JSF/F-35 Pollution Prevention Activities

ESTCP/SERDP DoD Metal Finishing Workshop
22-23 May 2006
Washington DC

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Report Documentation Page

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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)

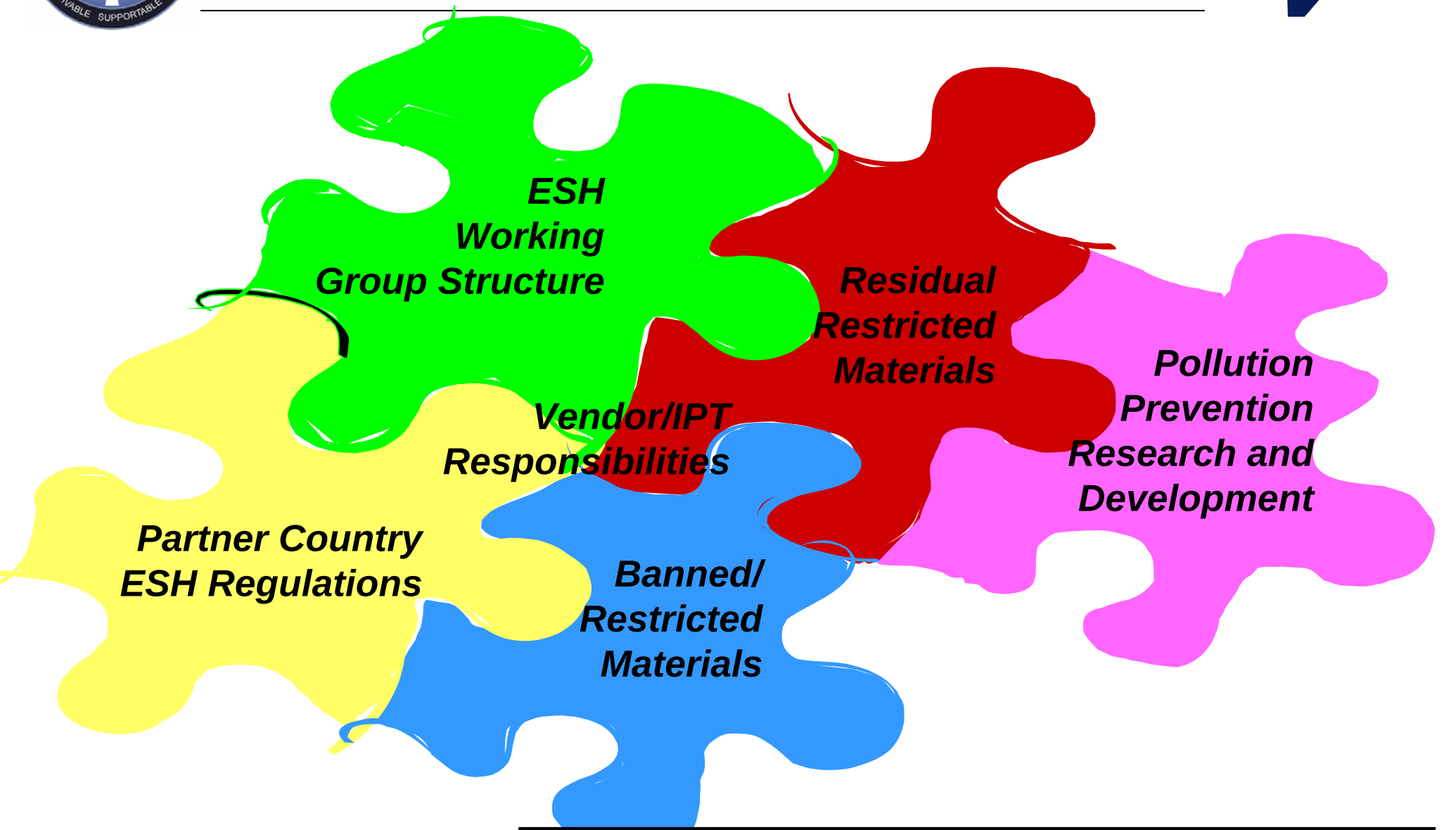
F-35C

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)



Dynamic, Results Oriented Document

The Continuing Sustainability Challenge and Interaction with Design for Environment (DfE)

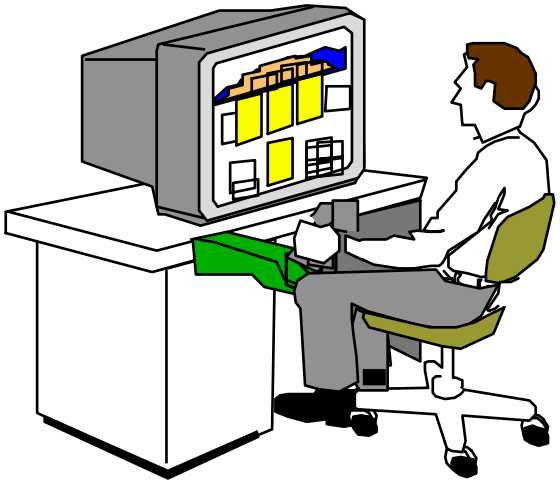
- **LMAero Solved the Easy-To-Do Material/Process Substitutions on Previous Programs**
  - ***Low Hanging Fruit***
  - ***Typically Focused on Employee Exposure During Manufacturing***
- **Now the Challenge is to Find Material Substitutions That Reduce Life-Cycle Expense, i.e. Sustainability**
  - ***Focus 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***

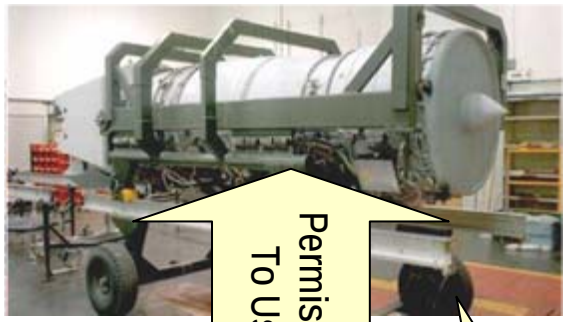
Identify the Goal and Force the Solution

