Qualification, Demonstration & Validation of Compliant Removers for Aircraft Sealants and Specialty Coatings

WP-0621

Jim Tankersley

Battelle

Jeff Kingsley

AFRL/RXSA

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PROJECT TEAM

- **Air Force**
  - Mr. Alan Fletcher, PI (AFRL/RXSA)
  - Mr. Jeff Kingsley (AFRL/RXSA)
  - Mr. David Tanner (OC-ALC)
  - Mr. Jerome Jenkins (OO-ALC) **DEM/VAL at Hill AFB**
- **Navy**
  - Ms. Diane Kleinschmidt, Navy Lead (NAVAIR)
  - Mr. Brad Youngers (FRC-SE) **DEM/VAL at FRC-SE**
  - Mr. Don Harmston (NADEP North Island)
  - Mr. Jack Fennell (NADEP Cherry Point) **DEM/VAL at MCAS New River/MCCS Cherry Point**
- **Battelle**
  - Mr. Jim Tankersley, Program Coordinator
  - Mr. John Stropki, DEM/VAL Coordinator
- **UDRI**
  - Ms. Susan Saliba
  - Mr. John Dues

Background

- Polysulfide, polythioether and silicone-based sealants, as well as various low observable coatings are commonly used on the Department of Defense weapon systems.
- Aerospace sealants and coatings are routinely removed during the structural maintenance, repair, and overhaul (MRO) operations of the aircraft for non destructive inspection (NDI) for structural integrity of the aircraft components.
- Current DoD approved removal processes for MRO operations are:
  - Extremely labor intensive.
  - Require the use of Toxic Release Inventory (TRI) chemicals.
  - Pose significant damage risks for Air Force and Navy airframes at MRO facilities.

Background

- DoD MRO facilities would significantly benefit from environmentally-friendly, effective alternatives to current chemical and mechanical methods.
- Air Force and Navy have funded studies to evaluate alternative DoD approved removal technologies
  - Mechanical (pressurized water, customized dry media blends, ultrasonic scrapers, bristle brushes, etc…)
  - Light energy (hand-held lasers and Flashjet™)
  - Chemical (softeners and strippers)
- Results confirm no universal solution quickly removes sealant or coating without potential for substrate damage.
- Environmentally friendly chemical sealant removers represents a low cost and efficient process.

Technical Objectives

- Identify chemical sealant removers that are:
  - Suitable
  - Environmentally-friendly
  - Effective
  - Available (COTS)
- Conduct successful multi-service, field-level demonstration/validation for removing sealants and specialty coatings from metallic aircraft structures.

Technical Approach

- Gather and define requirements
  - Evaluate current methods
  - Determine success criteria
- Down-selection activity
  - Conduct industry survey to identify candidate materials
  - Define screening tests
  - Conduct screening to select viable materials
  - Evaluate and select best performers
- Conduct demonstration/validation activities
- Conduct transition activities
  - Publish final reports
  - Disseminate information

Technical Approach

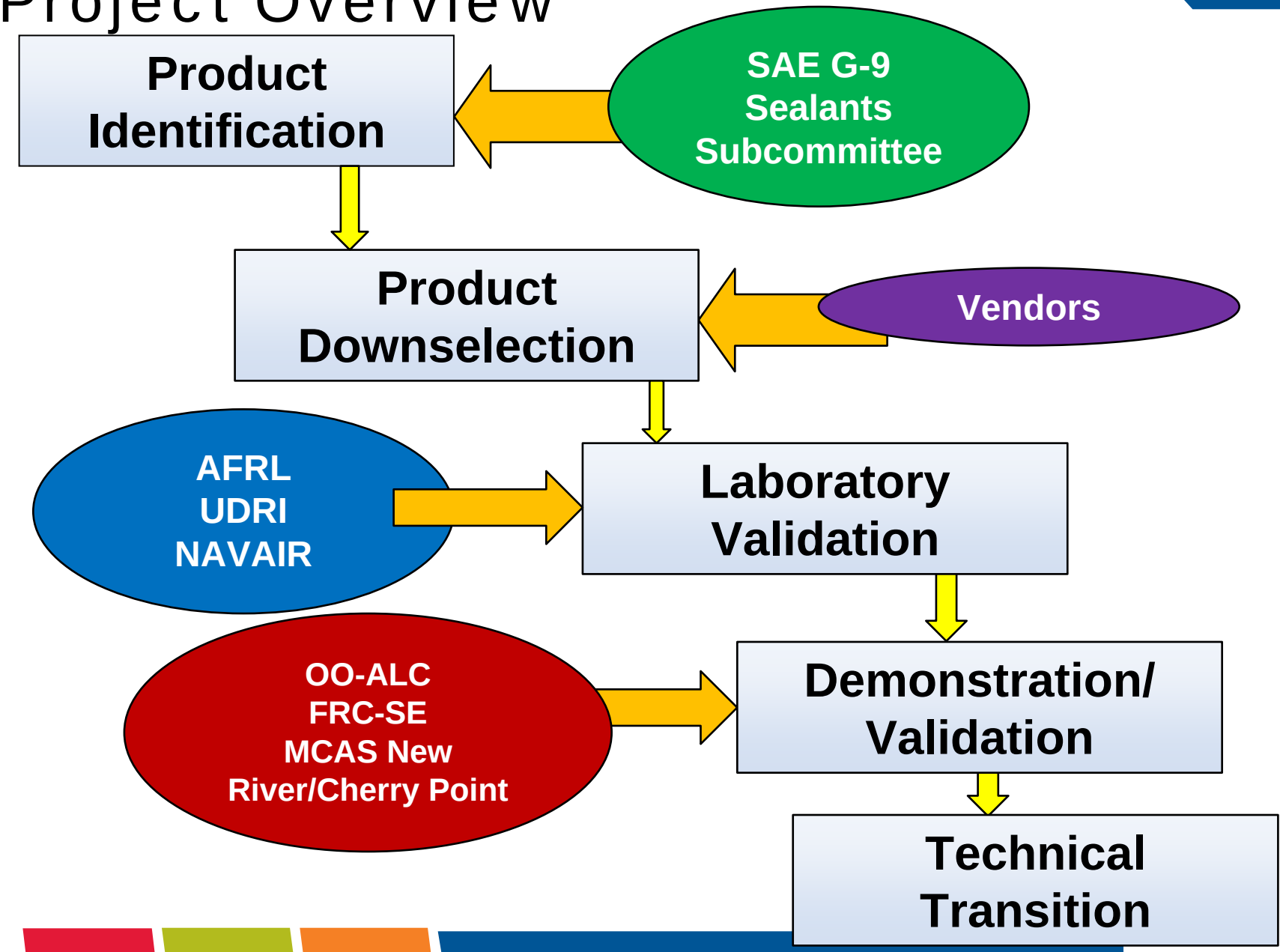
"Toolbox" Approach:

