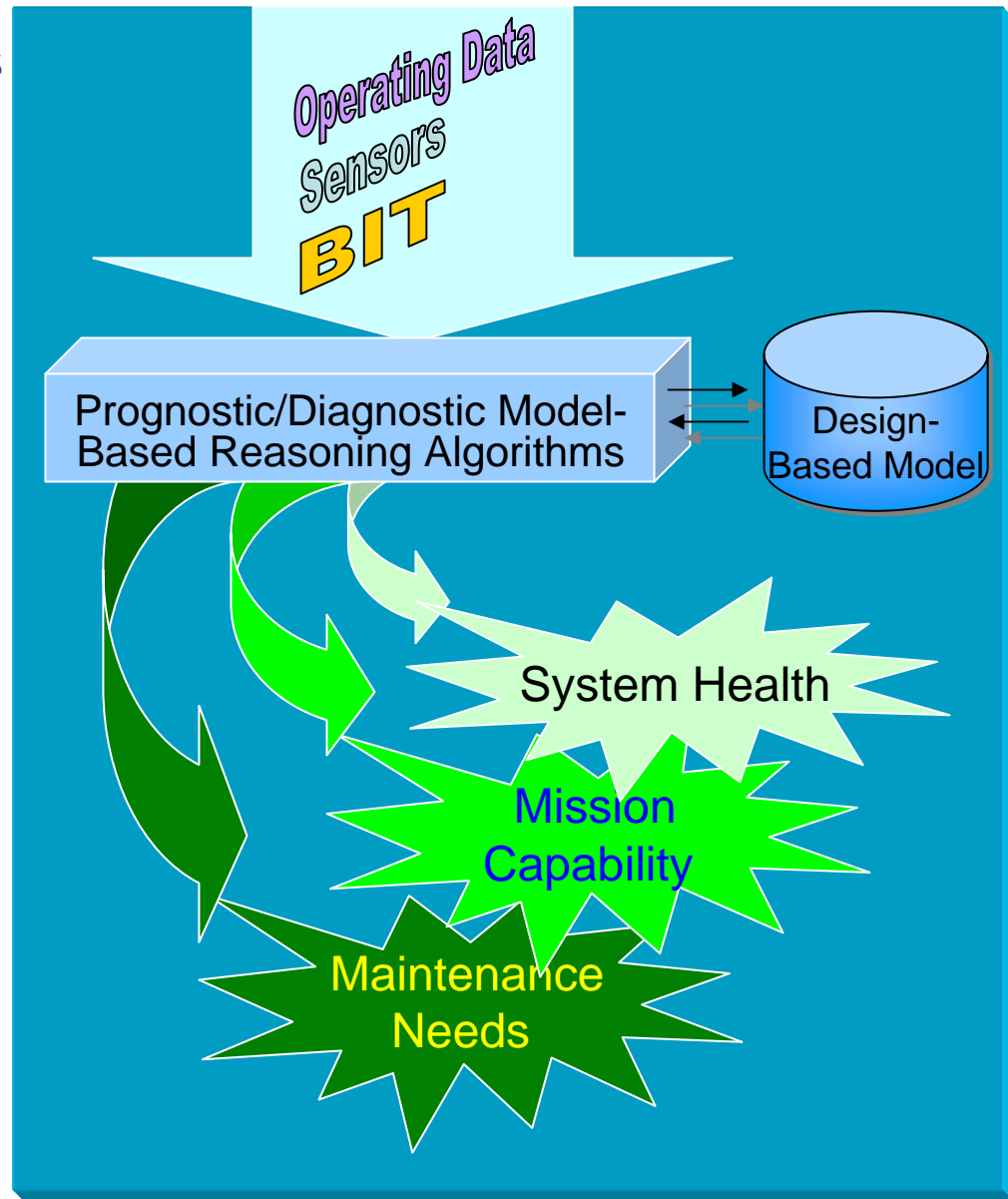


MAINTENANCE SUPPORT

- Repair Item Definition
- Combinations of Repair Items
- Repair Actions (IETM Interface)
- Parts Ordering Data
- PMCS Triggering and Tracking

Diagnostic/Prognostic Reasoning

- Model-based reasoner maximizes the information gained from sensors and built-in test
- Diagnostic / Prognostic Reasoner
 - Identifies stress and wear factors
 - Detects and interprets anomalies
 - Determines mission capability
 - Serial Number Tracking - Determines remaining useful life of each item
 - Performs condition-based prognostics