Hazardous Materials Control Approach – Controlled by HMMP and M&P

Support Equipment Design

Airframe/ Subcontractor Design





NEPA/Conformity Planning

Permission To Use

Permission To Use

Emission Impacts New Limitations

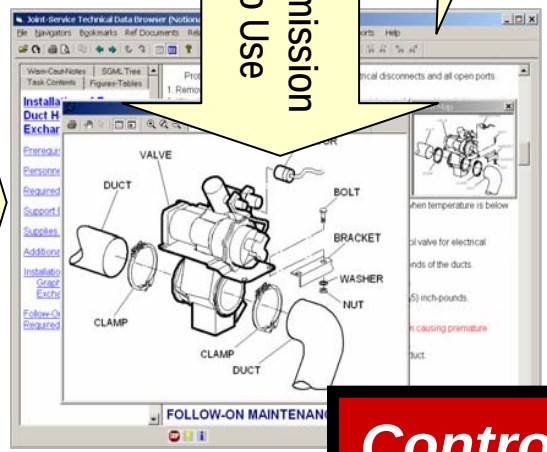
Restricted Materials

Approved Materials

Adopt New Requirements

Permission To Use

Tech Data



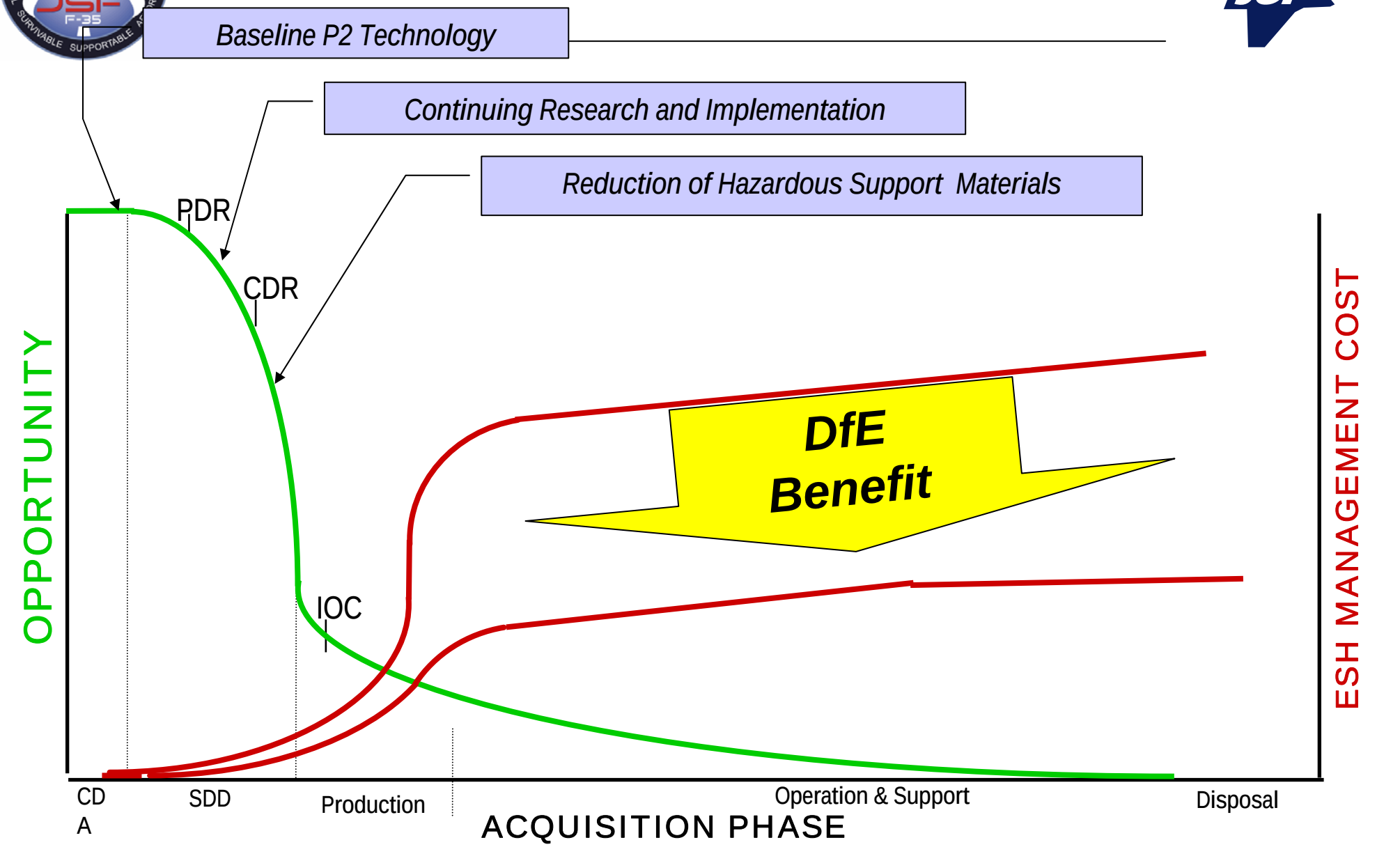
Controlled by Tech Data

Supply

Partner Country Regulation Research

Control Materials on Program

Pollution Prevention Insertion Opportunities



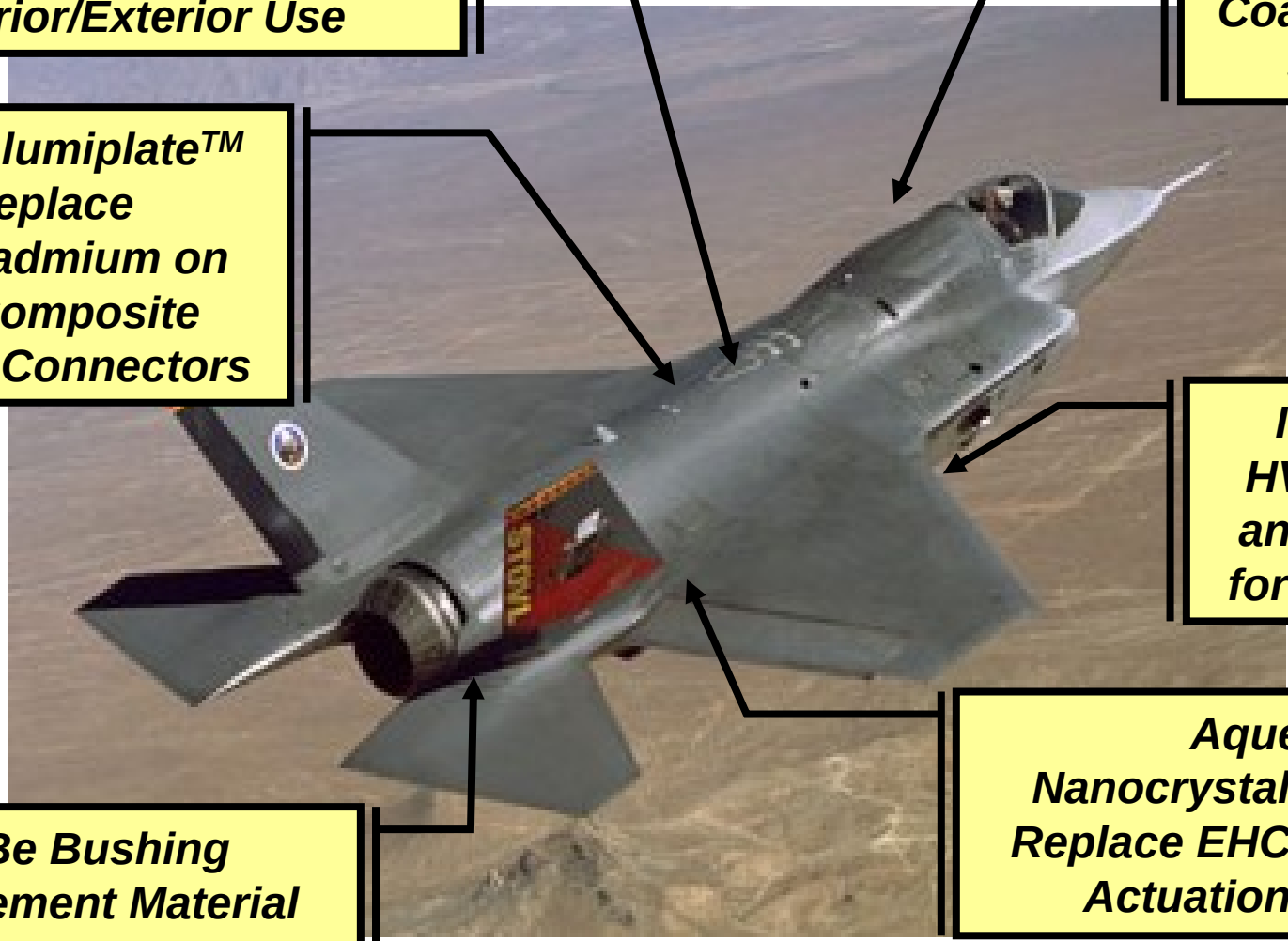
Reduce Life Cycle Costs Early in Program

