Abstract

NAVAIR involvement with cold spray dates back to 2005 with involvement in the US Army led Environmental Security Technology Certification Program (ESCTP) project. The project was aviation focused to use cold spray metallization to repair corrosion damage found on magnesium helicopter gearboxes. The Army ESTCP project built the foundation of the subsequent research and efforts to follow that focused on specific aircraft part repair for corrosion, handling, or wear damage. The success of using cold spray repairs led to procurement of low pressure cold spray systems at each depot facility and an intermediate repair facility as well as procurement of high pressure systems. Low pressure systems are relatively inexpensive, easy to use, portable and ideal for deploying to the depot. It is especially advantageous to deploy low pressure cold spray systems to intermediate aircraft maintenance facilities where repairs there avoid aviation depot level repair and provide local retention of assets. This paper will focus on select efforts to date that are in production using cold spray metallization technology.

Cold Spray Development b NAVAIR

Corrosion Repair of US Naval Aircraft by Cold Spray Deposition

Fred Lancaster NAVAIR-NAWCAD Cold Spray Integrated Products Team Lead

Cold Spray Action Team 2019 Meeting

WPI Worchester, MA

June 25-26, 2019

NAVAIR Cold Spray Initiative

- The US Navy has the need to perform dimensional **restoration** of metallic components caused by corrosion, restoration of material due to wear or damage, and the ability to easily and rapidly **repair** structures in place on Naval Aircraft.

- The objective is to develop and transition the cold spray metallization process that can be used to facilitate **repairs** on naval aviation assets at **all levels** of maintenance.

•Naval S&T Focus Areas:

- Affordability √
- Maintainability √
- Reliability

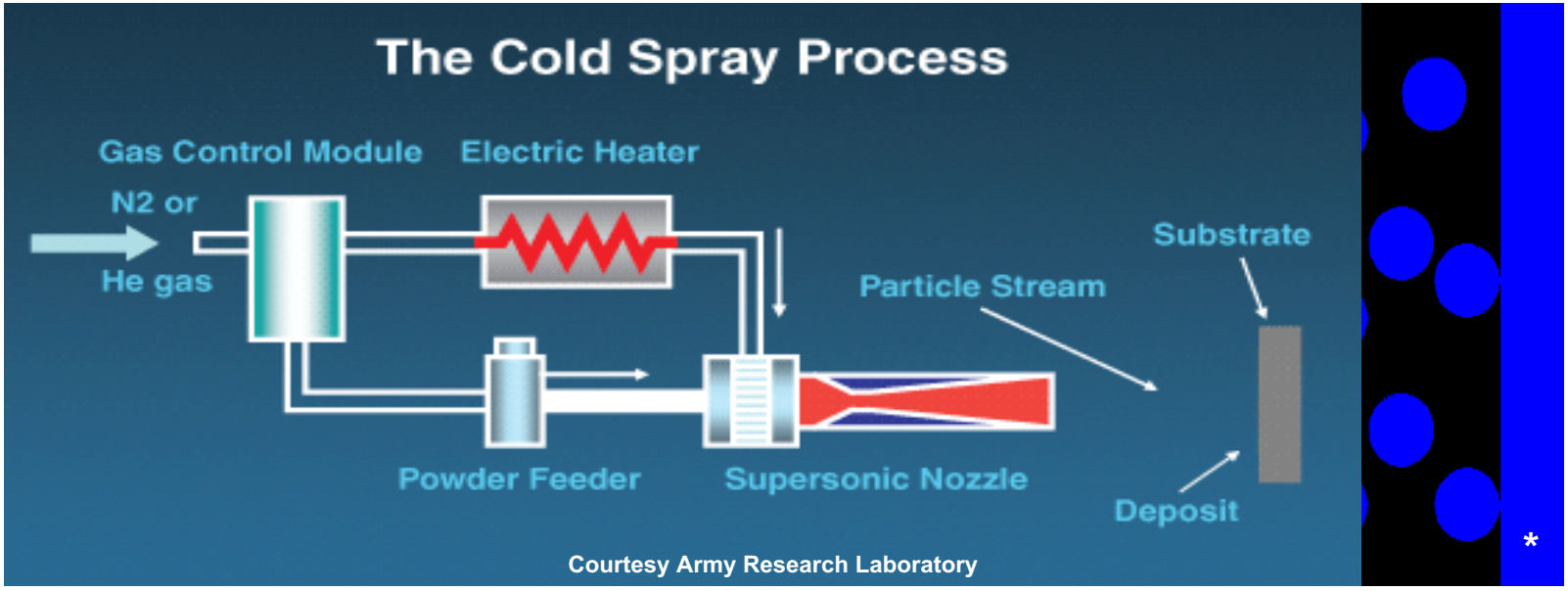
•Naval S&T Objectives:

- Platform Affordability √
- Availability √

Cold Spray Technology

Cold Spray Metallization is a thermal spray solid-state coating process which involves heated high-pressure gas (such as He or N2) used to propel 5-75u sized particles of metal, ceramic, and/or polymer through a De Laval nozzle such that the particles exit at supersonic speeds where the particles plastically deform and **consolidate** upon impact to form a dense low porosity coating that forms a **metallurgical bond** into to the surface.

Also known as Gas Dynamic Spraying, Kinetic Metallization, Supersonic Particle Deposition, High Velocity Powder Deposition and Kinetic Spraying