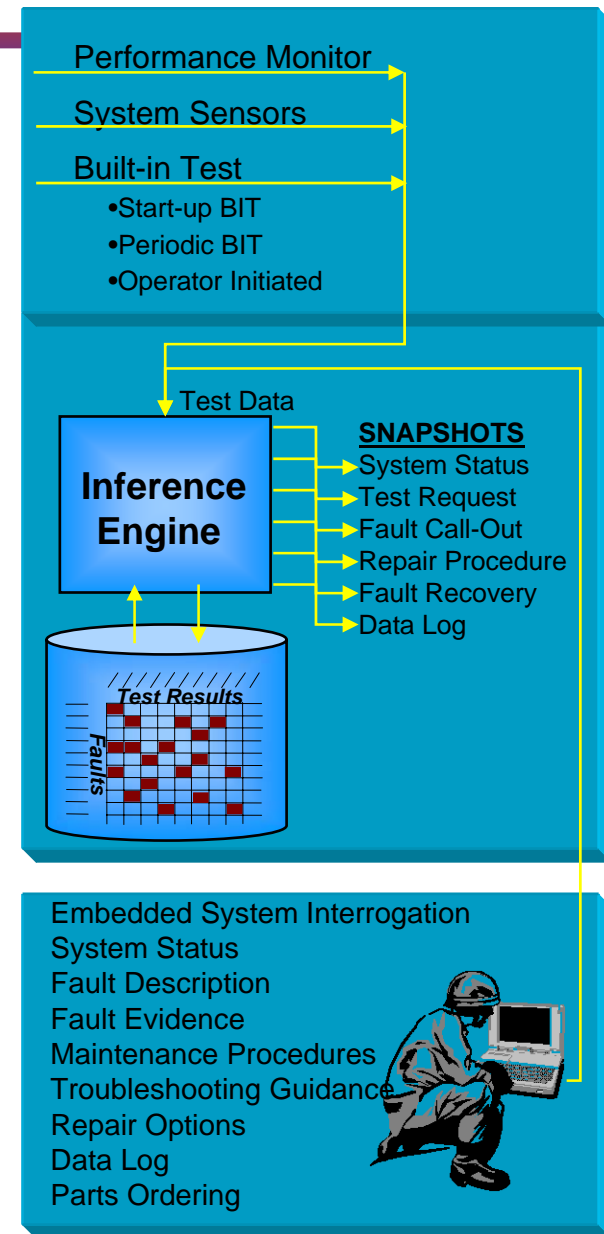
"Dynamic" Diagnostic Capability

- **Test Results can be input**
 - ... in any order
 - no pre-set sequence
 - ... from any source
 - operator observations, test instruments, data bus, data file, built-in test, automatic test equipment, system panels & displays, etc.
 - ... as many as test source(s) can provide
 - not restricted to one-at-a-time to traverse fault tree
 - zeroes-in on cause of fault(s)

- **Can identify multiple faults**
 - ... Diagnostic trees follow single-fault assumption

- **Will always zero in on fault**
 - ... Never leaves the technician hanging

- **Only requests tests of diagnostic significance**
 - ... Based upon snapshot of current fault possibilities