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 Solutions

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***

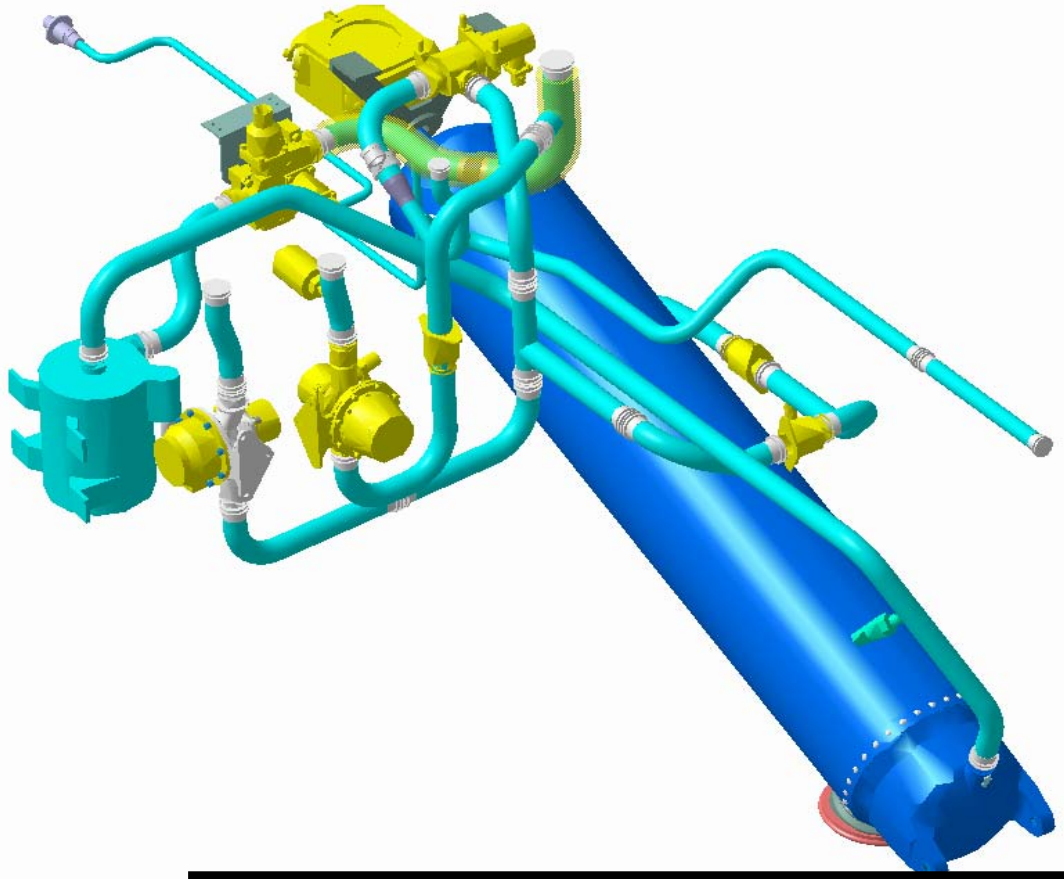
- **JSF Uses Titanium or Stainless Steel Fasteners**
  - ***No Cadmium***
    - Except for Three Locations with no Drop-in Replacement (QAD, SFD, Gun)
  - ***More Expensive Up-front But Less Life Cycle Cost***

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*

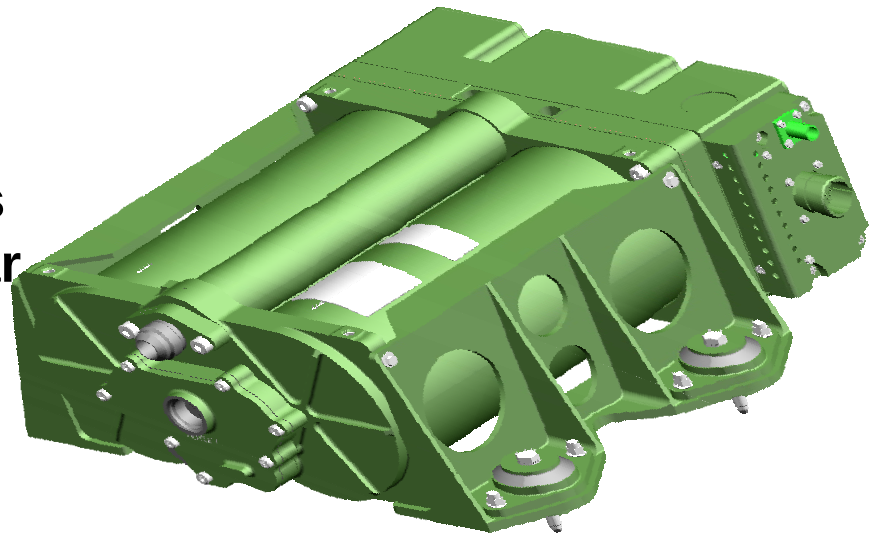


No More Halon Stockpiles

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***

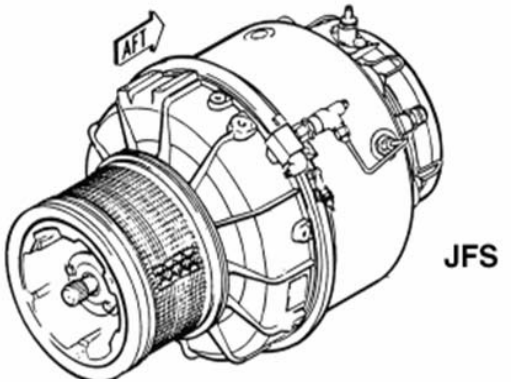
- ***On-Board Oxygen Generating System Replaced Liquid Oxygen***
  - **Produces Oxygen-Rich Breathing Gas From Engine Bleed Air Using Molecular Sieve Technology**
  - ***No Exotic Cleaning Solutions***
  - ***Military No Longer Required to Stockpile Freon for Oxygen System Cleaning***