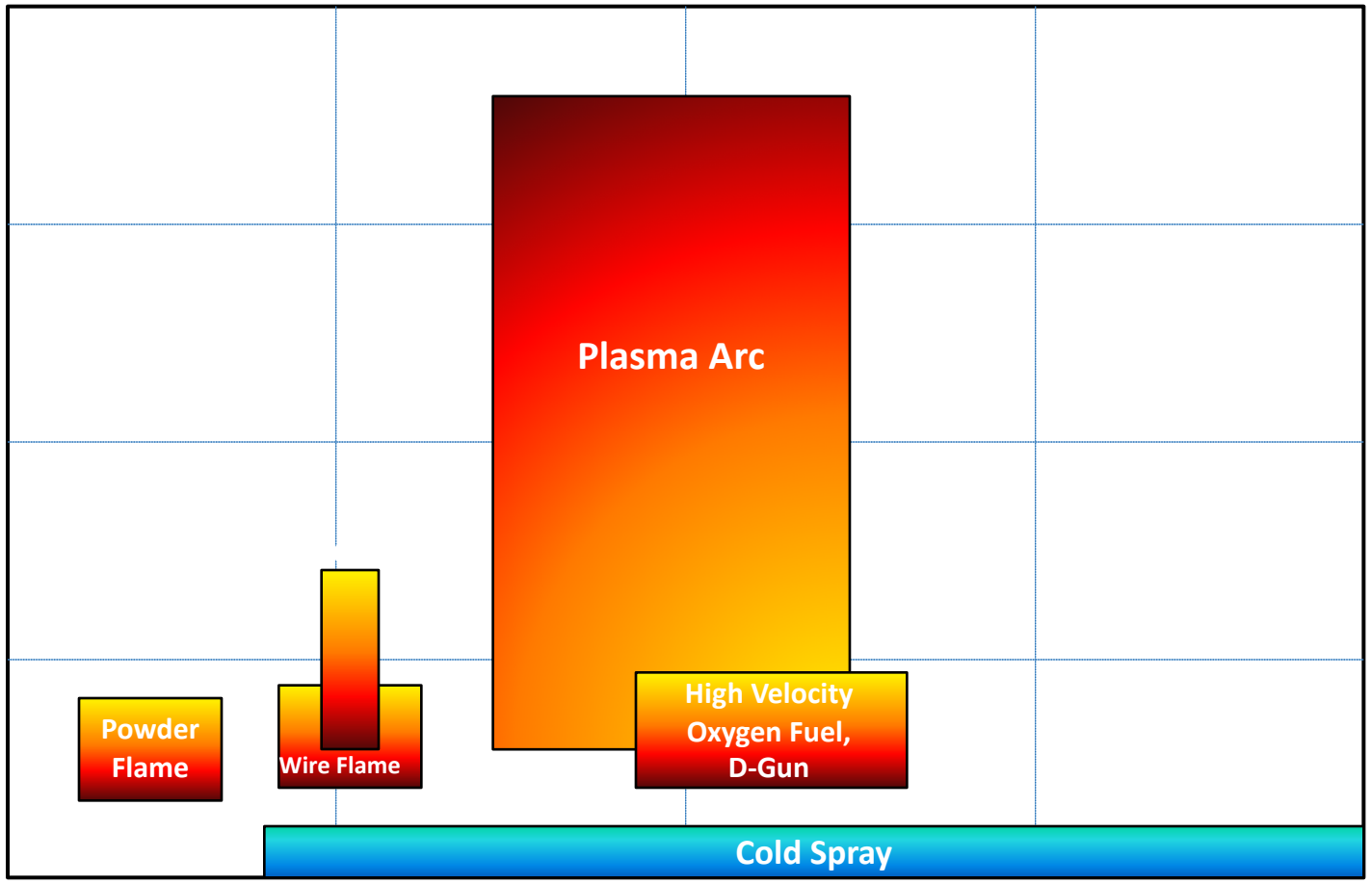


- Main gas pressure 100-1,000 psi
- Gas Temperature 0-1000C
- Gas Flow Rate 30-100 CFM

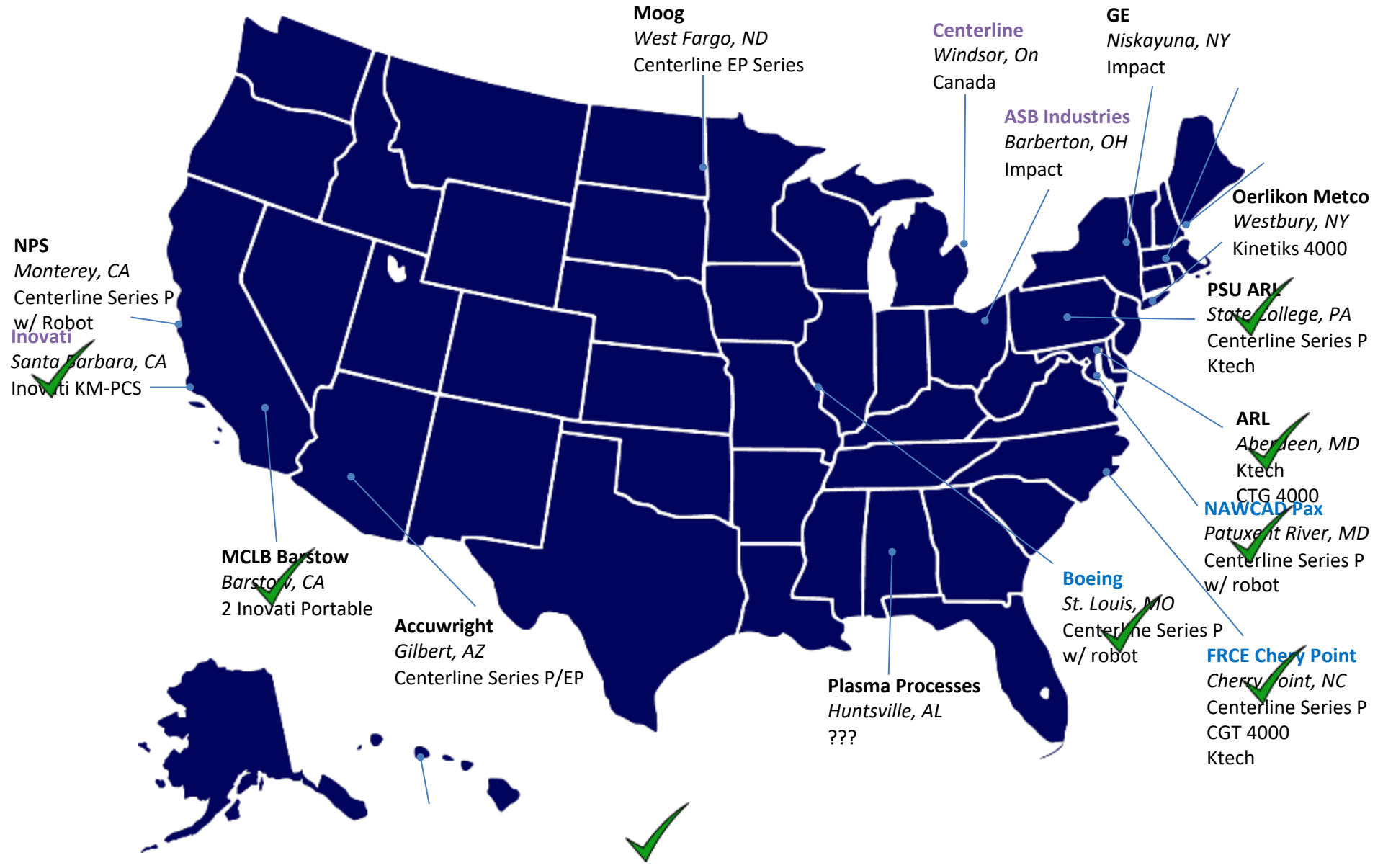
- **Powder Feed Rate 10-30 lbs/hr**
- **Particle Velocity 300-1500 m/sec**
- **Particle Size 5(20)-75 um diameter**