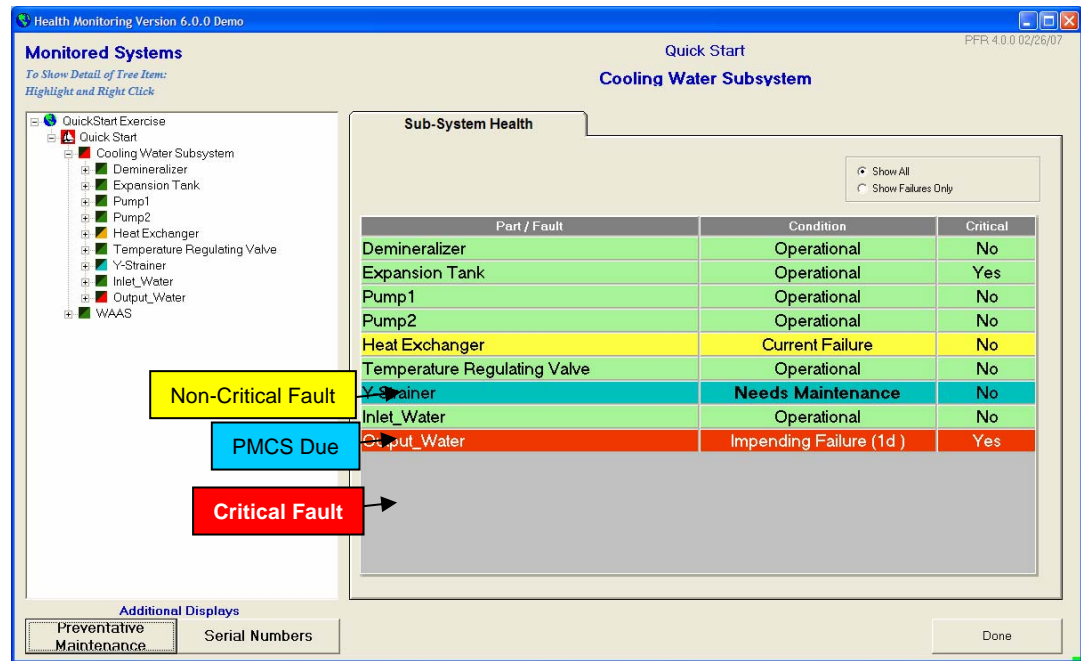


- Integrates diagnostic/prognostic results into a Health Management System

- Makes maximum use of existing Sensor/BIT data

- Provides Prognostics Analysis/Reasoning

- Degradation of signals/measurements over time
- Depletion of consumable items
- Accumulates wear factors
- Engineering correlations
- Tracks preventive maintenance based on time/wear/use
- Serial number tracking
- Remaining Useful Life



Health Monitoring Version 6.0.0 Demo

Quick Start

Monitored Systems

To Show Detail of Tree Item:
Highlight and Right Click

QuickStart Exercise

- Quick Start
 - Cooling Water Subsystem
 - Demineralizer
 - Expansion Tank
 - Pump1
 - Pump2
 - Heat Exchanger
 - Temperature Regulating Valve
 - Y-Strainer
 - Inlet_Water
 - Output_Water
 - WAAS

Sub-System Health

Show All
Show Failures Only

Part / Fault	Condition	Critical
Demineralizer	Operational	No
Expansion Tank	Operational	Yes
Pump1	Operational	No
Pump2	Operational	No
Heat Exchanger	Current Failure	No
Temperature Regulating Valve	Operational	No
Y-Strainer	Needs Maintenance	No
Inlet_Water	Operational	No
Output_Water	Impending Failure (1d)	Yes

Additional Displays

Preventative Maintenance Serial Numbers Done

- Allows for integration of 3rd party prediction techniques

- Compiles, interprets and displays trend data

- Creates multiple log files

- Links to maintenance systems (IETM, PMCS, Supply) based on specific fault

3 Views into Health Data

Operator – Am I OK?
If not, why not?
What do I do?

Mission Commander –
Will this system make it
through mission without
failure? Which of my
systems will make it
through the mission?

Maintainer – What repairs
need to be made? What
spares do I need to make the
repairs? What are the repair
procedures? What PMCS is
currently due?

Health Monitoring Version 6.0.0 Demo PFR 4.0.0 02/26/07

Monitored Systems

To Show Detail of Tree Item:
Highlight and Right Click

- [-] JLENS
 - [-] FCR
 - [-] Platform
 - [-] CPG
 - [-] Communications Systems
 - [-] Communications and Control Station (CCS)
 - [-] CCS Power Subsystem
 - [-] CCS Environmental Control System
 - ▶ CCS Environmental Control System.C
 - ▶ CCS Environmental Control System.C
 - ▶ CCS Environmental Control System.C
 - ▶ CCS Environmental Control System.C
 - ▶ CCS Environmental Control System.C
 - ▶ CCS Environmental Control System.C
 - ▶ CCS Environmental Control System.C
 - [-] Network Subsystem
 - [-] Processors Subsystem