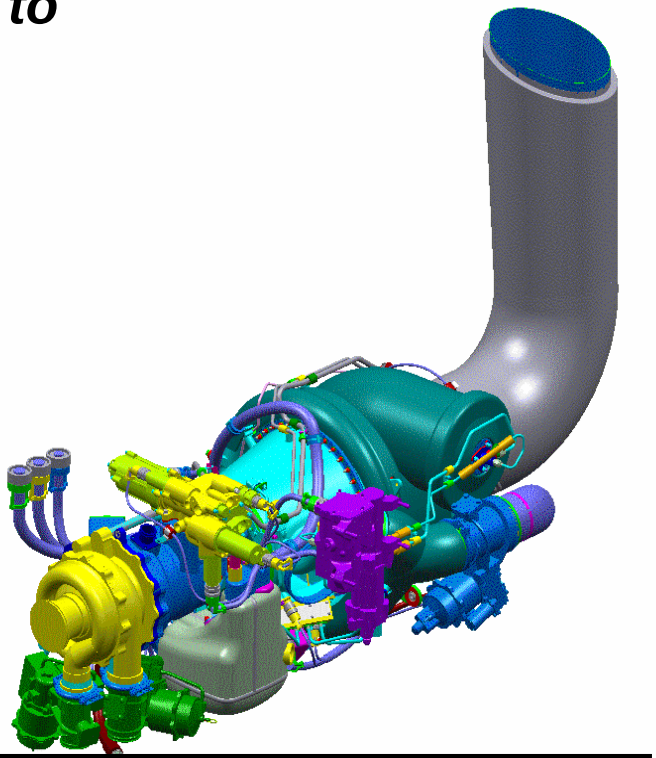
No More Freon Stockpiles

Key DfE Technology - IPP

- ***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***



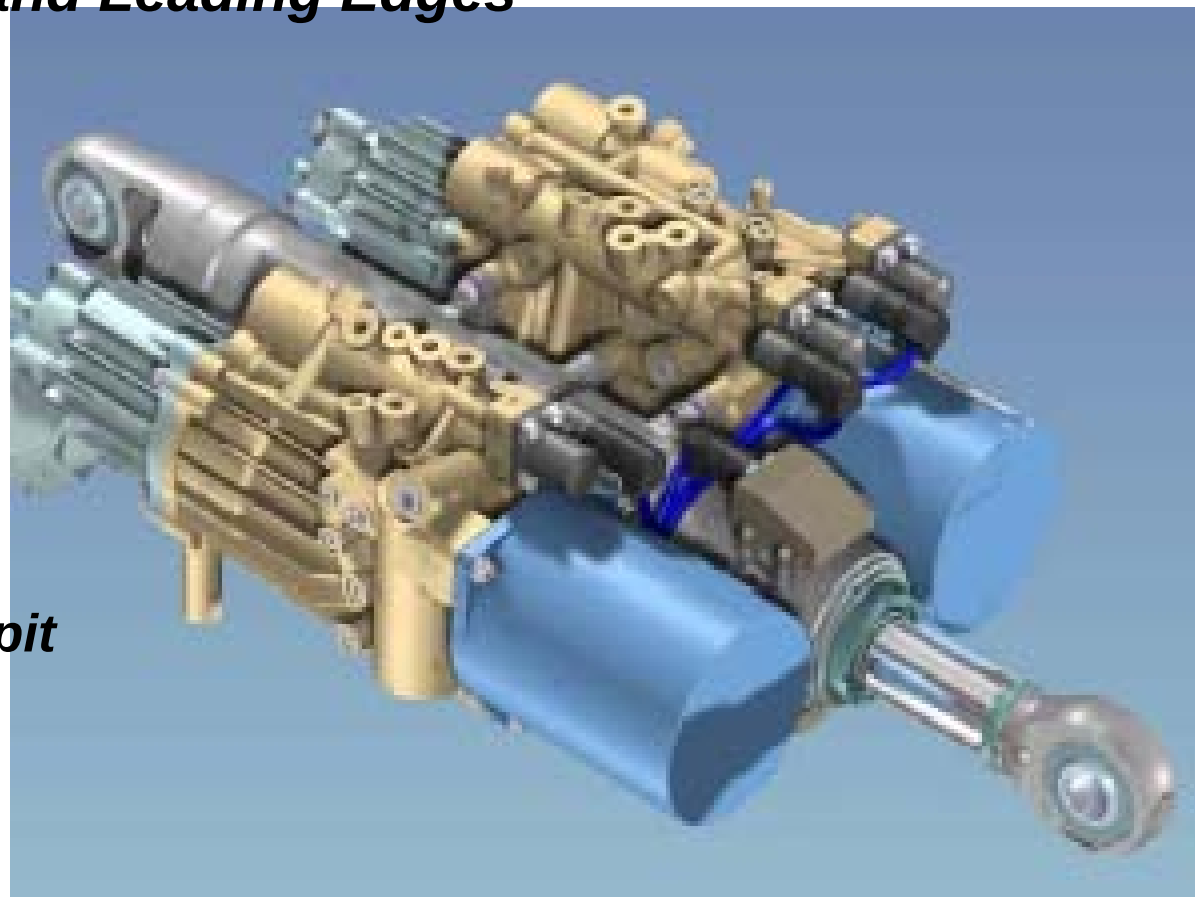
- ***Integrated Power Package (IPP) Replaces Hydrazine System***
  - ***Small Turbine Engine Integrated with Other Vehicle Cooling/Heating Systems***
  - ***Basically a Small Jet Engine***
  - ***Easy to Start/Stop, No Hydrazine, No Leaks***



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***

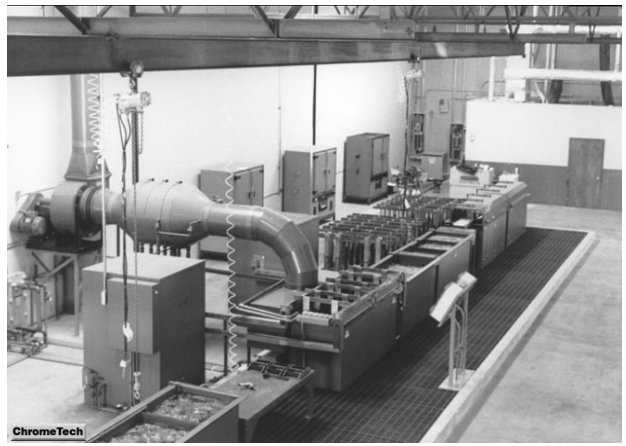


- ***F-35 Developed Electro-Hydrostatic Actuators to Replace Hydraulics***
  - ***Electric Control from Cockpit***
  - ***Very Small Quantity of Hydraulic Fluid***
    - ***Low Pressure***
  - ***Lifetime Sealed Unit***
    - ***No Maintenance Required***

