Cadmium and Chromium VI Elimination Technologies for Aircraft Components using Multiple Advanced Coatings and Auxiliary Processes

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Outline

Background

Multi-SBIR STTP
- PAWSS SBIR
- Amorphous Composite HVOF SBIR
- Novel Cooling SBIR
- LHE Alkaline Zn-Ni

What’s Ahead

Questions
Background

• Cadmium and Hexavalent Chrome are known carcinogens
• Cyanide (highly toxic) used in the plating process
• Millions spent each year on special EPA/OSHA-mandated handling/PPE/procedures
• Alternative coatings required for environmental concerns
• DoD began researching alternative coating technologies under the SBIR program
  • SBIRS sponsored by USAF Program Offices (Robins AFBs)
    • Pulse Automated Waterjet Stripping System (PAWSS)
    • Amorphous Composite HVOF Coating
    • Novel Cooling and Temperature Monitoring System
    • Low Hydrogen Embrittlement (LHE) alkaline Zn-Ni w/ Trivalent Chrome Conversion Coating
Multi-SBIR STTP

• SBIR STTP 2017-06 - Demonstration and Validation of Cadmium and Chromium VI Elimination Technologies for Aircraft Components using Multiple Advanced Coatings and Auxiliary Processes

• Four Advanced Integrated Technologies for Aircraft Component Overhaul; each technology has been qualified individually but not combined.
  – PAWSS
  – Amorphous Composite HVOF
  – Novel Cooling & Temperature Monitoring System
  – LHE Alkaline Zinc-Nickel

• Will focus on integrating these advanced technologies into a harmonious, interrelated whole; and ensure the aggregate process does not have detrimental effect on the components

• C-5 Candidate Components
  – Crew Entry Door Latch
  – Roller
  – Hor Stab Pivot Shaft
  – Slat Tracks
  – Flap Tracks
PAWSS

Airlifter of Choice

- **SBIR Topic Number: AF071-317 - Pulse Automated Waterjet Stripping System (PAWSS) process provides a complete solution for organic and inorganic coatings removal that will replace multiple hazardous chemical and mechanical stripping methods.**
- High-frequency pulses of water are generated by modulating a continuous stream of water through a specially designed nozzle. By optimizing the parameters associated with this process, ES3 is able to remove both organic and inorganic coatings.
- **SBIR Phase I, II, II.5, and III completed.**
PAWSS

Airlifter of Choice

- PAWSS provides a single process that will strip both organic and inorganic coatings, including: paint and primer, chrome plating, and thermal sprayed coatings (i.e. plasma, arc wire, HVOF, etc.)
- Elimination of multiple wet chemical strip tanks and mechanical coating removal methods
- Reduced process time from chemical/mechanical (8-24 hrs) to PAWSS (1-2 hrs)
PAWSS

Airlifter of Choice

- C-5 Dem/Val Applications

C-5 Hor Stab Pivot Shaft - PAWSS System Set-up
PAWSS

Airlifter of Choice

- C-5 Dem/Val Applications

C-5 Slat Tracks - PAWSS System Set-up
Amorphous Composite HVOF

- SBIR Topic Number: AF071-322- Amorphous Composite High Velocity Oxegenated Fuel (HVOF) coating will provide an alternative material to the existing Cr plating and HVOF Tungsten Carbide thermal spray coatings that is more resistant to spallation when subjected to high-bending stress loads on aircraft components.
- HVOF WC-Co and WC-Co-Cr coatings have been in development for hard Cr replacement on aerospace applications for several years. However, qualification testing of these coatings shows that as the component stress approaches levels that fall between the proportional limit and yield strength of the substrate, spallation of the HVOF coating may occur.
- SBIR Phase I, II, II.5, and III completed
Amorphous Composite HVOF

Airlifter of Choice

- Completed metallurgical, corrosion, impact, producibility, fatigue, & coating integrity testing
- Amorphous Composite coatings exhibited equivalent or better test result in comparison to WC-Co-Cr in coating integrity for flat bending surfaces.
- This allows for AC coatings to be used on aircraft, landing gear, engine and propeller components in place of Cr. WC-Co-Cr powder is not recommended to be used on high bending stress applications due to spallation at high bending stress.
- ES3 recommends revising Robins AFB HVOF process specification to include tighter material/powder and process controls during the subsequent phases of this effort.
Amorphous Composite HVOF

Airlifter of Choice

Amorphous Composite performs as good or better than Chrome
No undercutting in the scribe
Amorphous Composite HVOF

- C-5 Candidate Parts (typically exhibit wear and/or corrosion)

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<th>Current Coating</th>
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Novel Cooling & Temp Monitoring

• SBIR Topic Number: AF071-121 - The novel cooling and temperature monitoring system provides supplemental cooling for thermal spray coating applications (such as HVOF, plasma and combustion type coatings), which are utilized for many aerospace applications.

• The system monitors part temperature and delivers CO2 coolant to a part during the thermal spraying process to control part temperature without detrimental damage to the coating or the substrate.