System Health

Mission Readiness

Maintenance

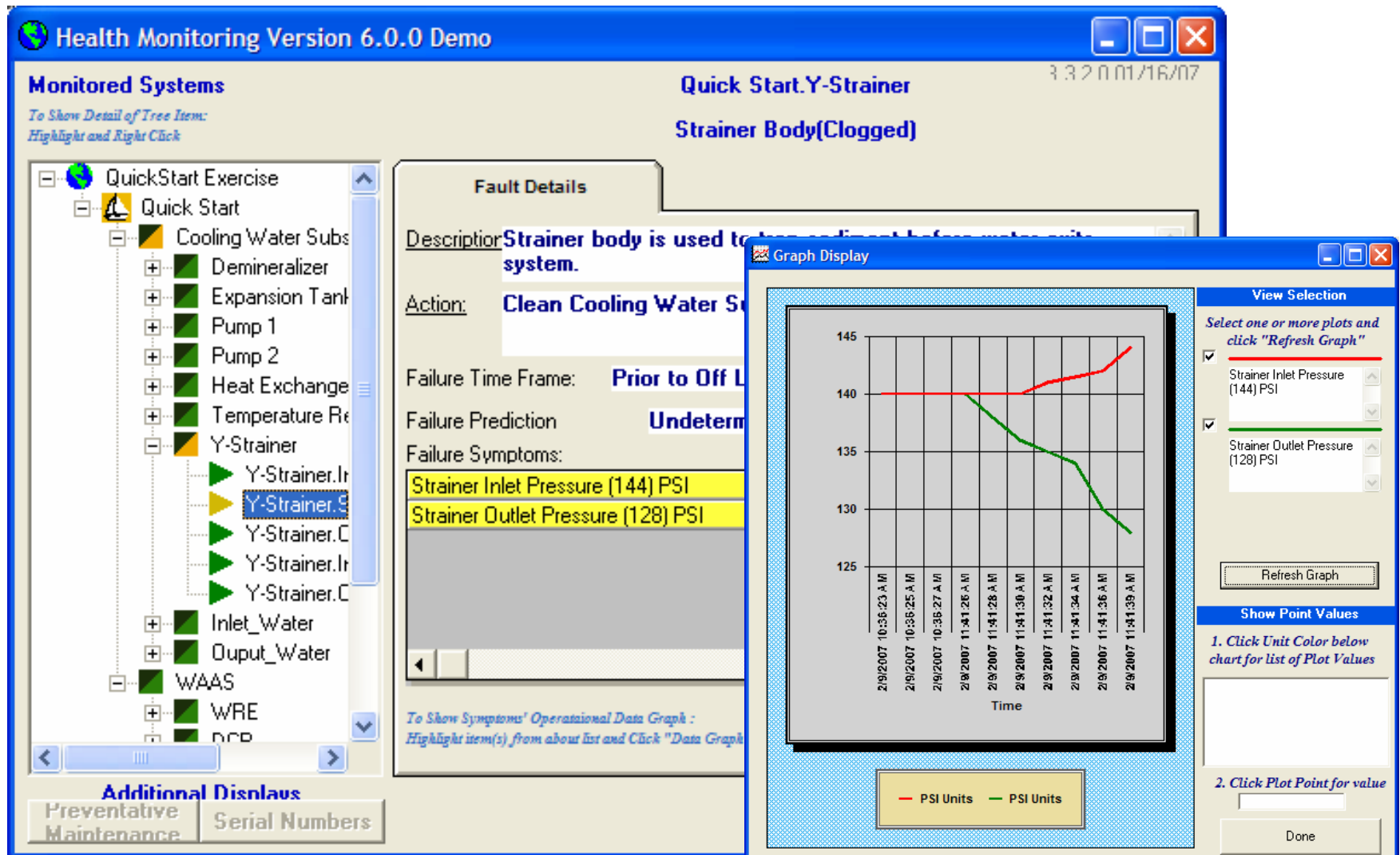
Show Sub-System Health Show All
 Show Functional Capabilities Show Failures Only

Part	Condition	Critical
Communications Systems	Operational	No
Communications and Control Station (CCS)	Impending Failure (12h)	Yes
Data Processing Station (DPS)	Operational	No
Signal Processing Station (SPS)	Operational	No

CPG

Operator View - Real-Time Status Monitoring & Health Assessment

- Drill down the hierarchical model to get the level of detail desired.



Health Monitoring Version 6.0.0 Demo

Monitored Systems
To Show Detail of Tree Item: Highlight and Right Click

- QuickStart Exercise
 - Quick Start
 - Cooling Water Subs
 - Demineralizer
 - Expansion Tank
 - Pump 1
 - Pump 2
 - Heat Exchange
 - Temperature Re
 - Y-Strainer
 - Y-Strainer.In
 - Y-Strainer.S**
 - Y-Strainer.C
 - Y-Strainer.In
 - Y-Strainer.C
 - Inlet_Water
 - Output_Water
 - WAAS
 - WRE
 - ncp

Quick Start.Y-Strainer
Strainer Body(Clogged) 3/3/2007/16/07

Fault Details

Description: Strainer body is used to...
Action: Clean Cooling Water S...
Failure Time Frame: Prior to Off L...
Failure Prediction: Undeterm...
Failure Symptoms:
 Strainer Inlet Pressure (144) PSI
 Strainer Outlet Pressure (128) PSI

To Show Symptoms' Operational Data Graph: Highlight item(s) from about list and Click "Data Graph"

Graph Display

View Selection
 Select one or more plots and click "Refresh Graph"

- Strainer Inlet Pressure (144) PSI
- Strainer Outlet Pressure (128) PSI

Refresh Graph

Show Point Values
 1. Click Unit Color below chart for list of Plot Values

Time	Strainer Inlet Pressure (144) PSI	Strainer Outlet Pressure (128) PSI
2/9/2007 10:36:23 AM	140	140
2/9/2007 10:36:25 AM	140	140
2/9/2007 10:36:27 AM	140	140
2/9/2007 11:41:26 AM	140	135
2/9/2007 11:41:28 AM	140	132
2/9/2007 11:41:30 AM	140	130
2/9/2007 11:41:32 AM	140	128
2/9/2007 11:41:34 AM	140	126
2/9/2007 11:41:36 AM	140	124
2/9/2007 11:41:39 AM	140	122