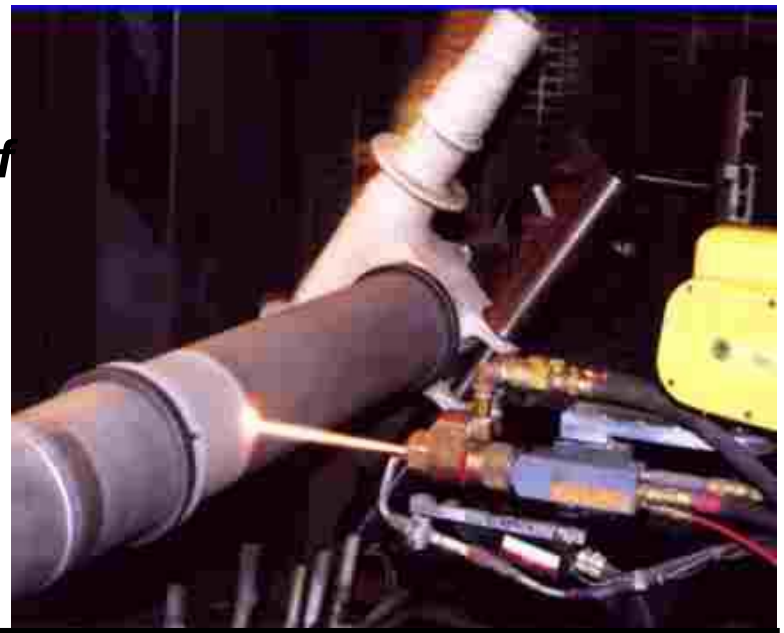
Avoids Hydraulic Leaks and Clean Up

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*

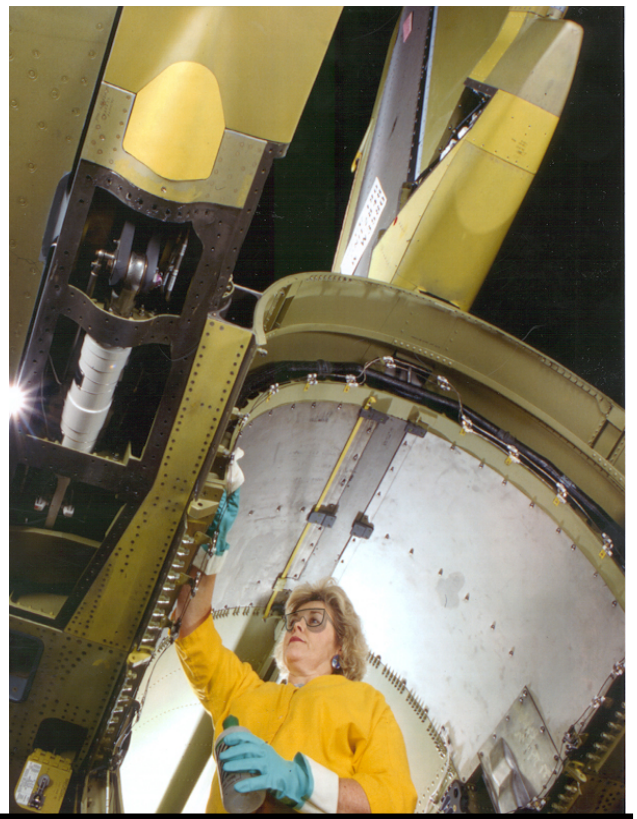


No More Chrome Plating

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

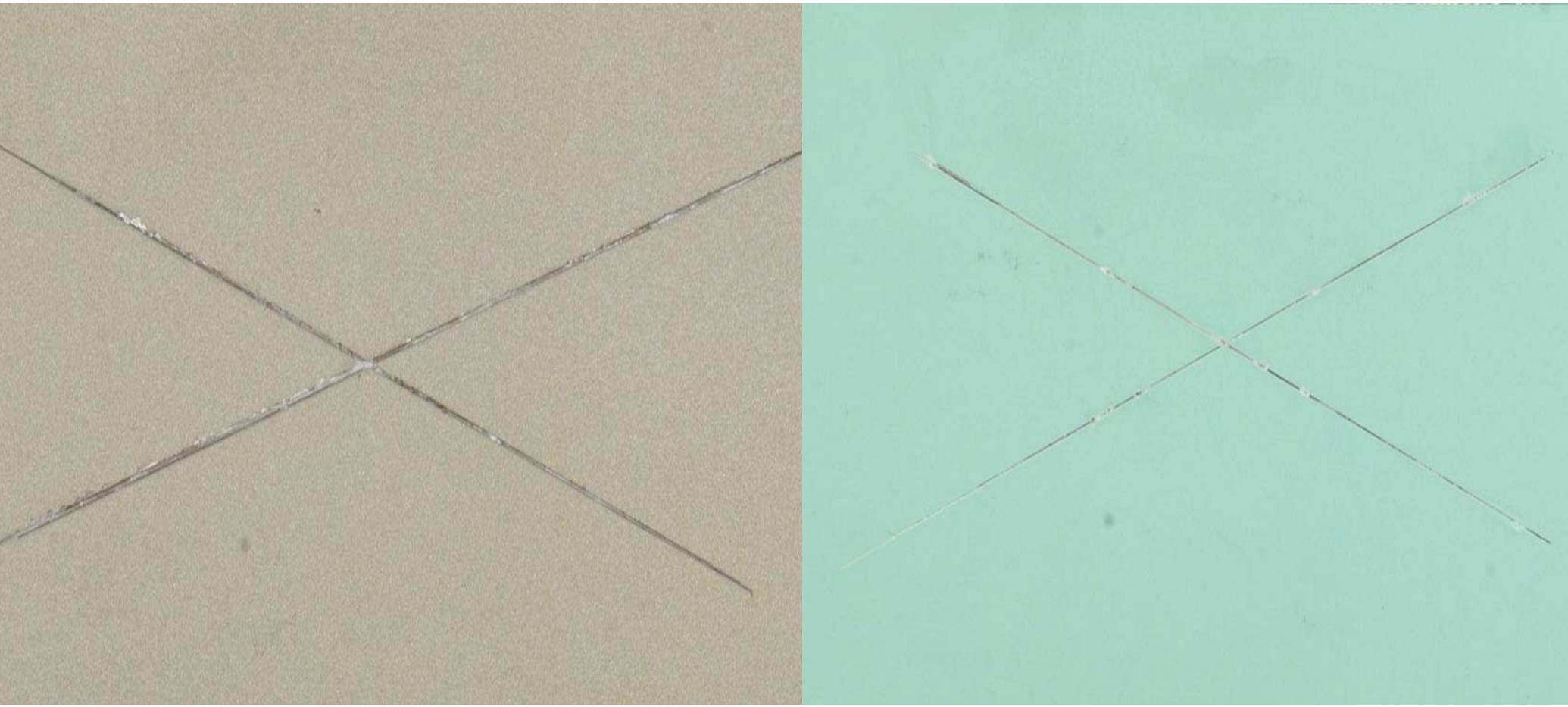
- **Many Different Projects Underway Domestically and Internationally**
- **Eliminate Chrome**
- **Eliminate Cadmium**
- **Improve Maintainability**

