JSF/F-35 Pollution Prevention Activities

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Agenda

• What is F-35/Joint Strike Fighter
• Pollution Prevention (P2) Background
• P2 Implemented System Solutions
• P2 Solutions in Work
• P2 Solutions Offering More
  Opportunities for Near Term F-35/ESTCP Partnerships
What is Joint Strike Fighter?

**F-35A**
Conventional
Take Off Landing
(USAF)

**F-35B**
Short Take Off
Vertical Landing
(USMC and UK)

**F-35C**
Carrier Variant
(USN)
F-35 ESH Requirements

• Contract Data Deliverable List CDRL-001
  Air System Lifecycle Plan
    – Hazardous Materials Reduction/Elimination Initiatives
      • Identified and Controlled in Detailed Plan 2YZA00049 Hazardous Materials Management Plan
    – Demilitarization/Disposal Plans
      • Demilitarization/Disposal Plan 2YZA00102

• Contract Statement of Work Commits LMAero/NGC/BAES to a Hazardous Materials Management Plan and Formal Working Group
Hazardous Materials Management Plan (HMMP)

- ESH Working Group Structure
- Partner Country ESH Regulations
- Vendor/IPT Responsibilities
- Banned/Restricted Materials
- Residual Restricted Materials
- Pollution Prevention Research and Development

Dynamic, Results Oriented Document
The Continuing Sustainability Challenge and Interaction with Design for Environment (DfE)

- LMAero Solved the Easy-To-Do Material/Process Substitutions on Previous Programs
  - Low Hanging Fruit
  - Typically Focused on Employee Exposure During Manufacturing
- Now the Challenge is to Find Material Substitutions That Reduce Life-Cycle Expense, i.e. Sustainability
  - Focus on Customer Maintainers Exposure During Operation, Maintenance, Depot Overhaul, Deactivation, Demilitarization, Disposal
  - Awareness of Hazmat Liability to Sub-tier Suppliers due to Current and Future Regulations
  - Reduce Life Cycle Cost Impact through Hazmat Minimization
  - This Results in the Design for Environment (DfE) Approach

Identify the Goal and Force the Solution
Hazardous Materials Control Approach – Controlled by HMMP and M&P

Support Equipment Design

Airframe/Subcontractor Design

NEPA/Conformity Planning

Partner Country Regulation Research

Control Materials on Program

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Pollution Prevention Insertion Opportunities

- Baseline P2 Technology
- Continuing Research and Implementation
- Reduction of Hazardous Support Materials

OPPORTUNITY

ACQUISITION PHASE

Reduce Life Cycle Costs Early in Program

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Current F-35 Pollution Prevention Activities

- Implementing New Deft Non-Chrome Primer for Interior/Exterior Use
- Various Vendors Testing New Coatings and High Strength SS
- Testing Alumiplate™ to Replace Nickel/Cadmium on Metal/Composite Electrical Connectors
- Implementing HVOF WC-Co-Cr and Alumiplate™ for Landing Gears
- Aqueous Nanocrystalline Co-P to Replace EHC and TDC for Actuation Systems
- Cu-Be Bushing Replacement Material

Aggressively Investigating New Materials
System Changes and Improvements Implemented on F-35 With Demonstrable Pollution Prevention Benefits
Key DfE Technology – No Cadmium Fasteners

• Traditional Aircraft Use Thousands of Steel Fasteners with Cadmium Plating
  – Cadmium provides corrosion protection and lubricity
  – Exposes Maintenance Workers to Cadmium During Depainting Because They Grind the Old Coatings Off
  – Several Thousand Dollars per Year for PPE and Longer Grinding Time Due to Occupational Limits

• JSF Uses Titanium or Stainless Steel Fasteners
  – No Cadmium
    • Except for Three Locations with no Drop-in Replacement (QAD, SFD, Gun)
  – More Expensive Up-front But Less Life Cycle Cost

Reduces Up/Down Stream ESH Impact
Key DfE Technology - OBIGGS

- Traditional Military Aircraft Used Halon 1301 (ODC) to Provide Fire Protection to Fuel Tanks
  - Empty Fuel Tank Volume Must be Filled with Inert Gas to Prevent Fire/Explosion from Bullets/Shrapnel