2. Click Plot Point for value

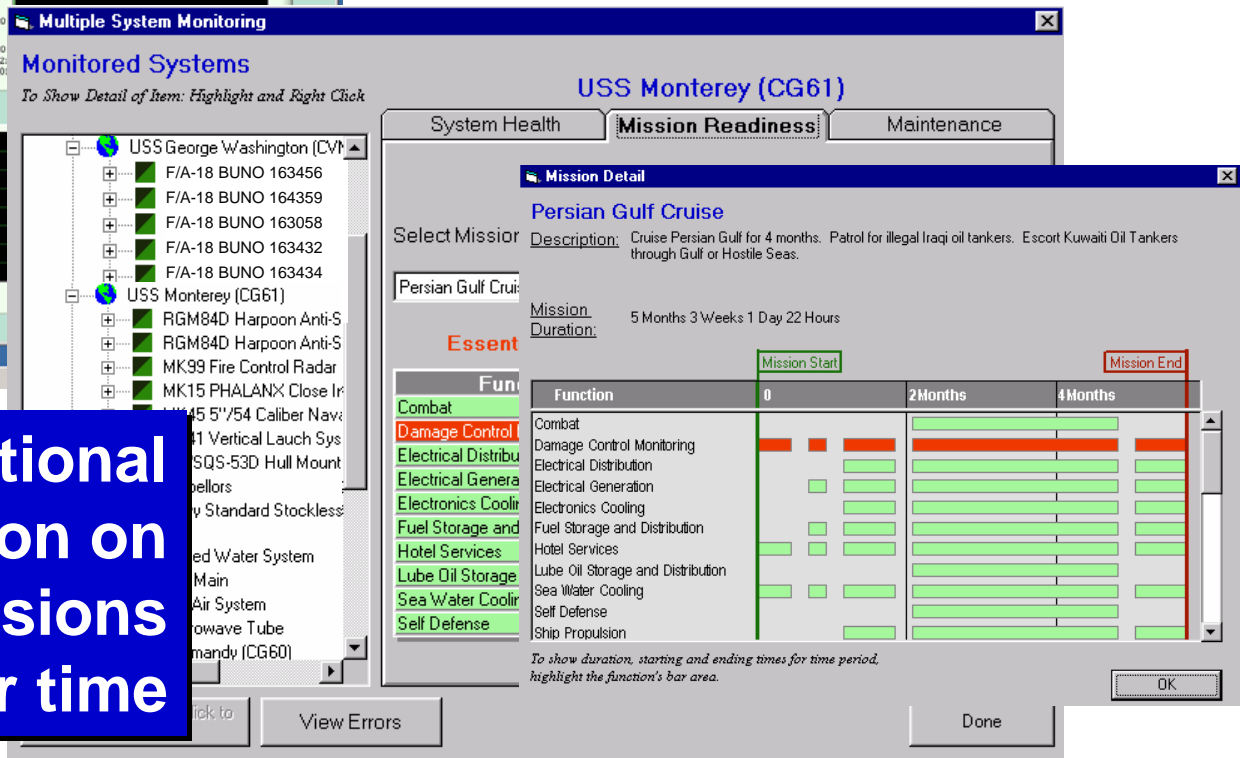
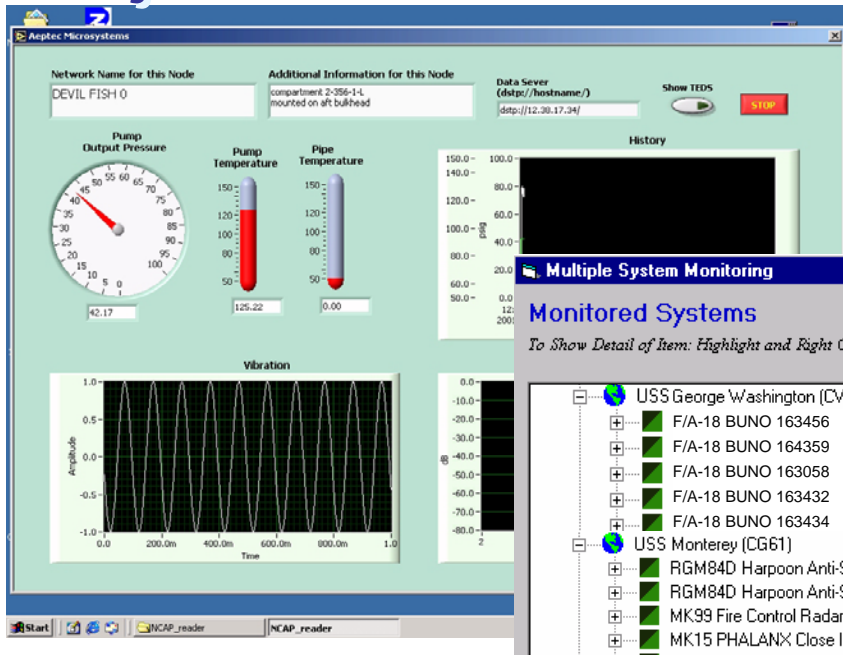
Done

Additional Displays
 Preventative Maintenance Serial Numbers

Mission Commander View

Not just sensor data.....