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**

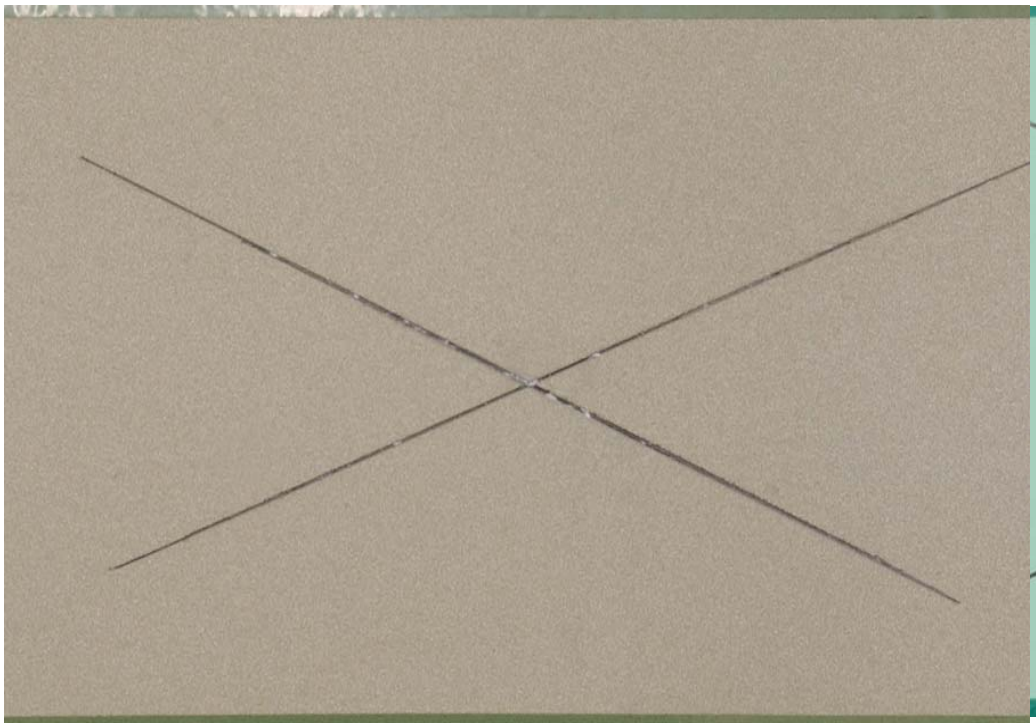
Deft Non-Chrome Primer Corrosion Testing

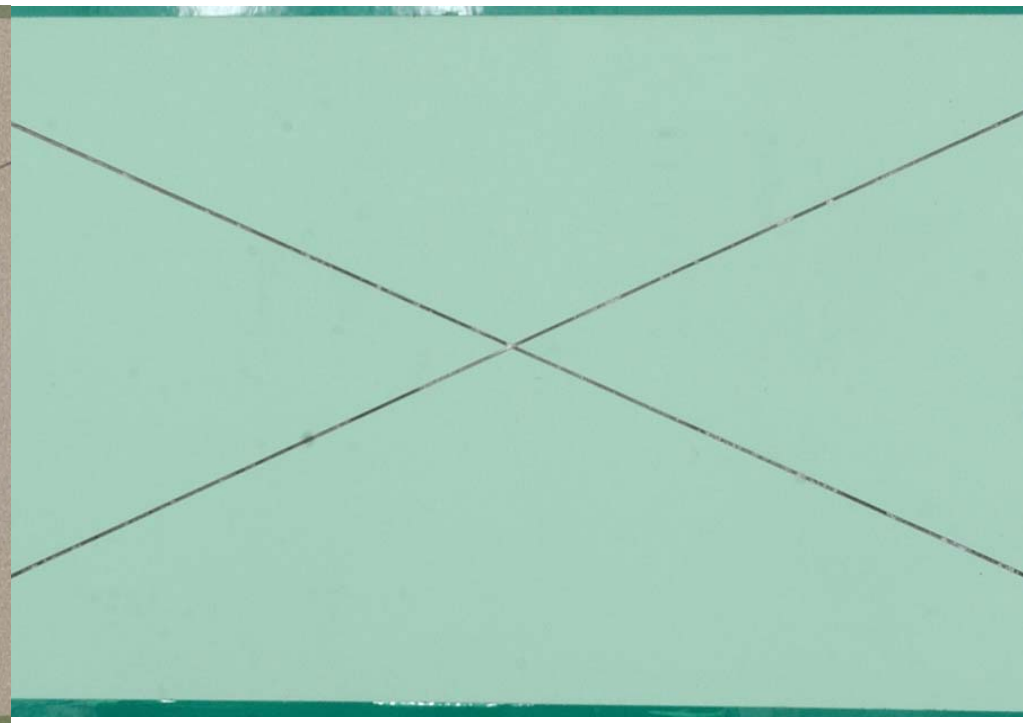
2000 Hours Neutral Salt Fog
Chromated Conversion Coated 2024 Aluminum



Deft Non-Chrome Primer Corrosion Testing

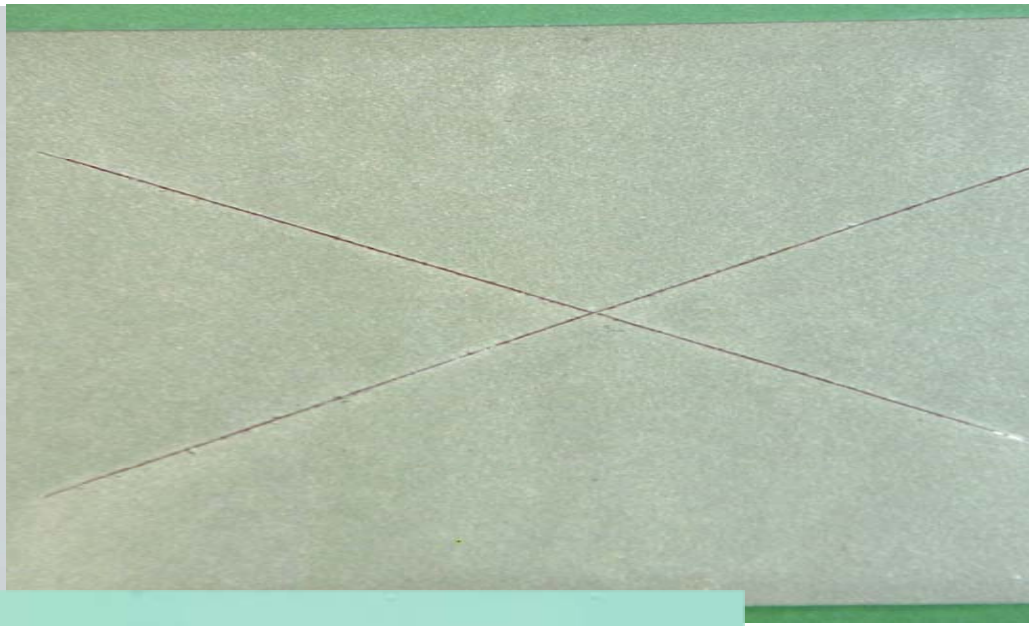
4000 Hours Neutral Salt Fog
Chromated Conversion Coated 2024 Aluminum