- On-Board Inert Gas Generating System (OBIGGS) Replaced Halon 1301
  - Filters out Oxygen from Ambient Air to Create Nitrogen Enriched Air Suitable for Fuel Tanks
  - Military No Longer Required to Maintain Halon Stockpile for Wartime Fuel Tank Inerting

No More Halon Stockpiles
Key DfE Technology - OBOGS

• Traditional Aircraft Carried the Pilots Oxygen Supply in Liquid Oxygen Tanks
  • Liquid Oxygen will Trigger Rapid Combustion of Any Dirt or Contaminates in the Supply System
  • Supply System Must Be Perfectly Clean
  • Best Cleaning Solutions Freon CFC-113 and HCFC-141b

• On-Board Oxygen Generating System Replaced Liquid Oxygen
  • Produces Oxygen-Rich Breathing Gas From Engine Bleed Air Using Molecular Sieve Technology
  • No Exotic Cleaning Solutions
  • Military No Longer Required to Stockpile Freon for Oxygen System Cleaning
  
No More Freon Stockpiles
• Traditional Military Aircraft Contain An Emergency Power Generation System to Restart Failed Engine at Altitude
  • Some Systems Like F-16s Used Hydrazine
  • Unstable, Toxic, Dangerous Fluid Produces Gas to Turn a Turbine and Generate Enough Power to Restart Engine

• Integrated Power Package (IPP) Replaces Hydrazine System
  • Small Turbine Engine Integrated with Other Vehicle Cooling/Heating Systems
  • Basically a Small Jet Engine
  • Easy to Start/Stop, No Hydrazine, No Leaks

No More Hydrazine Hazards
Key DfE Technology – Electric Actuators

- Traditional Aircraft Use High Pressure Hydraulic Systems to Move Control Surfaces Like Flaps and Leading Edges
  - Frequent Maintenance
  - Spill Control and Clean Up
  - Filter Disposal

- F-35 Developed Electro-Hydrostatic Actuators to Replace Hydraulics
  - Electric Control from Cockpit
  - Very Small Quantity of Hydraulic Fluid
    - Low Pressure
  - Lifetime Sealed Unit
    - No Maintenance Required

Avoids Hydraulic Leaks and Clean Up
Key DfE Technology - HVOF

• Traditional Aircraft Landing Gear and Other High Wear Surfaces were Chrome Plated
  • Chrome Plating Bath Environmental Liability
  • High Life Cycle Cost:
    • Requires Stripping/Replating every 3-5 Years
    • Military Services Must Have Plating Facilities
    • Replating Takes 2-3 Months
  • Requires Large Quantities of Spares

• High Velocity Oxygenated Fuel (HVOF) Technology
  • High Velocity High Temperature Stream of Powder Shot Onto Part Surface Forming Hard Impervious Wear-Resistant Coating
  • Long Life – Minimal Maintenance
  • Ultra-Smooth Superfinish Extends Life From Seals That Rub Against HVOF Coating
  • Standard Coating for All JSF Actuators, Wear Surfaces, Landing Gear

No More Chrome Plating
Key DfE Technology – ODC Free Manufacturing

• Traditional Aircraft Fabrication Aids, Sealants, and Cleaning Solutions Often ODC-Based
  • Good Cleanliness and Efficient Product Delivery

• LM Replaced All ODC-Containing Products in 1995
• No Class I/II ODCs Allowed on F-35 to Date

No More Ozone Depletion
In Work DfE Projects

- Many Different Projects Underway Domestically and Internationally
- Eliminate Chrome
- Eliminate Cadmium
- Improve Maintainability
Key DfE Technology Non-Chrome Primer

• Approved Deft 44GN098 as F-35 Structural Primer
  – *B-1 Effectivity (First STOVL)*
  – *Fully Implemented on Airframe by B-2*
    • Implementation on System Suppliers Voluntary to Avoid Costs
• LM Aero and Northrop Grumman Running Four Batch Verification
• Galvanic Corrosion Testing In Progress
• Additional Compatibility with Exterior Finishes and Materials
• Potential Use as Flexible Primer
• Landing Gear 300M/A100 Steel Sacrificial Coating
  – *Verified 6000 Hours Scribed Neutral Salt Fog with no Corrosion*
• Qualified to LMA-MR003 Primer Specification
  – *Equivalent to Mil-PRF-85582*
• NAVAIR Recently Completed Qualification to Mil-PRF-85582
Deft Non-Chrome Primer Corrosion Testing