• Completed SBIR Phase I, II, III; and, Phase II.5 is on-going.
Novel Cooling & Temp Monitoring

- The user sets the controllers to maintain a specific temperature range during the HVOF spraying operation, and the system will apply coolant as needed to maintain that range.

Novel Cooling and Temperature Monitoring System & Bulk CO2 Storage @ Robins AFB
Novel Cooling & Temp Monitoring

- C-5 Candidate Parts

Novel Cooling Set-up for C-5 Slat Track
Novel Cooling & Temp Monitoring

- Demonstration Part Testing (C-5 Slat Track)

Close up – Air Cooled(left) and CO2 cooled (right)
No difference in appearance or micro structure

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LHE Alkaline Zn-Ni Description

• Many Zn-Ni plating solution types – most not suitable for aerospace environment

• As of Dec 2017, the AFRL found the IZ-C17+ Zn-Ni plating composition acceptable and recommended publishing a Zn-Ni specification (Ref. AFRL Report No. AFRL/RXS 16-099)
  – LHE alkaline Zn-Ni performs through combination of chemistry and process
  – Repeatedly demonstrated production-ready levels of quality for both barrel and rack plating techniques
  – Effective Cd and IVD replacement for both Low Strength Steel (LSS) and High Strength Steel (HSS) general surfaces and threaded components applications
ES3 – USAF/DoD SBIR Status

- **SBIR Topic AF161-007:** Development of LHE Alkaline Zn-Ni plating as Cd plating replacement for usage on aluminum and steel electrical connectors.
- **SBIR Topic AF171-002:** Development of LHE Alkaline Zn-Ni brush plating chemistries as brush Cd plating replacement.
- **SBIR Topic AF071-320:** Development of LHE Alkaline Zn-Ni plating as Cd plating replacement for usage on High Strength Steel (HSS) and Low Strength Steel (LSS) general landing gear applications.
- **SBIR Topic AF081-101:** Development of LHE Alkaline Zn-Ni plating as Cd plating replacement for usage on High Strength Steel (HSS) and Low Strength Steel (LSS) general landing gear applications.
SBIRs AF161-007

Airlifter of Choice

• AF161-007, Development of LHE Alkaline Zn-Ni plating as Cd plating replacement for usage on aluminum and steel electrical connectors
• Phase I feasibility testing completed in 2017. Successfully developed process and conducted feasibility testing to plate aluminum and steel connectors, back-shells, etc. and meet MIL-DTL-38999 conductivity requirements. Phase II started in spring 2018.

View of LHE Zn-Ni Plated Aluminum MIL-DTL-38999 Circular Connectors Plug (Left), Receptacle (Right)
SBIR AF171-002

- AF171-002, Development of LHE Alkaline Zn-Ni brush plating chemistries as brush Cd plating replacement
- Phase I feasibility testing underway to develop brush LHE alkaline Zn-Ni plating chemistries and processing techniques for localized repair
  Test results are compared to current brush Zn-Ni and brush Cd baseline

View of Technician Applying Brush LHE Zn-Ni with common equipment (Left), Typical Cd tank plated coupons with simulated Brush Zn-Ni SIFCO 4018 repairs (Right)
SBIRs AF071-320 and AF081-101

Airlifter of Choice

• Phase I, II, II.5 completed and multiple Phase III efforts ongoing for General Surfaces, Threaded Fasteners and Aircraft and Landing Gear Components
  • Rack Plating
  • Barrel Plating

• Types of testing included, but not limited too:
  • Appearance, Uniformity, Thickness, Adhesion
  • Mechanical properties: Fatigue, Hydrogen embrittlement, Re-embrittlement, Installation (such as torque tension, break away torque), Stress Rupture
  • Fluid Compatibility
  • Impact and Wear Resistance
  • Corrosion: B117, G-85 cyclic, galvanic, beachfront (ongoing), etc.
C-5 Landing Gear LHE Zn-Ni Applications

- **C-5 Landing Gear Part converting to LHE Zn-Ni**
  - 242 different parts from NLG, MLG, Bogie, Lock Cylinder, Ballscrew are currently being plated for overhaul at HAFB
  - 7 C-5 Technical Manuals (T.O.) have been changed to allow LHE Zn-Ni
  - First C-5 Part plated with LHE Zn-Ni in May 2014 C-5 Roll pin

C-5 Roll pin  
MLG Brake Collar  
MLG Bogie Aft Axle  
MLG Ballscrew Nut
C-5 Landing Gear LHE Zn-Ni Applications

**Airlifter of Choice**

- **MLG Gudgeon Pin**
- **MLG Rotational Collar**
- **NLG Gimble**
C-5 Landing Gear LHE Zn-Ni Applications

Airlifter of Choice

MLG Piston

MLG Fwd Retract Arm

NLG Gimble
C-5 Aircraft Components

- Plating parts at ES3 Georgia Technical Operations Center (GTOC) located in Warner Robins, GA.
- 40 part numbers identified and processed using LHE Zn-Ni to-date

Pressure Door Lock Hooks
Pivot Bracket Bushings
Bushing Locking Arms
Pressure Door Hinge Fittings
Hor Stab Pivot Shaft
LHE Alkaline Zn-Ni

