Applying Autonomic Logistics to the F-35

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F-35 Program

F-35A  CTOL
F-35B  STOVL
F-35C  CV
The right mix to be effective and affordable
This Program is Different …

…VERY Different

Different in Everything We Do

- **Transformational Weapon System**
  - Multi-role Combat Aircraft Infrastructure Replacement
  - Coalition Operations Enabler

- **Innovative, Integrated Management Concepts**
  - Best Athlete, Best Practices, Best Value
  - Integrated Management Framework

- **Affordability Based Paradigm(s)**
  - Economies of Commonality and Scale
  - Global Best Value Supply Chain Management
  - Autonomic Logistics

- **True International Partnerships**
  - Allied Co-Development and Long Term Relationships
Breaking Rice Bowls

Specific Performance Requirements

- Mach 2.3
- 18°/sec turns
- Range
- Acceleration
- Surfaces
- Weight
- Training
- Skill Codes
- Support Equipment
- Trade Spaces for Cost Savings
- Title 10
- MIL SPEC
- MIL STD
- Repair Technologies
- Joint Tech Data
- Legacy Systems

JSF Paradigm

- Safety
- Data
- Title 10
- Training
- Information Systems
- Supply Support
- Maintenance Planning
- Configuration Management

Trade Space

Three AL KPPs:
- Mission Reliability
- Logistics Footprint
- Sortie Generation Rate

KPPs & Boundaries Open Up Trade Space

Approved for public release
The Autonomic Logistics Concept

- Smart, Reliable Aircraft
- Agile Support
- Integrated Electronic Training of Pilots and Maintainers
- ALIS-Integrated Infrastructure
- Partnering with Government and Industry for Best Value

A global evolution of our role in fighter sustainment
Why Autonomic Logistics?

- The Affordability Challenge
  - DoD has to reduce O&S costs

- AL Performance Requirements
  - Logistics Footprint
  - Sortie Generation Rate
  - Mission Reliability

Three of Eight KPPs are in AL
An Affordable, Integrated Solution

Affordability Baseline Cost

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- Prognostics and Health Management (PHM) is part of the affordable solution
- Training and Information Systems are also Logistics Elements

O&S Savings Sources

- R&M
- SLO
- ISP
- PHM
- Training
Highly Supportable Aircraft
- Reliable Design
- Prognostics and Health Management
- Repair/Return (R/R) Maintenance

Training System
- Pilot Embedded Training
- On Demand Maintenance Training
- Air Vehicle Software Reuse
- Integrated Training

Support System
- Maintenance Support
- Supply Chain Management
- Support Equipment
- Joint-Service Tech Data
- Sustaining Engineering
- Intelligent Help Desk

Autonomic Logistics Information System
- Distributed Information System
- Elements include
  - Support Services
  - Training Services
  - Mission Support Services

Autonomic logistics provides order of magnitude O&S savings
The “Intelligent” Air Vehicle

PHM
- Enables opportunistic and on-condition maintenance
- Eliminates troubleshooting
- Dramatically reduces CND/A799s
- Significantly reduces support equipment
- Reduces training required
- “Triggers” the Autonomic Logistics System

RM&S
- Reduces spares
- Reduces support equipment
- Reduces manpower requirements
- Allows skill level reductions
- Reduces training requirements

Design Interface – The First Step to O&S Affordability
On-Board PHM CONOPS

Remote Diagnosis
Prognosis
Design Feedback

Lethality/Survivability
• In-flight Health,
Situation
Awareness

Sortie Generation
• Autonomic
Logistics
Enabled

Affordability/Supportability
• Near Zero False Alarms
• On-Condition Maintenance

ALIS
Off-Board PHM CONOPS

Aircraft Support
- Maintainer Vehicle Interface
- Augment Aircraft Diagnostics
- Component Performance Tracking
- Support PHM Maturation
- Clear Faults
- Execute Test
- Display Repair Task List
- Execute Diagnostic System Control
- Upload Algorithm Updates

Fleet Support
- Intelligent Help Desk
- Distribute PHM Information
- Support Knowledge Discovery
- Support PHM Maturation

- Downlink Health Data
- Assess and Report Aircraft Health
- Uplink Combat Turn Requirements

Supplier
Contractor
Portable Maintenance Aid
Maintenance Interface Panel
PHM Architecture

Air Vehicle On-Board Health Assessment

Integrated Caution, Warning, and Advisory System

PHM Area Managers
- Vehicle Systems
- Flight Control Systems
- Utility Subsystems
- Structures
- Mission Systems and Subsystems

Propulsion

Provides:
- AV-Level Info Management
- Intelligent Fault Isolation
- Prognostics/Trends
- Auto. Logistics Enabling/Interface

Health Management, Reporting & Recording

Non-volatile Crash Recorder

Methods Used:
- Sensor Fusion
- Model-Based Reasoning
- Tailored Algorithms
- Systems Specific Logic / Rules
- Feature Extraction

Results In:
- Decision Support
- Troubleshooting and Repair
- Condition-Based Maintenance
- Efficient Logistics

Autonomic Logistics & Off-Board PHM

Integrated Caution, Warning, and Advisory System

Displays & Controls

Portable Maintenance Device

Maintenance Interface Panel

Portable Maintenance Aid

ALIS

Portable Maintenance Aid

Maintenance Interface Panel

ALIS

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NDIA
Advanced Techniques Are Applied to JSF Weapon System PHM Solution