2000 Hours Neutral Salt Fog Chromated Conversion Coated 2024 Aluminum
4000 Hours Neutral Salt Fog
Chromated Conversion Coated 2024 Aluminum
Deft Non-Chrome Primer Corrosion Testing

500 Hours $\text{SO}_2$ Salt Fog
Thin Film Sulfuric Acid Acid 2024 Aluminum
Field Exposure Evaluations

Daytona Beach Exposure

On-Board
CVN USS Stennis
In Indian Ocean
More Field Exposures

Air Force C-130 Hatches Special Mission Aircraft at Antarctic Base – Coated May 2004
Other Non Chrome Primers

- **White Structural Primer to Eliminate Two Coat System**
  - *Replaces Typical Primer/White Urethane Topcoat*
- **Fuel Tank**
  - *Deft Adopting New Corrosion Inhibition Package for Structural Primer for Fuel Tank Coating*
  - *F-35 Program Office-Sponsored Small Business Innovative Research Project*
    - Down-select to Two Vendors
- **Flexible Primer**
  - *Current Baseline Deft 09Y010 But Evaluating 44GN098*
- **Conversion Coating**
  - *LMAero FW Evaluating Options*
- **Adhesive Bonding Primer**
  - *3M (EW5000-AS) and Cytec (BR6747-NC) Partially Qualified*
- **Adhesion Promoters**
  - *Replace PR182/AC160 with Waterborne PR188/AC-135*
- **Rain Erosion (Trivalent Chrome Colorant)**
  - *Two Vendors Developing Non-Tri Versions*
Key DfE Technology – Cadmium Plated Connectors

- Traditional Aircraft Power and Signal Connectors are Cadmium/Nickel Plated Aluminum
  - Dirty Cadmium Plating Operations
  - Limited Life on Aircraft Carriers
  - Soft Cadmium Rubs Off Connector

- Alumiplate™ Qualified as Cadmium Replacement
  - Environmentally Friendly Application
  - Better Corrosion Protection out to 336 Hours in SO₂ Salt Fog
  - Almost All F-35 Connectors Switched to Composites
  - Working Alumiplate™ as Conductivity Coating for Composite Connectors

Improved Performance Less ESH Impact
SO₂ Salt Fog Results

Figure 6.1.11 Ni/Cd connector after 336 hours in SO₂-salt-fog

Figure 6.1.5 TTH after 336 hours in SO₂-salt fog

Figure 6.1.6 Corrosion resistant stainless steel after 336 hours in SO₂-salt fog

Figure 6.1.3 Bright Zn/Ni after 336 hours in SO₂-salt fog

Figure 6.1.9 Dull Ni composite after 336 hours in SO₂-salt fog

Figure 6.1.10 Bright Ni composite after 336 hours in SO₂-salt fog

Figure 6.1.4 Dull Zn/Ni after 336 hours in SO₂-salt fog
Alumiplate™ Results

Figure 6.5.1 Cannon Alumiplate connector with chemfilm after 338 hours in SO₂-salt fog

Figure 6.5.2 Cannon Alumiplate connector with clear coating after 338 hours in SO₂-salt fog
Amphenol® Cadmium Free Connectors
With Electroplated High Purity Aluminum Finish
Provide Superior Corrosion Resistance and Electrical Performance Under the Harshest Environmental Conditions

Now available in MIL-DTL-38999 Series III Aluminum or Composite And MIL-DTL-5015 Series III (MS3450-3459) shell styles

Amphenol® connectors with the AlumiPlate® Electroplated High Purity Aluminum finish outperform all other Cadmium alternatives in terms of Corrosion Resistance, Electrical Conductivity, Galvanic Compatibility and other end use environments such as Salt, Sulphur Dioxide, De-Icing Fluids and Lightning Strike.