***from H. Assadi, www.modares.ac.ir/eng/ha10003/CGS.htm**

“Cold” Is Relevant



DoD Affiliated CS Systems 2008




DoD Affiliated CS Systems
2018
???
Bangor, WA
???
NUWC Keyport
Keyport, WA
Inovati KM-PCS
VRC Metal Systems
Rapid City, SD
VRC Gen III
Raptor
Ellsworth AFB-Moog
Rapid City, SD
VRC Gen III
Moog
Grand Forks, ND
Centerline EP
Able Aero Services
Wood Dale, IL
Centerline EP
WPAFB-UDRI
Dayton, OH
VRC Gen III
Centerline EP
GE
Niskayuna, NY
Impact
Moog
Webster, MA
VRC Gen III
PSNS
Bremerton, WA
UTRC CSV1
VRC Gen III
VRC Raptor
Moog
West Fargo, ND
Centerline EP Series
Centerline
Windsor, On
Canada
ASB Industries
Barberton, OH
Impact/Protect
PNSY
Kittery, ME
VRC Gen III
Oerlikon Metco
Westbury, NY
Kinetiks 4000
NPS
Monterey, CA
Centerline Series P
w/robot
PSU ARL
State College, PA
VRC Gen III Max
Centerline Series P
Ktech
Inovati
Santa Barbara, CA
Inovati KM-PCS
NAVFAC EX?
Port Hueneme, CA
???
ARL
Aberdeen, MD
VRC Gen III
CTG-4000
NAWCAD Pax
Patuxent River, MD
Centerline Series P
w/ robot
FRCSW North Island
San Diego, CA
Inovati KM-PCS
Centerline Series P
MCLB Barstow
Barstow, CA
2 Inovati Portable
Boeing
St. Louis, MO
Centerline Series P
w/ robot
NSWC Carderock
Carderock, MD
Inovati
Able Aero Eng Svs
Phoenix, AZ
Centerline EP/P
???
Accuwright
Gilbert, AZ
VRC Gen III
Centerline Series P
MALS-16
Miramar, CA
Inovati KM-PCS
Inovati Portable
Plasma Processes
Huntsville, AL
???
MALS-39
Camp Pendleton, CA
Centerline Series P
The Univ. of AL
Tuscaloosa, AL
VRC Gen III
AFLCMC
Warner Robbins, GA
VRC Gen III
TRF
Kings Bay, GA
VRC Gen III
PSU ARL System
FRCE Cherry Point
Cherry Point, NC
Centerline Series P
CGT 4000
Ktech
PHNSY
Pearl Harbor, HI
VRC Gen III (Coming Soon)
FRCSE Jax
Jacksonville, FL
Centerline Series P

Equipment Suppliers

Company		Robotic	Manual	HP	LP
Inovati - USA		X	X	X	X
Centerline Systems - Canada		X	X	X	X
VRC Metal Systems - USA		X	X	X	
Impact Innovations- Germany **(formerly CTG)** ASB Industries – US distributor		X	X	X	X
RUAG Australia RUAG Mecanex USA		X* *Portable Trailer Mounted	X	X	X
RUS SONIC Technology Inc			X		X
Dycomet			X		X

Current Equipment in NAVAIR

System	SST Series P	KM-PCS	CTG-4000-17	RUAG/Gen III™
Vendor	Centerline	Inovati	ASB (CGT)	RUAG Australia/VRC Metal Systems
Cold Spray Approach	Low Pressure	Low Pressure	High Pressure	High Pressure
Max Gas Temperature	550°C	3.8kW heater=1000°C	800°C	15kW heater=800°C 45kW heater=1200°C
Max Gas Pressure	250 psi	130 psi	20 bar (290 psi)	1000 psi
Gas supply needed	300 psi	300 psi	350 psi	1250 psi
Gas types	Helium Nitrogen Compressed Air	Helium	Helium Nitrogen	Helium Nitrogen Compressed Air
Gun	Hand-Held	Hand-held or Robotic	Robotic	Hand-held or Robotic, Robotic Portable
Dimensions	Wheeled Cart	Fixed Workcell	Fixed Workcell	Mobile, Trailer Mounted

- The Centerline P Series and the KM-PCS systems are currently used in production.
- Non-structural repairs, no fatigue debit/credit accounted for.
  - Coatings and Dimensional Restoration

Cold Spray Powders for Dimensional Restoration & Corrosion Resistance

Substrate	Powders	Refined
Magnesium Casting ZE41A	Al 6061*/SST A5001®/CP Al-1100	yes
Magnesium Casting AZ91E	Al 6061*/ SST A5001®/CP Al-1100	yes
Aluminum Casting A357o r 356	Al 6061*/Al 4047*/ SST A5001®/CP Al-1100/Al-Trans® 7075 w/ Ni	
Aluminum 7075-T7351	Al-Trans Chrome®/Al 7075*	
Aluminum 2014-T61	Al-Trans Chrome®	
AMS 6265 Steel	W-C-Co	
*efficient when applied with a high pressure system		

- Aluminum 1100 Series is an all around coating used for
  - Dimensional restoration for blending/filling
  - A general dense aluminum coating
- Aluminum 6061 Series is used for more robust areas
  - Larger dimensional repairs
  - Wear susceptible areas
- Tungsten Carbide Cobalt (WCCo) is used as an alternative to hard chrome plating for wear areas.