....but also mission readiness based on status of inter-related systems



Impact of functional degradation on specific missions over time

Health Monitoring Version 6.0.0 Demo FR 4 0 0 02/26/07

Monitored Systems

*To Show Detail of Tree Item:
Highlight and Right Click*

QuickStart Exercise

- Quick Start
 - Cooling Water Subsystem
 - Demineralizer
 - Expansion Tank
 - Pump1
 - Pump2
 - Heat Exchanger
 - Temperature Regulatin
 - Y-Strainer
 - Y-Strainer.Inlet(Hig)
 - Y-Strainer.Strainer
 - Y-Strainer.Outlet(H
 - Y-Strainer.Inlet(Lov
 - Y-Strainer.Outlet(Lc
 - Inlet_Water
 - Output_Water
 - WAAS

Quick Start

System Health
Mission Readiness
Maintenance

Task Details for Repair Item

Y-Strainer Return to Task List

Item Description **CAGE Code ABCDE**

Part Information **NSN 123-4567**

To View Repair Procedure: Highlight Task below and Click "View Repair Procedure"

Name
Y-Strainer

To Record Repairs: Click "Record Repair Data"

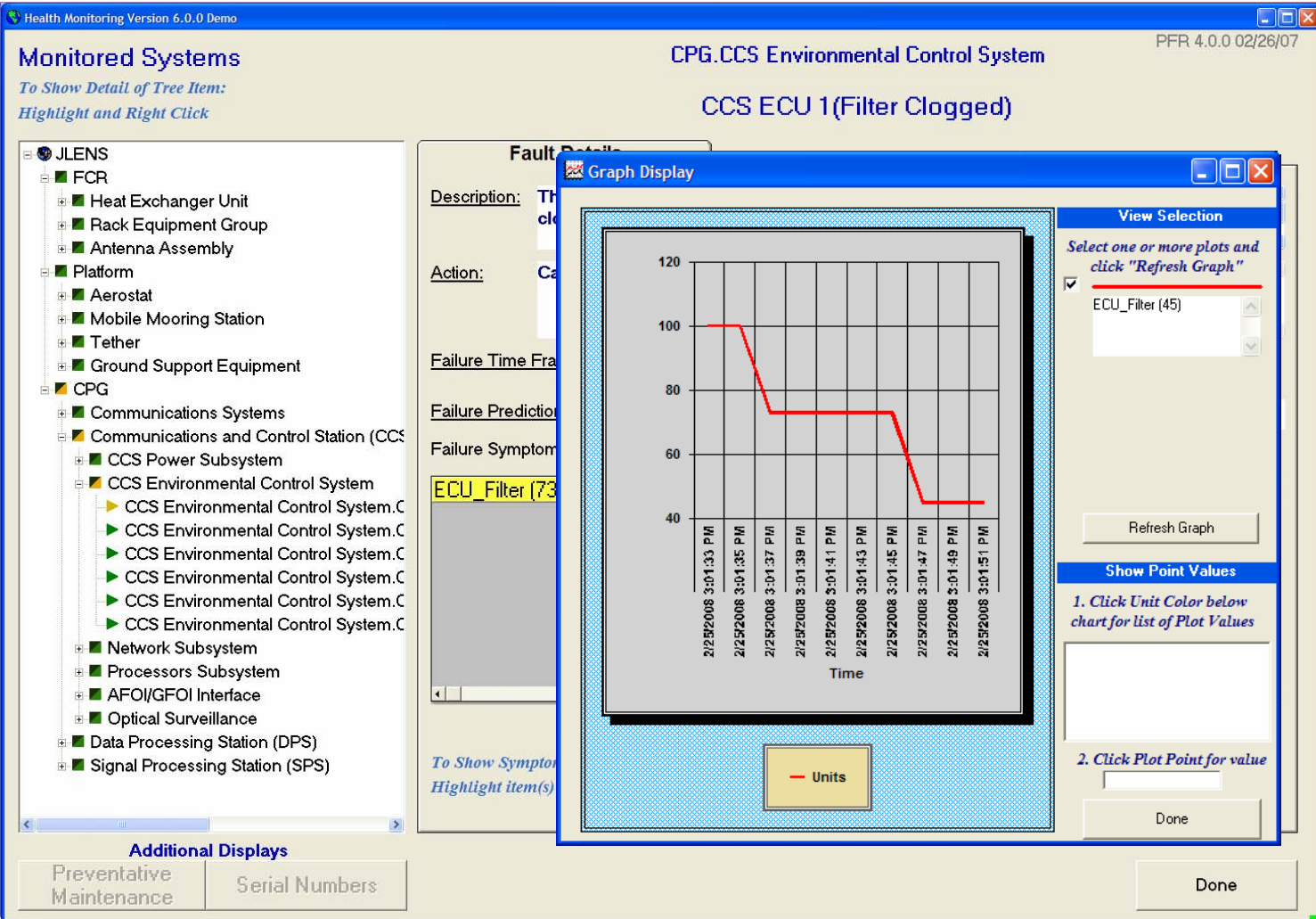
Record Repair Data
View Repair Procedure