**Airlifter of Choice**

- **Commercialization**
  - USAF Jedmic Drawings 201027456 & 201427804 published
  - Partnered with Boeing; resulted in BAC5860 spec for commercial application
  - NDA with Lockheed and other OEMs, and plating coupons for their evaluation
  - Creating NAS Industry Fastener Plating Specification – in ballot currently
  - Creating Mil-Spec for US Air Force Landing Gear applications
  - Creating Mil-Spec for US Navy for aircraft and ground support equipment applications
What’s Ahead

• Complete PAWSS depaint testing
• Work with Robin AFB for tighter powder supplier controls for Amorphous Composite HVOF, and cylindrical coating integrity application testing
• Complete SBIR Phase II.5 testing for Novel Cooling
  – Fatigue & Coating Integrity on multiple substrate/coatings
• Convert/install LHE Alkaline Zn-Ni plating line into the Robins AFB AMFF, NAVAIR depots (FRCE and FRCSW) and other DoD facilities
• Start Multi-SBIR STTP
  – Identify and complete testing (i.e. additional substrates, gap testing, multi-process validation testing, etc.)
  – Identify and candidate components and complete dem/val testing, tooling design and manufacture, and technical data updates
US Air Force POCs

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Questions

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Back Up Slides
Corrosion Testing Results

LHE Alkaline Zn-Ni meets or exceeds Cd performance in all tests.
Corrosion Testing Results

• Beachfront Exposure
  • 3.5 yr test ongoing at Duck, N.C. facility
  • 3 yr test Daytona, FL facility*

Cd and LHE alkaline Zn-Ni Fasteners in Galvanic Panels and SAS structure at Duck NC Beachfront Test Facility.
Corrosion Testing Results

- Effects of Fasteners and Coatings on Corrosion of Galvanic Samples at Daytona; Spray Group; 3 Years (1/2017)

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- Zn-Ni/steel
- Zn-Ni/Steel
Corrosion Testing Results

- Effects of Fasteners and Coatings on Corrosion of Galvanic Samples at Daytona; No-Spray Group; 3 Years

- Corrosion Testing Results
  - Chromate
  - DEFT Non-Chrome
  - Zn-Ni/Steel

Airlifter of Choice
### C-5 Aircraft Components

**Airlifter of Choice**

#### 40 Parts identified to date:

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IZ-C17+ LHE Zn-Ni Plating Line Fully Operational at Hill AFB May 2013
**US Navy**

**Airlifter of Choice**

**US Navy Implementation**
- Installed plating line at FRCSE – completed on 30 Sep 2017
- Conducting qualification testing
- Created Tech Data Package (TDP) including Local Process Specification (LPS)
- Creating Mil-Spec for US Navy for aircraft and ground support equipment applications
- Conducting field service evaluations
- Identifying and converting aircraft parts

![LHE Alkaline Zn-Ni Plating Line installed at FRCSE](image1)

![Field Evaluation of Dolly Pin](image2)

![Dolly Pin](image3)
Way Ahead

Airlifter of Choice

• Convert/install LHE Alkaline Zn-Ni plating line into the Robins AFB AMFF, NAVAIR depots (FRCE and FRCSW) and other DoD facilities

• Conduct site assessment and qualification testing for US Army.

• Design and manufacture conforming anodes.

• Implement Specification/Drawing/T.O. changes to include LHE Alkaline Zn-Ni

• Additional testing of LHE alkaline Zn-Ni for other applications
LHE Alkaline Zn-Ni Partners

Airlifter of Choice
Cold Spray Repair

Airlifter of Choice

SBIR Topic AF131-190 - Dimensional Restoration of Aircraft Components Damaged by Corrosion

• To resolve issues with aircraft components damaged by corrosion in hidden and/or hard to access locations by providing a capability for on-site dimensional restoration of damage awhile providing improved corrosion protection.

• ES3 utilizing Centerline SST system for current evaluation and will evaluate other cold spray systems in future Phases
Cold Spray Repair

**Corrosion Testing**
- ASTM B117 ✓
- Beach Exposure ✓
- ASTM G85 ✓

**Mechanical Testing**
- Axial Fatigue & Tensile ✓
- Triple lug shear ✓
- Lap Joint shear ✓

Cold Spray Corrosion Samples in Corrosion Chamber @ ES3 Facility

Cold Spray Corrosion Samples @ Duck, NC atmospheric exposure test facility
C-5 Cold spray Repair Development Efforts

• C-5 Slat Track Cold Spray Repair (2009):
  – Initial repair application focus on cold spray as non-structural application for local dimensional restoration of worn spots on titanium slat tracks to return contour prior to application of the HVOF WC-Co-Cr coating.

• C-5 Crew Entry Door Ladder Anti-Skid (2015):
  – Development of a permanent anti-slip alternative, (cold spray process to apply material onto aluminum ladder steps) that will be meet or exceed the performance of #610 anti-slip tape (MIL-PRF-24667C, Type IV).