Current Production Parts Summary

FRC	Nomenclature	Part Number	Replacement Cost*	Quantity Recovered to Date	Costs Avoided**
Southwest	F/A-18A/B/C/D AMAD Gearbox Housing (PTS Axis)	42312-231	$31,593.00	11	$318,648
Southwest	F/A-18A/B/C/D/E/F APG-73 Radar Rack Assembly	5099984	$193,510.00	20	$3,690,200
Southwest	F/A-18E/F/G AMAD Main Housing (Hydraulic Pad)	764035B	$168,573.00	10	$1,672,730
Southwest	F/A-18E/F AMAD Main Housing (Internal Gear Damage)	764035B	$168,573.00	4	$666,292
Southwest	F/A-18E/F Brake Carrier	2612020	$8,057.00	65	$347,165
Southwest	F/A-18E/F/G AMAD Hydraulic Gear Shaft	764123	$1,485.92	42	$9,492
Southwest	F/A-18A/B/C/D Outboard Wheel Bolt Spot Face	2606302-1	$7,664.67	0	$ -
East	H-1 Combining Gearbox		$756,000.00	12	$9,072,000
			Totals:		**$15,776,527**

Corrosion Mitigation/Prevention Strategy

- Repair before structural damage occurs to achieve full part life.
  - ***Cold Spray as an alternative to Blend and Fill***
- OSD Corrosion Office LMI Cost of Corrosion Studies back up blend and fill repair.
  - **Estimated $2.6-$2.8 billion per year for Navy/MC aircraft due to corrosion**

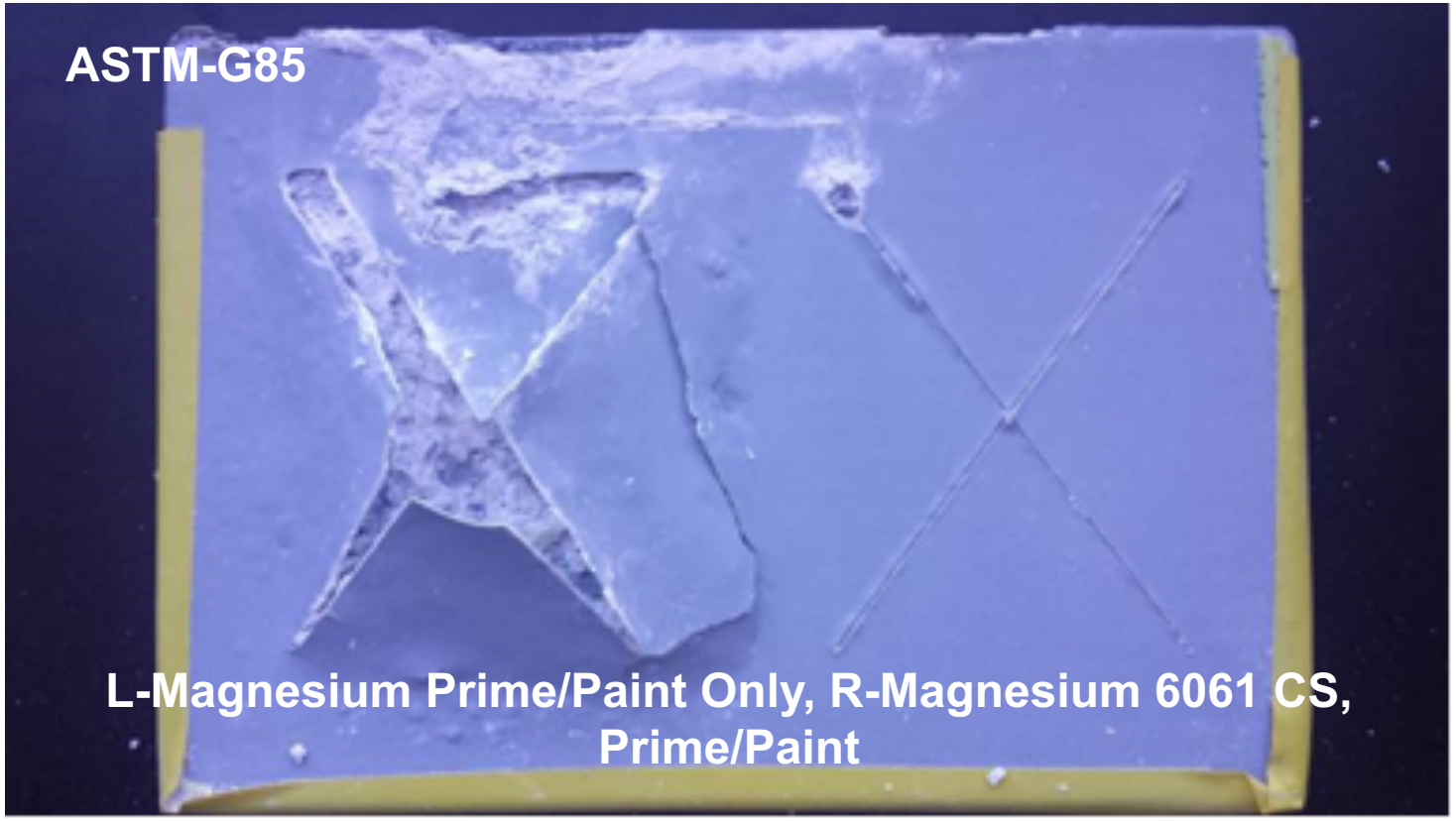
Highest Contributors to Navy/MC Corrosion Cost by LMI System

04	Power Distribution And Electrical	$320	1
01	Engines	$229	2
02	Airframe	$121	3
35	Armament	$111	4
09	Miscellaneous Aircraft	$95	5
19	Avionics	$77	6