Done

Additional Displays

Preventative Maintenance Serial Numbers

System Capability (SYSCAP)



•SYSCAP displays system status based on the hierarchical breakout of the system:

- System
- Prime Item
- Critical Item
- LRU
- Fault
- Failure Mode

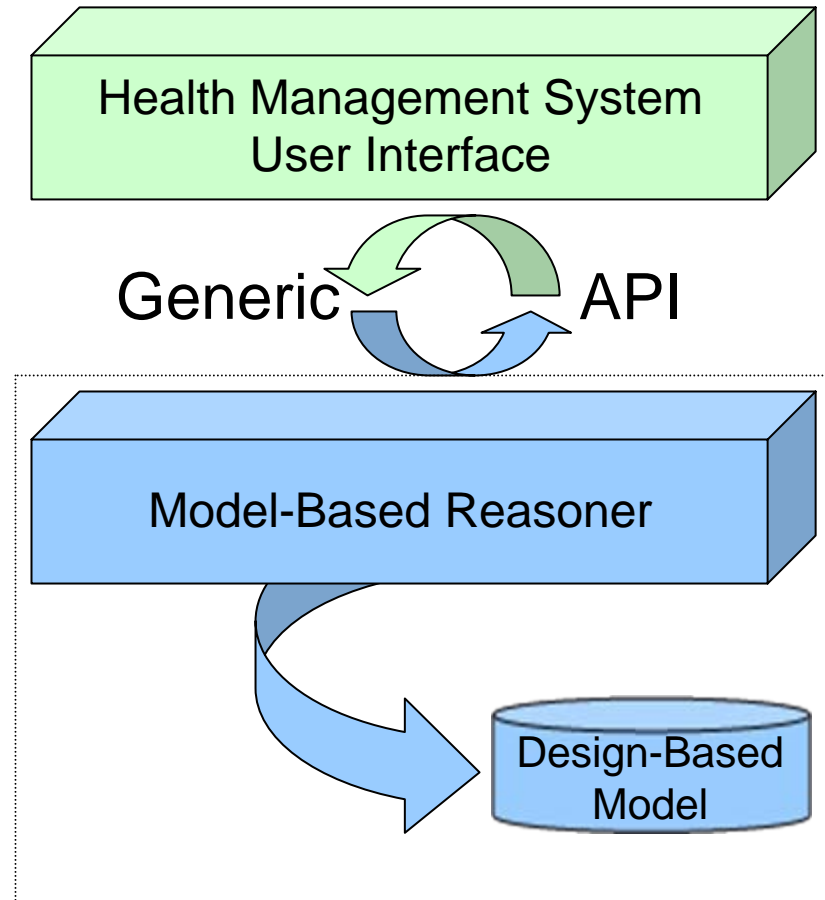
•At each level, appropriate information is displayed.