When tested, Amphenol® connectors with the MIL-DTL-83488D pure aluminum electroplated coating provide Cadmium-Free:

☑ Corrosion resistance up to 1000 hours in ASTM B117 salt spray testing
☑ Corrosion resistance up to 336 hours in ASTM G85, Appendix 4 Sulphur Dioxide testing
☑ Durability per MIL-DTL-38999K - 500 cycles mating/unmate for aluminum components, 1500 cycles on composite components.
☑ Durability per MIL-DTL-5015H Series III - 100 cycles mating/unmate for aluminum components.
☑ Shell-to-Shell conductivity values which meet or out perform Nickel and Cadmium finishes both before and after environmental testing
☑ Superior galvanic compatibility with mating materials

Amphenol® connectors with the AlumiPlate® Electroplated High Purity Aluminum finish have been tested by Lockheed Martin Aeronautics Company and are being considered as the leading choice for the F-35 Joint Strike Fighter program.

For further information on Amphenol® connectors with the Electroplated High Purity Aluminum finish please contact us at:

Amphenol Corporation
40-60 Delaware Avenue, Sidney NY 13365-1395
Phone: 607-563-5011 or 800-678-0141 Fax: 607-563-5157
Website: www.amphenol-aerospace.com

Amphenol
Key DfE Technology - Copper-Beryllium Bushing Replacement

• Copper-Beryllium (Cu-Be) Bushings Added to LMAero Restricted Materials List February 2004
  – F-35 Technical Mgmt Concurred with Action Plan to Identify Locations and Develop Alternative Material Where Feasible
• Typically Used for Flight Control Actuators and Other High Load Environments
  – 350+ Specific Locations
  – Switched to Other Materials for Many Applications

Rapidly Qualify/Implement New Materials
Bushing Replacement Lab Testing

• F-35 Evaluation of Alternative Materials
  – ToughMet, Nitronic 50/60, 304/HBN, SBIR Developed, etc..
  – Phase 1 Completed Tensile, Compression, Bearing, and Shear
  – Phase 2 Completed Wear and Galling
  – Phase 3 Completed Elevated Temp Tensile
  – Phase 4 Completed SCC and Salt Fog exposure
  – All F-35 Bushings <2.5”Ø Switched to Cold Worked Nitronic 60
  – Phase 5 test plan Evaluating Installation Issues

• ASC PP3010 FY05-06 Funding
  – Subscale Testing and Implementation

• Materials Affordability Initiative (MAI)
  – 25/75 Contractor/Government Cost Share with LM/Boeing/BrushWellman
  – Phase III Advanced Screening and Toughmet “S” Basis Generation
  – Phase IV Toughmet “A/B” Basis Generation, Fatigue and Fracture, Installation
  – Phase V Implementation Studies
Key DfE Technology - Corrosion Detection

- F-35 Needs Low Budget Device to Solve Several Issues
  - Corrosion Detection, Locate OML Panel Edges and Fasteners, Detect Fluid Leaks, Inspect Composite Material Beneath Several Coating Layers, Verify Coating Thickness
- Existing Phase II SBIR Developed Microwave Corrosion Detection Device
- F-35 JPO ESH Sponsored Phase II Extension and Phase III Commercialization
  - LMAero F-35 Generating Reqmts
- P2 Benefit – Reduce Scheduled (non-necessary strip/repaint cycles) Coating Maintenance, Minimize Coating Damage During Event Maintenance

Avoid ESH Impact of Needless Coating Rework
Future ESTCP Cooperation

How F-35 and ESTCP Can Continue to Work Together and Expand Work to Enhance Value
Key DfE Technology - Cadmium Plating

• *Traditional Aircraft Steel Parts Protected From Corrosion by Cadmium Plating*

• *Several Alternative Technologies Under Development*
  • *Alumiplate™*
  • *New High Temp Metal Coatings*
• *ESTCP Funded S-53 High Strength Stainless Steel Dem/Val Program on F-35 RGAs*
  • *Risk Reduction Phase Underway by Fabricating One RGA ‘Set’ and Fatigue Testing*
  • *LMAero/BAES Studying Corrosion Performance Enhancements*
  • *Full Demonstration Starts 2007*

*Eliminate Cadmium Plating*
Cadmium Plating Irrelevant with S-53?