Highest 20 Contributors to Navy/MC Corrosion Cost by Work Unit Code

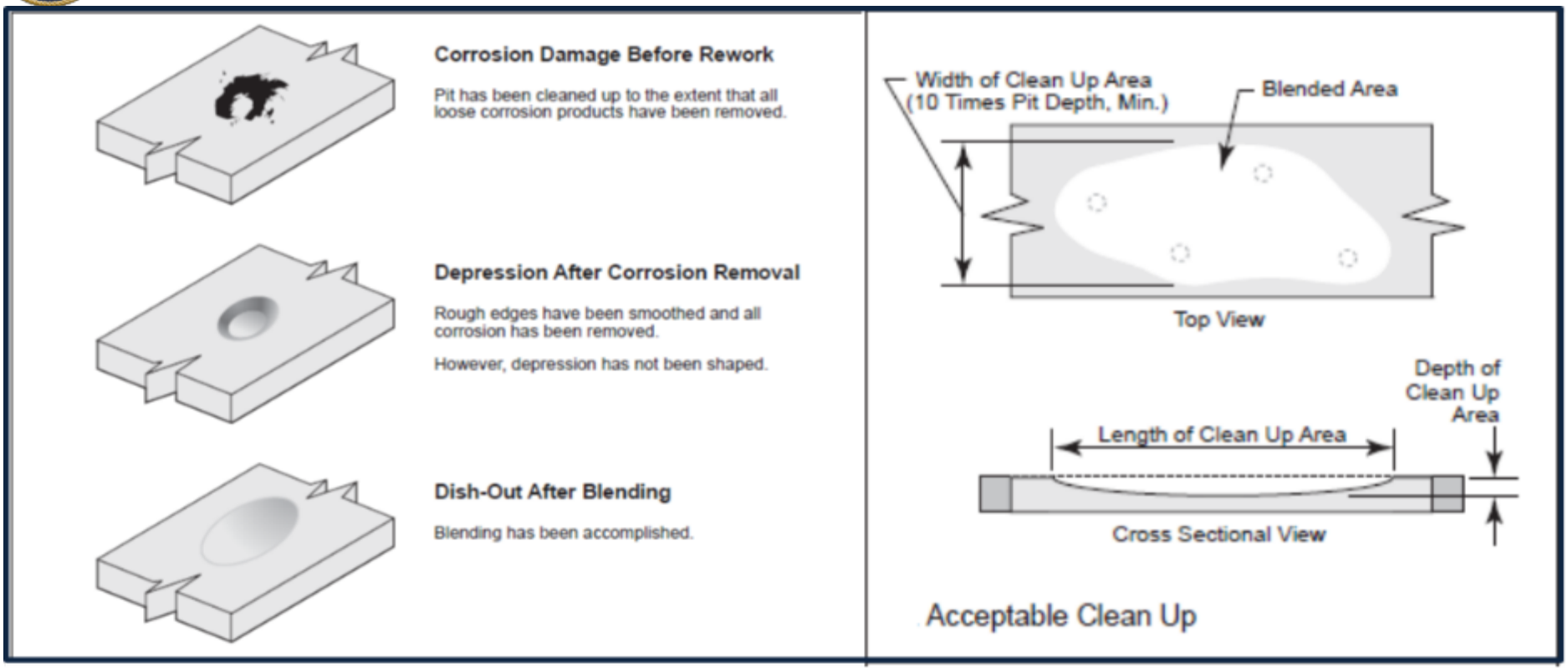
WUC	WUC Description	Corrosion cost (in millions)	Rank
03	Scheduled inspection	$569	1
04	Special inspection	$384	2
11	Airframe-Structural components	$243	3
13	Arm/launch/launching system	$60	4
14	Directional flight	$58	5
75	Weapon delivery systems and associated equipment.	$58	6
15	Rotary wings	$48	7
29	Power plant installation	$45	8
22	Turboshaft/turboprop engines	$43	9
27	Turbofan engines	$40	10
74	Weapons control systems	$40	11
42	Electrical power supply/distribution/lighting systems	$35	12
46	Fuel systems	$33	13

Corrosion Performance



- Typical coatings stackup for magnesium gearboxes.
  - Dow pretreatment, (*rockhard) Epoxy Prime, Polyurethane Paint
- Performance significantly better with 3-4 mils of CS
- Across the board has mitigated corrosion in every application or better than current system
- Validated by Australian DSTO/RAN tests on active helicopter flying in marine environment – full life after application: typical of other applications

Blend & Fill Process



- Cold spray metallization can apply back base metal or tailor galvanic protection by applying a new, better alloy, than an organic coating (paint/epoxy/sealant).
- Repairs within structural limits, brings part back to original dimensions
  - No fatigue debit or credit, considered a coating
- Mitigates future corrosion and can be reapplied indefinitely
- If universally applied, potential to mitigate over 80% of corrosion issues that lead to structural damage.