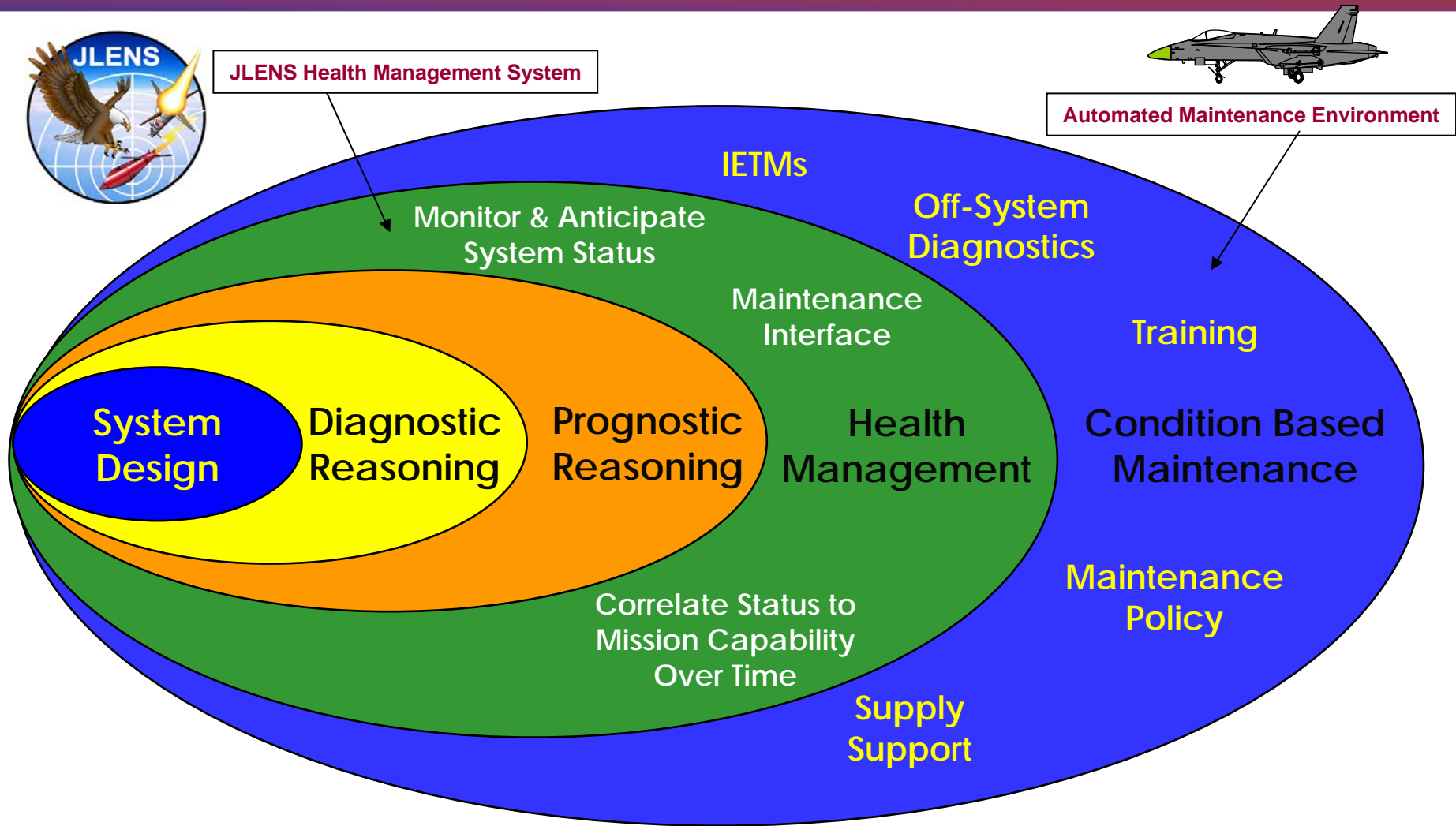
•Operator can drill-down to investigate health

- Preventive Maintenance
- Maintenance and repair procedures linked to fault enunciation
 - Model can launch IETM to specific repair procedure for fault
- Serial Number Tracking
- Interface to Parts Ordering
- Data Logging
- Validate Sensor Data
 - Missing or invalid data
 - Valid sensor ranges

Software Architecture of the Health Management System

- Run-Time Software designed for embedded applications
- C Code that can be cross-compiled to any platform
- Implementation Strategy:
 - Centralized
 - Distributed
 - Hierarchical
- Software functions serve as building blocks
 - Integrate building blocks to build desired functionality
 - Design User Interface as desired or use existing
 - Well-documented API





Design-Based Comprehension of System Condition is the Most Fundamental Enabler of CBM+

Diagnostics/Prognostics Based Programs

- Navy SPS-48E Radar
- C-130 Gunship
- A-10/KC-135 Turbine Engine Monitoring System
- Kiowa Warrior Mast Mounted Sight
- Seawolf Ship Control System
- Avitronics Radar Warning Receiver
- NASA Remote Power Controller
- F-16 Universal Data Acquisition System
- Navy Total Ship Monitoring (TSM) Program
- Navy Battle Group Automated Maintenance Environment Program
- FAA Wide Area Augmentation System



VSE Capabilities: Total Implementation Support

- Tailorable to any platform or system
- VSE has the capability and experience to bring all of the resources together to forge a PRACTICAL, EXPEDIENT and, COST EFFECTIVE solution:
 - Requirements Analysis/Implementation Strategy
 - Integration & Middleware
 - Legacy Data Capture
 - Development of System Diagnostic/Prognostic Models
 - Installation & Fielding
 - Training
 - Fleet Support Team



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