Deft Non-Chrome Primer Corrosion Testing

500 Hours 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 SO_2 Salt Fog***
- ***Almost All F-35 Connectors Switched to Composites***
  - ***Working Alumiplate™ as Conductivity Coating for Composite Connectors***

Improved Performance Less ESH Impact

SO_2 Salt Fog Results

Figure 6.1.11 Ni/Cd connector after 336 hours in SO_2-salt-fog

Figure 6.1.5 TTH after 336 hours in SO_2-salt fog

Figure 6.1.6 Corrosion resistant stainless steel after 336 hours in SO_2-salt fog

subje

Figure 6.1.9 Dull Ni composite after 336 hours in SO_2-salt fog

Figure 6.1.10 Bright Ni composite after 336 hours in SO_2-salt fog

Figure 6.1.3 Bright Zn/Ni after 336 hours in SO_2-salt fog

Figure 6.1.4 Dull Zn/Ni after 336 hours in SO_2-salt fog

Alumiplate™ Results

Figure 6.5.1 Cannon Alumiplate connector with chemfilm after 338 hours in SO_2-salt fog

Figure 6.5.2 Cannon Alumiplate connector with clear coating after 338 hours in SO_2-salt fog

Connectors Released And Available

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 mate/unmate for aluminum components, 1500 cycles on composite components.
- ✓ Durability per Mil-DTL-5015H Series III - 100 cycles mate/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.

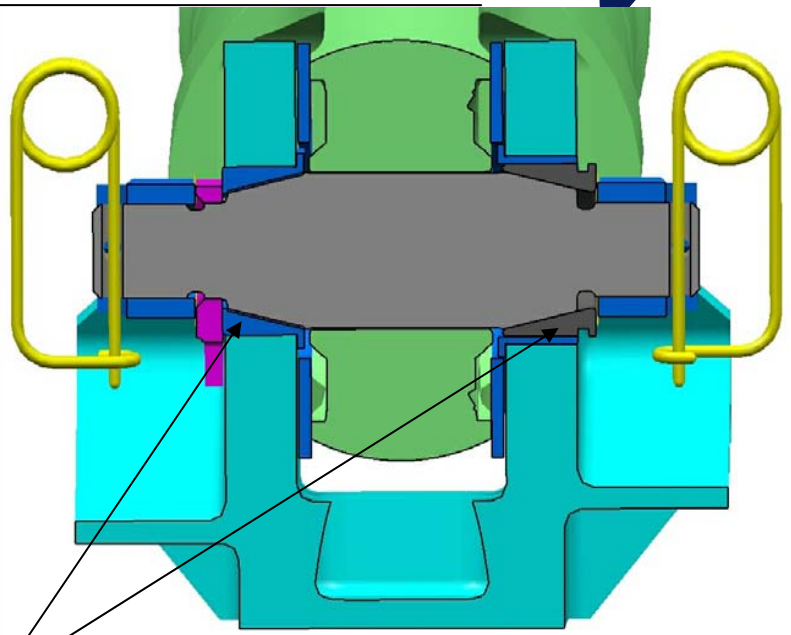
For further information on Amphenol® connectors with the Electroplated High Purity Aluminum finish please contact us at:

Amphenol Corporation
40-60 Delaware Avenue, Sidney NY 13838-1395
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

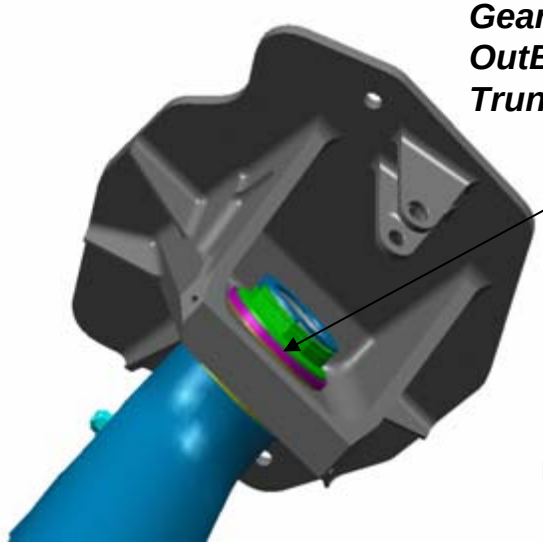
- **Copper-Beryllium (Cu-Be) Bushings Added to LMAero Restricted Materials List February 2004**
  - ***F-35 Technical Mgmt Concurred with Action Plan to Identify Locations and Develop Alternative Material Where Feasible***
- **Typically Used for Flight Control Actuators and Other High Load Environments**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