Magnesium On Aircraft

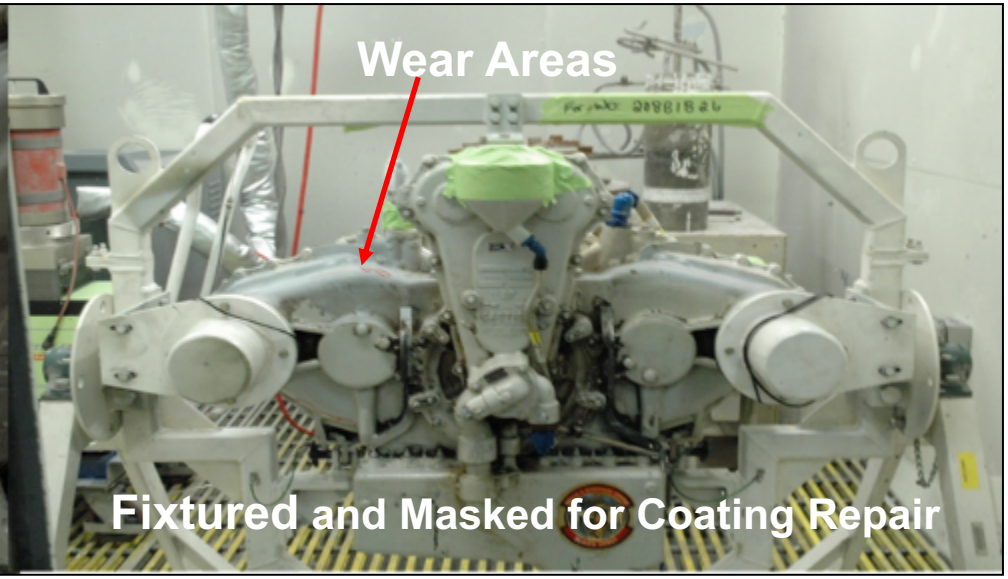
Gearboxes

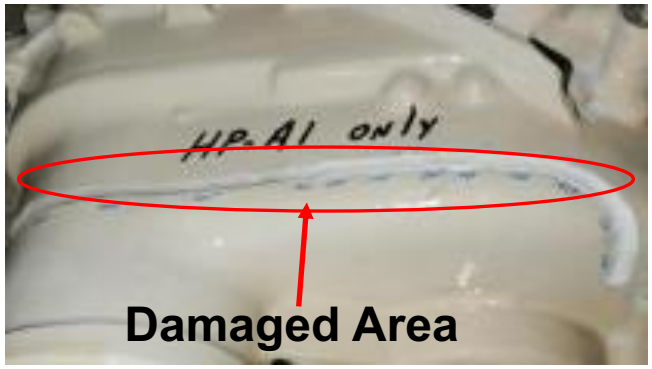
Accessory Drives

Generator Housings

Magnesium + Seawater = Corrosion

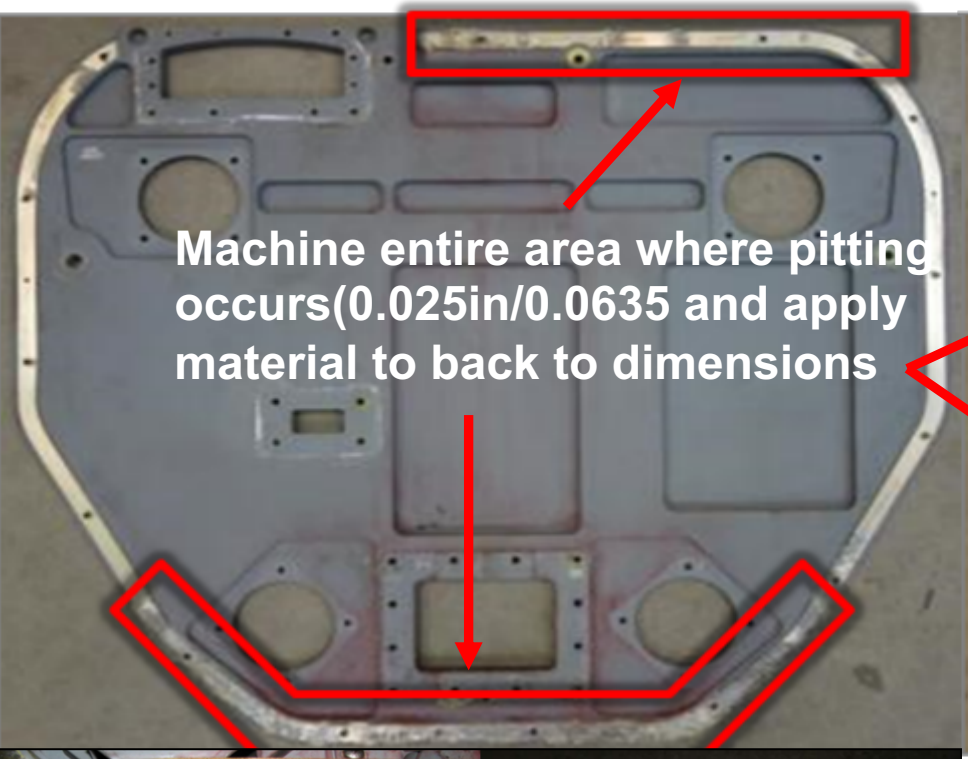
ZE41A Magnesium Gearbox





- Wear damage caused by a faring rubbing, repair .090inch thick
- Repaired manually using 1100 series aluminum, or 6061 preferred using nitrogen as the carrier gas
- Repaired by depot artisans and Intermediate level Marine Aviation Machinists

Aluminum Avionics Rack



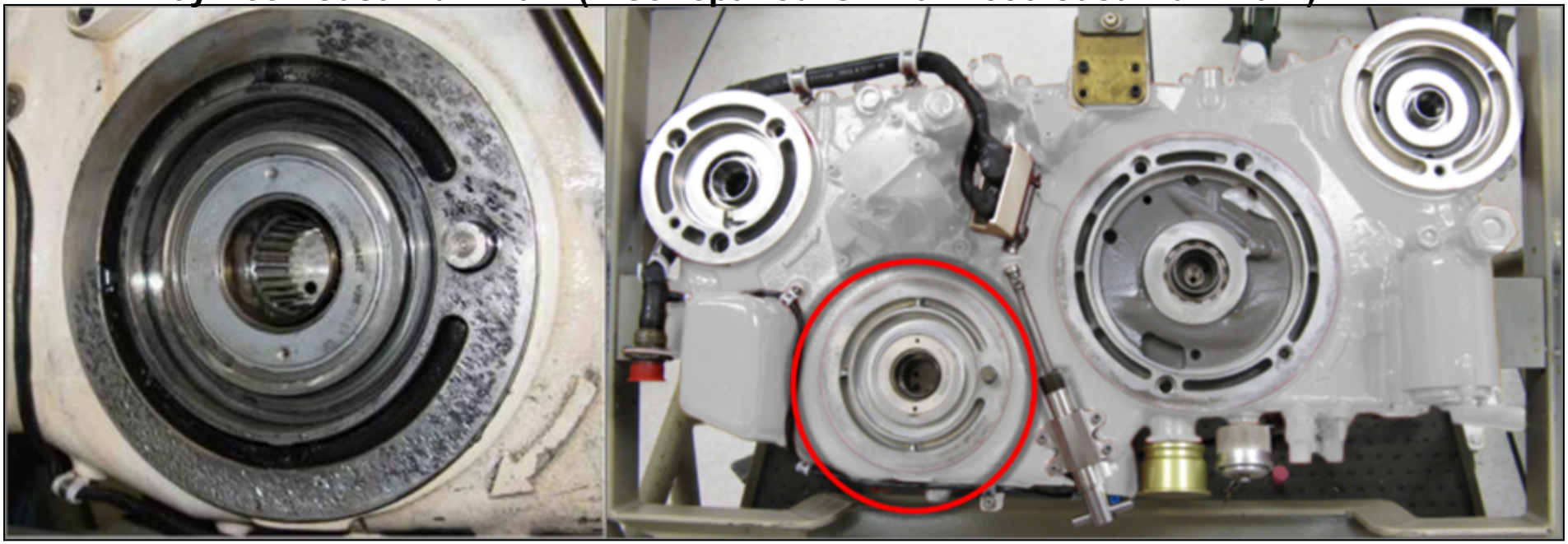
Corrosion damage caused by hot gun gasses, heavy pitting

Al-Trans 10-20-50 Chrome® aluminum blend onto the 7075-T7351 aluminium rack using a low pressure cold spray system, with Helium.