• Ultimate Solution is New High Strength Stainless Steel
  – No Secondary Plating
  – Ferium S-53 from Questek Once Class A Allowables Complete
  – Strength of 300M (225Ksi YS and 285Ksi UTS) With 15-5PH Stainless Steel Corrosion Resistance
  – Fracture Toughness 85 ksi-inch$^{1/2}$ Versus 300M 50 ksi-inch$^{1/2}$
  – Stress Corrosion Cracking Strength >50 Versus <10
  – 3 Heat Qualification Underway for ESTCP Program
  – Ogden ALC Intends to Adopt for All AF Landing Gears Where Possible to Avoid Cadmium Plating
  – Goodrich/MOOG/Curtis Wright Monitoring Product for F-35 Use and Participating in RGA Demonstration

Elimination is Ultimate Solution
• TDC used for corrosion and wear resistance – numerous callouts on gears, bearings, actuator IDs
  • **Nodular Surface Provides Lubricity**
• F-35 Sponsored ESTCP Follow on for Nanophase Cobalt-Phosphorus
  • **Will Screen Process Development Samples**
  • **F-35 Vendors Moog/Curtis Wright/Smiths Participating**

<table>
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<tr>
<th></th>
<th>TDC</th>
<th>nCo-P</th>
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<tr>
<td>Thickness</td>
<td>0.0001-0.0006”</td>
<td>0.0001-&gt;0.020”</td>
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<tr>
<td>Hardness</td>
<td>900-1,100HV</td>
<td>650-1,000HV</td>
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<td>Morphology</td>
<td>Nodular</td>
<td>Nodular</td>
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<tr>
<td>Coeff friction</td>
<td>~60% EHC</td>
<td>~60% EHC</td>
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<tr>
<td>Roughness</td>
<td>4-10µ” Ra</td>
<td>&lt;4µ” Ra</td>
</tr>
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**nCo-P Promising TDC Alternative**
Key DfE Technology – Supersonic Particle Deposition

- Current In-Field Coating Repair of Cadmium/IVD-Alum Coated Surfaces is Brush Cadmium or Other Chromated Products Like SermateK™
- Cold Spray Emerging Technology
- More Effective Magnesium Corrosion Repair Needed
- 2004 Navy SBIR IVD Repair Evaluating Several Cold Spray Techniques
  - NADEP Cherry Point
  - Purchased Inovati Kinetic Metallization™ System
- F-35 Funded DSTO (Australia) and AFRL
  - Leverage off NRL ESTCP
  - Provide Effect of Defects Panels
  - In Cooperation with
    - Hamilton Sundstrand (ESG Mag Generator Housing, Pump Housing, more)
    - Honeywell (PTMS with Mag Housing)

May Require Several Repair Options

Brush Cadmium

K-Tech Cold Spray Equipment
Key DfE Technology - Material Disposal

- CDRL A001 Requires Disposal Plan
- No Available Methods for Composites/Low Observable Materials
- Need Recycling Alternative with Beneficial Reuse to Avoid RCRA HazWaste Designation for Disposal
- Phase II Air Force SBIR LO Coating Destruction
  - Phase I Fluidized Bed Reactor Concept Demonstrated Complete Breakdown of Materials and Conversion to Calcium Carbonate
- F-35 Participating in Phase II
  - Provide Materials, Lab Verification of Destruction
- ESTCP Scale Up Assistance?

Eliminate Composite Disposal Uncertainty
Key DfE Technology - Gap Fillers

- LO Aircraft Require Gap Fillers Between Exterior Panels
- Typically Nickel Filled
- Maintainer Exposure Issue During Panel R&R Due to Sanding/Grinding Filler
- F-35 Studying Alternative Materials
  - Northrop Grumman Awarded AFMC P2 R&D Program
    - Non-nickel Alternatives
    - Other Internal R&D Projects
- If Successful Alternative Found, Can ESTCP Assist with Cross-Program Qualification/Implementation?
  - Unique Program Qualification Requirements will Drive Cost

Improved Performance Less ESH Impact

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Summary

• **F-35 Largest DoD Weapon System Acquisition Program**
• **Replaces Several Legacy Aircraft Worldwide**
• **Operates Under Comprehensive ESH Management and Hazmat Control**
• **Conducts Aggressive Pollution Prevention and Material Substitution Activities Focusing On Life Cycle Cost Reductions**
• **Integrates Partner Country Requirements into Program**
DfE/Sustainability Objective

Minimize ESH Impacts on Four Program Tenants