Performance Monitoring / Trending:
PTMS (IPP, Filters, Reservoirs, Coalescer, etc.)
Hydraulic System (Pumps, Filter, Reservoirs, Accumulators)
Fuel System (Pumps, Valves, Heat Exchanger)
Weapon Bay Door Drive (Pump Speed & Swashplate Angle)
Rotary Actuators, EHAs
Weapon Racks
OBIGGS Filter

Auto Calibration / Gain Trending:
Radar
Displays
Fuel Probes
Stick & Throttle

Enhanced Sensor Technologies:
Engine - FOD Detection, Oil Debris,
Oil Condition, Blade Tip Monitoring,
Vibration Monitoring
SDLF - FOD Detection, Oil Debris,
Oil Condition, Shaft Alignment / Torque,
Clutch Wear / Vibration
Brake Temperature
Landing Gear (Strut Servicing, ‘Smart Tire’)

Operational Loads/Usage Monitoring:
Structures, Landing / Arresting Gear
Gun, EPS Starter/Generator
CSMU (Write Cycles)

Cross-Comparison (Redundancy Management):
Flight Controls (VMC, Inceptors, EHAs, Sensors)
EPS (Degraded modes, Emergency Power)
Fuel Probes

Capacity Trending:
28 & 270 volt Batteries
Cryo Cooling Capacity
ESA (loss of Elements)
OBIGGS / OBOGS
HIPPAG Recharge Rate

Information Management:
Model-Based Reasoning, Trending,
Pattern Recognition (Enhanced Diagnostics, Fault Isolation)

Automated Testing:
WBDD Actuator Backlash
External Fuel Tanks
RIOs, VSP Software
Nose Wheel Steering Friction Collar
CSMU (Periodic Read/Write Testing)
Aircraft Wiring

Off-Board Technologies:
Diagnostic Tools
Intelligent Help
Prognosis Models

PHM Is an Integral Part of Every Facet and Subsystem of the Weapon System

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Benefits of PHM

Change of Maintenance Philosophy

- On-condition
- Opportunistic
- Not “on-failure” nor “per schedule”
- Less interruption of mission schedule

Benefits to the Maintainer

- Unprecedented insight into vehicle/squadron/fleet health
- Less time spent on inspections
- Better ability to plan maintenance
- Simplified training
- Improved fault detection

Reduction in Test Equipment

- Less intermediate and flight line TE
- 35% less peculiar support equipment during SDD
- Eliminated O-level TE:
  - 81 CTOL pieces
  - 77 STOVL pieces
  - 61 CV pieces

PHM Cost Savings

82% Reduction in CNDs

- F-16C: Legacy 63, JSF 11
- AV8B: Legacy 77, JSF 13
- STOVL: Legacy 83, JSF 17

18% Reduction in Maintenance Man-Hours Due to Reduction in CNDs
ALIS Provides Off-Board PHM Support

ALIS Architecture

Interoperable With DoD/MoD External Systems
- Command & Control
- Maintenance
- Mission Planning
- Supply Support
- Training
- Transportation

Training Services
Support Services
Mission Planning Services

Status/Decision Support
Generate Maintenance Actions
Locate/Issue Parts
Training
Joint Tech Data
Analyze Health of Fleet

Air System Interfaces
- Air Vehicle
- Training Devices

Autonomic Logistics Information System Concept
- Interoperable
- Affordable
- Effective
- Proven Processes
- Rationale Justifies Concept
- Achievable Software Development
- Open Architecture
- Meets Requirements

LM JSF Commercial Virtual Enterprise Infrastructure
- Product Data Mgmt
- Integrated Mgmt Framework
- Procurement

JV03-332
Supportive Business Processes

- Joint Depot Maintenance Core Capability Requirements Determination and Quantification Procedure
- Joint Depot Source of Repair Determination
- Partnering with Depots
- “Power-by-the-Hour” Performance-based Logistics Contracting
- Supply Chain Management
Lift Fan Shaft Alignment Demo

- Health assessment of engine and lift fan
- Non-contact sensors
- Measured 50 out of 50 within required accuracy (+/-0.2 degree)
Beacon-Based Exception Analysis for Maintenance (BEAM)

- BEAM Technology developed and demonstrated at Jet Propulsion Laboratories (JPL), applied to JSF
- Provides failure detection and isolation
- Fusion of complex inputs - combines
  - Advances in wavelet theory
  - Non-linear information filtering
  - Neuro-fuzzy systems identification
  - Stochastic modeling
Rotational Machinery Prognostics

- Combines vibration analysis techniques with data fusion
- Detects and assesses equipment damage
- Predicts remaining component life
- Demo showed that impending lift fan failure can reliably be detected in time to avert catastrophe
Model Based Reasoning

- Prognostics Not Diagnostics
- Redundancy management
- Demonstrated on
  - Engine
  - Radar
  - Fuel system

- Fusion of diagnostic information using intelligent system techniques
  - Fault and degradation detection
  - Fault confirmation
  - Enhanced isolation
  - Cross-system correlation
  - Evaluation of AV functional capabilities