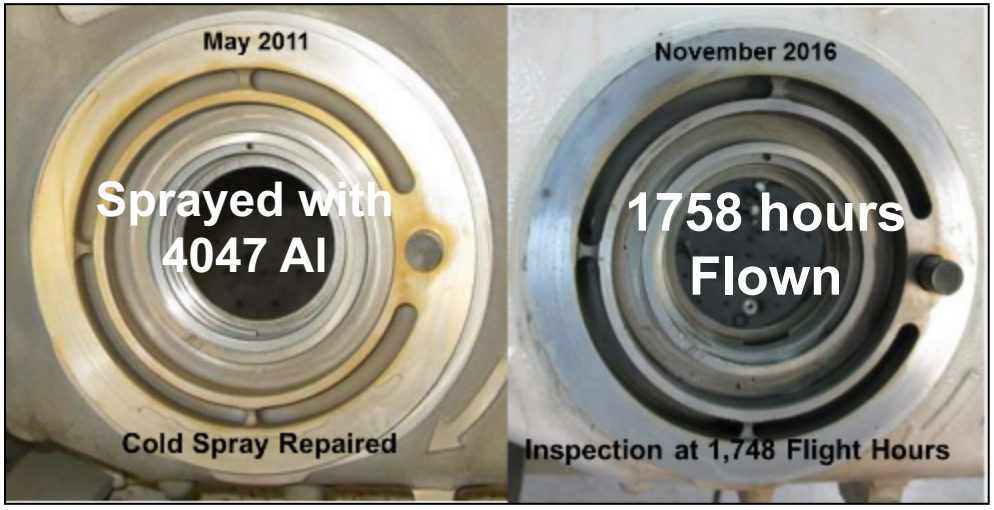
- Chrome used as an aggregate to compress aluminum alloy into surface
- **Better alloy than 7075, mitigated pitting restored matched set parts.**

Aluminum Gearbox Housing

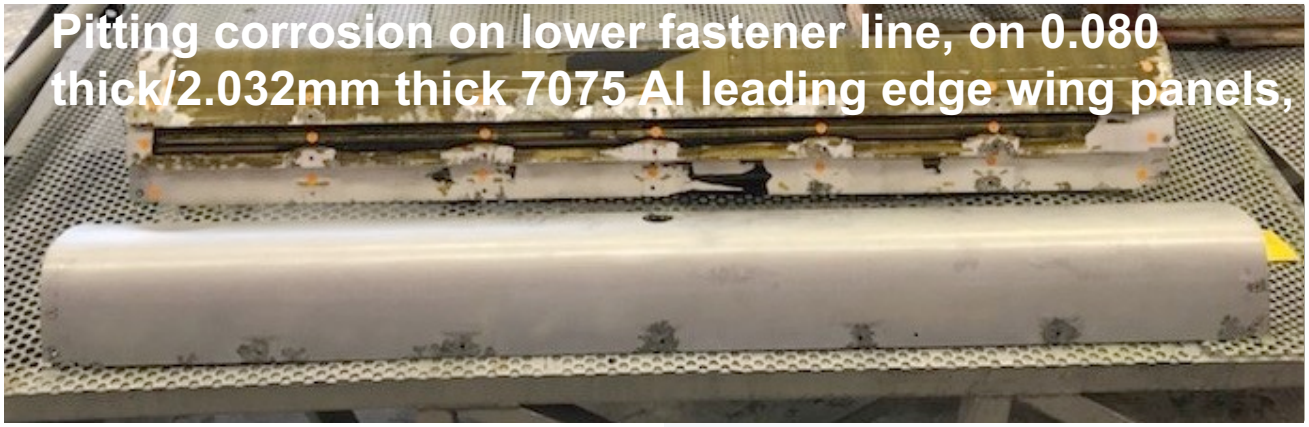
Alloy A357 Cast Aluminum (Also repaired similar A356 Cast Aluminum)

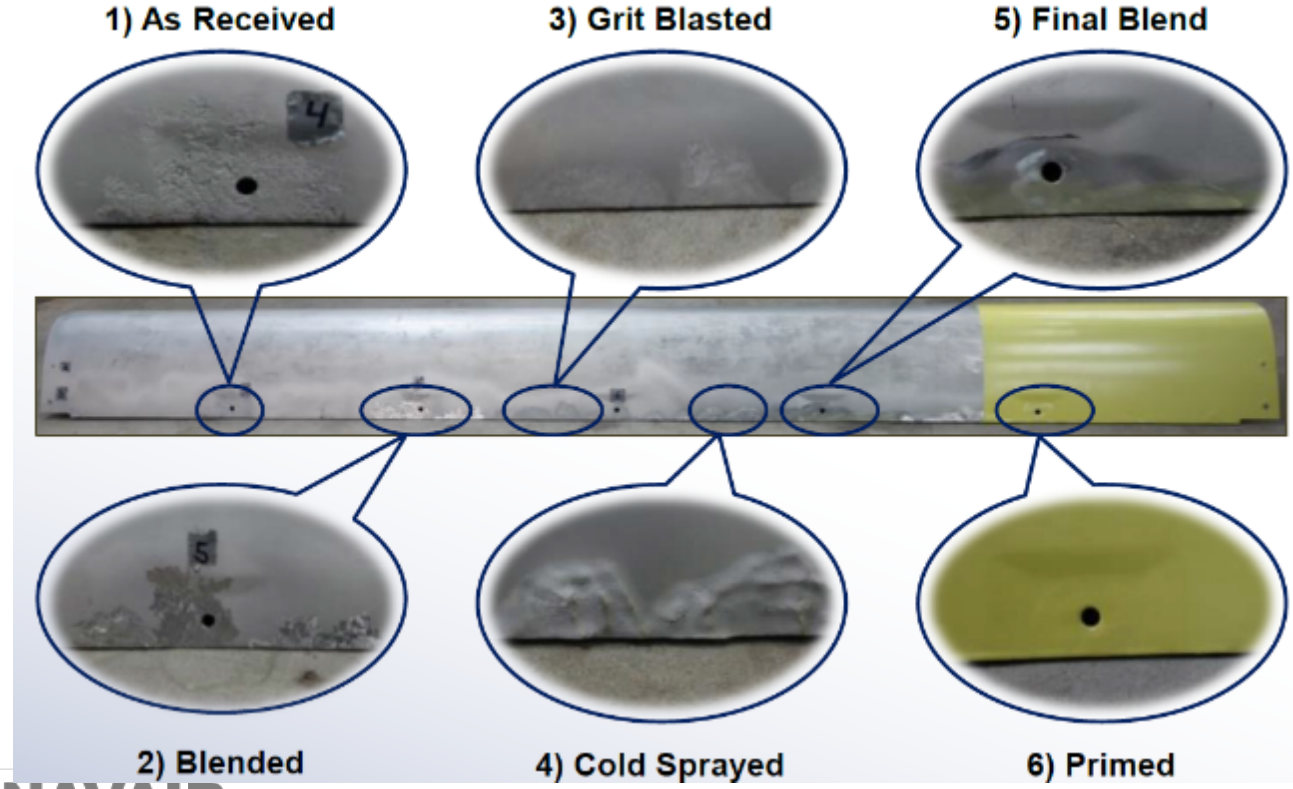


- Fretting Corrosion Damage
- **Multiple alloys** applied to during repair development, all are flying, **qualified**
  - 4047 Al high pressure, nitrogen
  - CP1100 series Al (SST A5001®) Low Pressure using nitrogen
  - Aluminum-nickel blend (Al-Trans® 7075 with nickel) low pressure using helium



Wing Leading Edge Cover

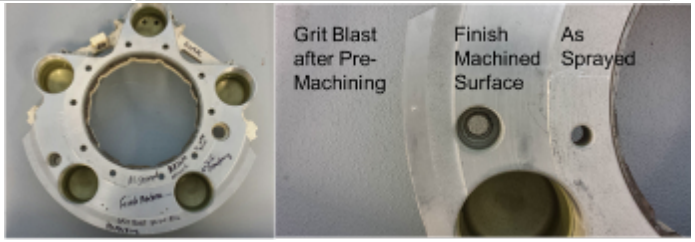




- Pitting around lower edge fastener holes.
- Deicer boot placed on top
- No primer under deicer boot
- Repaired using Al-Trans Chrome® using a low pressure system.