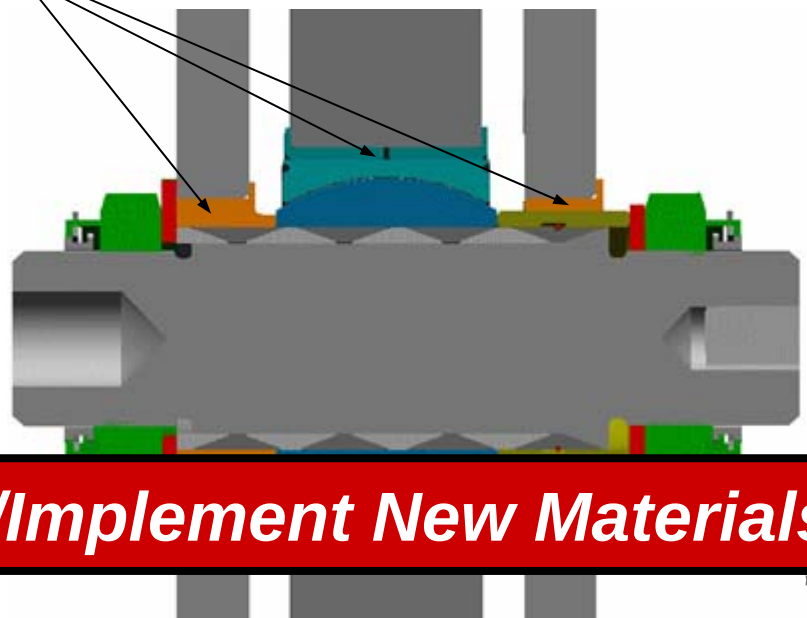
Horiz Tail Actuator

Cu-Be Bush

Main Landing Gear OutBoard Trunnion Fitting



Horiz Tail Inboard Hinge



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

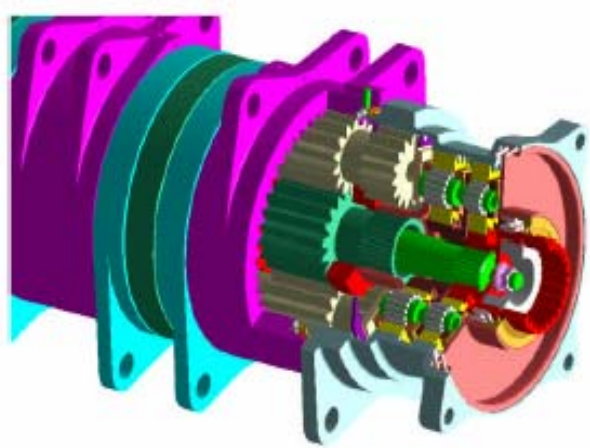
Future ESTCP Cooperation

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***



Rotary Gear Actuators

Eliminate Cadmium Plating

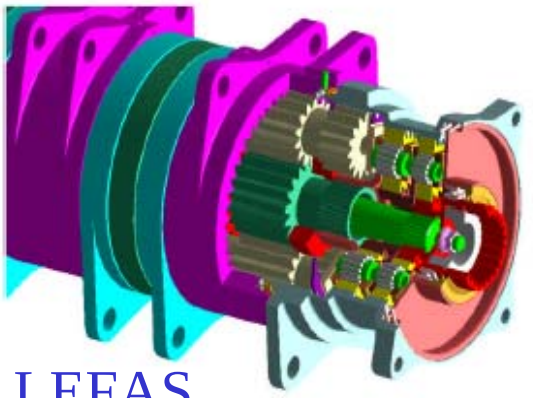
Cadmium Plating Irrelevant with S-53?

- **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

Key DfE Technology - Nodular Thin Dense Chrome (TDC)

- **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***



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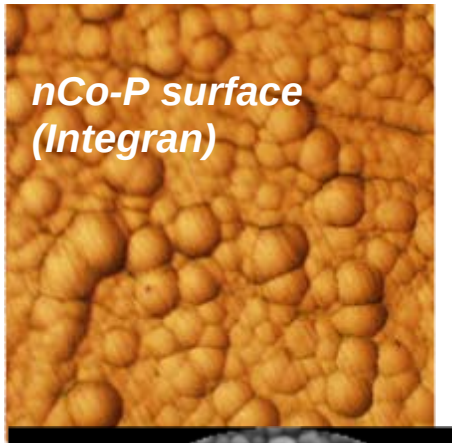
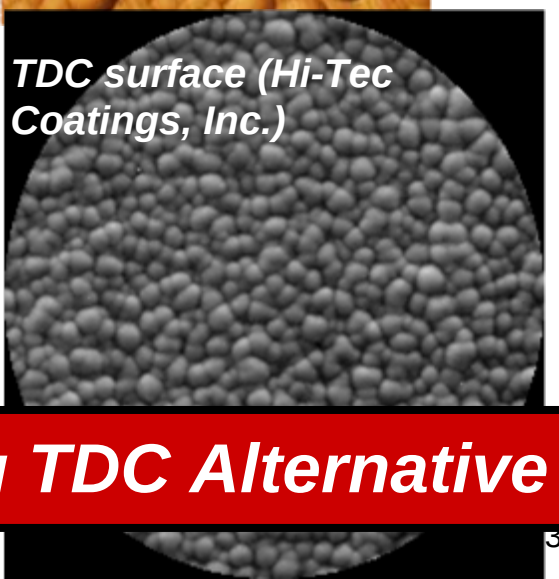


nCo-P surface (Integran)



TDC surface (Hi-Tec Coatings, Inc.)

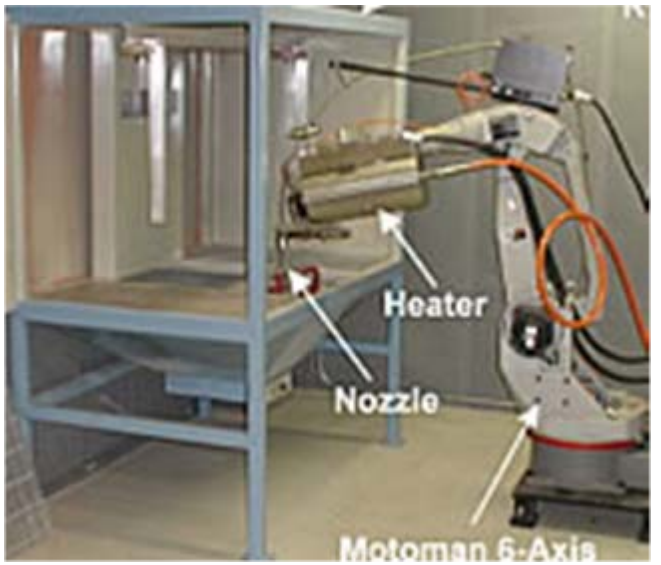
	TDC	nCo-P
Thickness	0.0001-0.0006”	0.0001->0.020”
Hardness	900-1,100HV	650-1,000HV
Morphology	Nodular	Nodular
Coeff friction	~60% EHC	~60% EHC
Roughness	4-10µ” Ra	<4µ” Ra

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 Sermatel™**
- **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)

Brush Cadmium

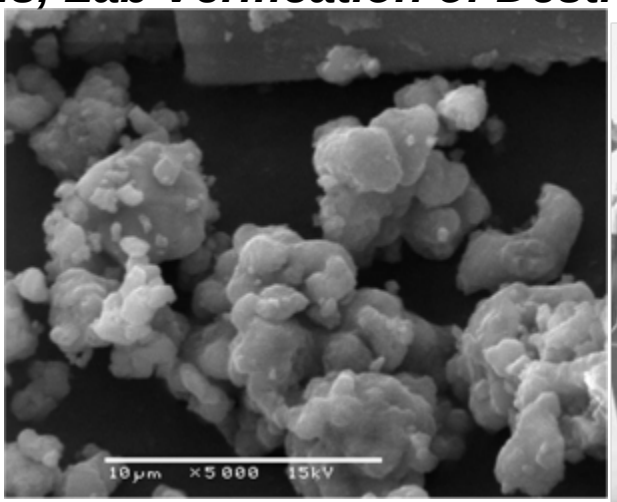


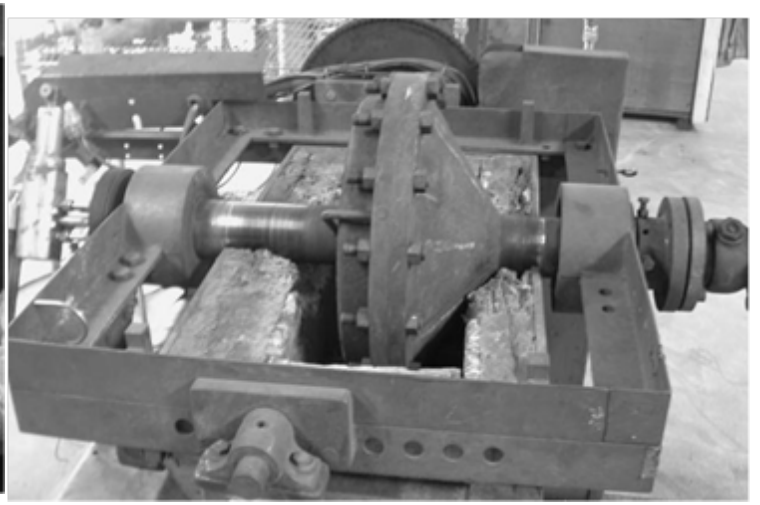
K-Tech Cold Spray Equipment

May Require Several Repair Options

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

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