Brake Carrier Corrosion Repair

- Pitting of aluminum 2014-T61 cast brake carriers
  - **High use item**
- Current repair is plasma spray
  - 50 percent of the brake carriers reprocessed due to coating disbonds after processing.
    - Injects heat into the part requires post processing heat treatment.



Al-Trans Chrome 10-20-50® powder using helium as the carrier gas using a low pressure cold spray system, robotically.

- Approximately 0.040-inch-thick coating, and then machined back to the final dimension.
- **70% of cost, faster process, 100% quality, no post heat treatment**,

Hard Chrome Alternative

- Part: AMS 6265 steel, part of accessory gearbox
- Wear damage to top sealing surface, dimensional restoration
  - Previous repair was hard Chrome Plating
- Repaired using low pressure system using helium to deposit Tungsten Carbide Cobalt
  - Faster (15 min/part), no post hydrogen embrittlement bake
  - Tested for 3000 hours on gearbox test stand, better than chrome performance for sealing.

S&T Analysis

Issues for all materials of interest to the Navy/NAVAIR

- Process parameters
  - Repair limitations
- Coating optimization
  - Powder
  - Surface preparation
  - Spray parameters
- **Coating bond strength**
- **Coating cohesion**
- **Post-coating preparation**
  - Sealing/Pretreat
  - Welding
  - Machining
- Microstructural characterization
  - **Metallurgical bond**
  - **Coating Porosity**
  - Dislocation density
  - Coating formation
- Mechanical properties (comparison to existing technology)
  - Fatigue, Tensile, Residual stress

- Fatigue/Tensile
- **Corrosion**
- Evaluation/Development of NDT
- Significance of Flaws
- Specifications and Requirements
- In-service repair
- Safety/Environmental concerns
- Application based cost benefit analysis
- Modeling, process & materials
- Logistics constraints
  - Material
  - Equipment

Need to tie fundamental understanding of process parameters/operating envelope to coating properties

NAVAIR Cold Spray Developmental Timeline

Past: 10 years

- Comparative Analysis
- Hazard & Benefit of new Technology
- SBIR/Sect219/DLA-Dem/Vals/Transition
- Dimensional Restoration Applications Developed
- Part Specific LPS's Developed
- Deployment of CS Systems to all Depots & Intermediate Level (DLA 2010, SBIR TTA 2013)

Current: 2018-2019

- Corrosion is a major A/C degrader, Estimated $2.6-$2.8 billion per year for Navy/MC aircraft due to corrosion. Major impact to aircraft readiness. Repair the substrate before structural damage occurs to achieve full part life. NAVAIR Authorization Letter for CS as an alternative to blend and fill-Dim/Corrosion.
- Finalize NAVAIR CS Standard Work Package
- Low Pressure Units for Corrosion Control
- Delivery of FCT Robotic Unit: Feb 2019
- Standard Navy NAVFAC install & EH&S Guidance
- Technical Warrant Holder Concurrence:
  Need authorization from Project Offices for Cold Spray to meet repair requirements & incorporation into specific T/M/S repair instructions

Future: 5 Years

- COTS LP Units installed & being used in all Navy/USMC Depots, Squadrons & MALS
- Helicopter Gearbox Coating Stackup Mod
- Replace existing process of ordering, utilizing, and ultimately scrapping long-lead, high-cost parts, using developed structural repair qualified Cold Spray repair processes.
- Modeling & Simulation for Cold Spray Repair Evaluation
- 90% Parts damaged by corrosion/ abrasion can be repaired by Cold Spray
- High Pressure & Laser assisted Cold Spray used for Structural Repairs

Cold Spray Technologies

COTS Units:
Available, Used in Production at 2/3 Depots since 2010, 1 at I-Level since 2016
Housed inside dust booths, doing dimensional repair with robotic controls followed by CNC machining.
Hand held units for spot repairs.

COTS Units Expansion:
2018-19 Establish NSN's for low pressure portable systems & powders.
Low Pressure, low cost, Hand Held Units to be used in Depots and I-Level for corrosion control maintenance as an alternative to current blend and fill practice.

Foreign Comparative Test (FCT) Units:
Delivery, Feb 2019
System demonstration May 2019
Used to perform robotic high pressure repair on-aircraft. Coating application, dimensional restoration, potential structural repairs.

Expansion COTS Units:
Robotic Portable, Robotic work cell, Hand-held
Standard CIP procurement process
Title III Additive Repair machining centers at all Navy Depots
Addition of Laser Ablation technology to enhance existing COTS CS Units

Near Term 1-2 Years Plan

- ***General Authorization for Cold Spray as a blend and fill alternative***
- **Identify all candidate parts for all aircraft type/model/series**
- **Develop a NAVAIR Cold Spray Quality Assurance Plan**
  - ***Qualification guide/Process Guide Similar to NAVSEA's***
- **Develop NAVAIR Aerospace grade powder specifications**
- **Safety Guidelines standardized by NAVFAC**
- **Develop a standard training plan.**
- **Full Implementation of physical capabilities at all FRC's**
- **Standardize workcells and systems installation**
- **Deploy Robotic Portable High Pressure Field System**

Long Term Plan

- **Repair other metals and alloys**
- **Hard chrome plating alternative**
- **Repair of landing gear components**
- **Structural repair**
  - Useful tool for Service Life Extension Programs
  - Alternative to fastened doublers
  - Alternative to bushings
- **Laser Assisted Cold Spray (ie laser cladding)**
- **Process modeling**
- **Logistics: Simplify powder packaging and delivery**

Thank You.