Provide end users with materials/methods to approach sealant removal tasks consistently and effectively, depending upon situation.

Project Overview

- Two Phases conducted in this program.
  - First phase focused on polysulfide fuel tank sealants
  - Second phase focused on polythioether and polyurethane fuel tank sealants
- Results from both phases are reported together.

Project Overview



Project Overview

Material Selection

- **Sealant Materials**
  - PR-1422 B-2 (Polysulfide) – AMS-S-8802
  - PR-1750 B-2 (Polysulfide) – AMS 3276
  - PR-1826 B-2 (Polythioether) – AMS 3277
  - EFC 100 B-2 (Polyurethane) – AMS 3278
- **Coated Substrates**
  - MIL-C-27725 (Polyurethane)
  - MIL-PRF-23377 (Epoxy Primer)
  - BMS 10-20 (Epoxy Primer)
- **Uncoated Substrates**
  - AMS 2471 (Anodized Aluminum)
  - AMS 4911 (Titanium)
  - AS-4/3501-6 (Graphite/Epoxy)
  - IM-7/5250-4 (Graphite/Bismaleimide)

Project Overview

- Down-selected Sealant Removers for use with **Polysulfide**
  - SkyKleen 2000
  - PolyGone 300
    - Also PolyGone 310 AG
- Down-selected Sealant Removers for use with **Polythioether**
  - SkyKleen 2000
  - SkyRestore LM 306

Laboratory Demonstration Tests (UDRI) - Testing Protocols

Parameter	Test	Test Method
Sealant Removal	Force Measuring Unit	UDRI Proprietary
Substrate Damage Potential	Visual	Fourier Transform Infrared Microscopy (FTIR)
	Discoloration (metallic)	ASTM G 1
	Pitting (metallic)	ASTM G-46
	Visual - 100X (composite)	Scanning Electron Microscopy (SEM)
	Interlaminar Shear Strength	ASTM D 2344
	Tensile Strength	ASTM E 8
Surface Residue	Pencil Hardness	MIL-C-83286A
	Tape Adhesion	FED STD 141, Method 6301
Re-Adherence	Peel Strength	AS 5127

Note: Removal methods included application of respective chemical removers w/ and w/o automated (powered) scrapers

Summary of Laboratory Results

- "Primer" Coating Effects
  - Solutia SkyKleen 2000 did not appreciably affect any of the coatings
  - PolyGone 300 locally damaged the BMS 10-20 topcoat
  - Neither SkyKleen nor PG300 affected pencil hardness and tape test results after stripping
  - Elixair® SkyRestore and Solutia SkyKleen sealant removers did not chemically degrade the MIL-PRF-27725 coating nor either of
  - Neither SkyRestore and SkyKleen remover affected the pencil hardness and tape test results after stripping the two composite substrates
  - Both removers had 100% cohesive failures on AS4/3501 and IM-7/5250-4

Summary of Laboratory Results

- Substrate Effects
  - AMS-2471 and AMS-4911 tensile and % elongation properties were not affected by either stripper
  - The results of the interlaminar shear strength were not affected by either remover
  - The SEM photos at 100X were inconclusive, therefore, select specimens being evaluated at 500X to determine if there was damage caused by either the remover or hand held tool
  - Substrates stripped with Solutia SkyKleen 2000 had 100% cohesive failures on all substrates with all sealants, except PR 1750 B-2/AMS-2471 which was 95% cohesive
  - Substrates stripped with PolyGone 300 did not have 100% cohesive failure on the majority of the substrates with sealants PR 1422 B-2 and PR 1750 B-2
  - Neither PG300 nor SkyKleen did not cause a change in lap shear test results

Additional Lab Analysis

PolyGone 310 AG Corrosion Testing

- Concerns from customers about potential sandwich corrosion testing on PolyGone 300 AG
  - Vendor (RPM technology) responded by modifying COTS formulation
- Submitted new formulation to NAVAIR for additional testing
  - Results of new formulation relieved concerns
  - Results of new formulation confirmed possible applications removing specific fuel tank coating and primers

PolyGone 310 AG Corrosion Testing Results

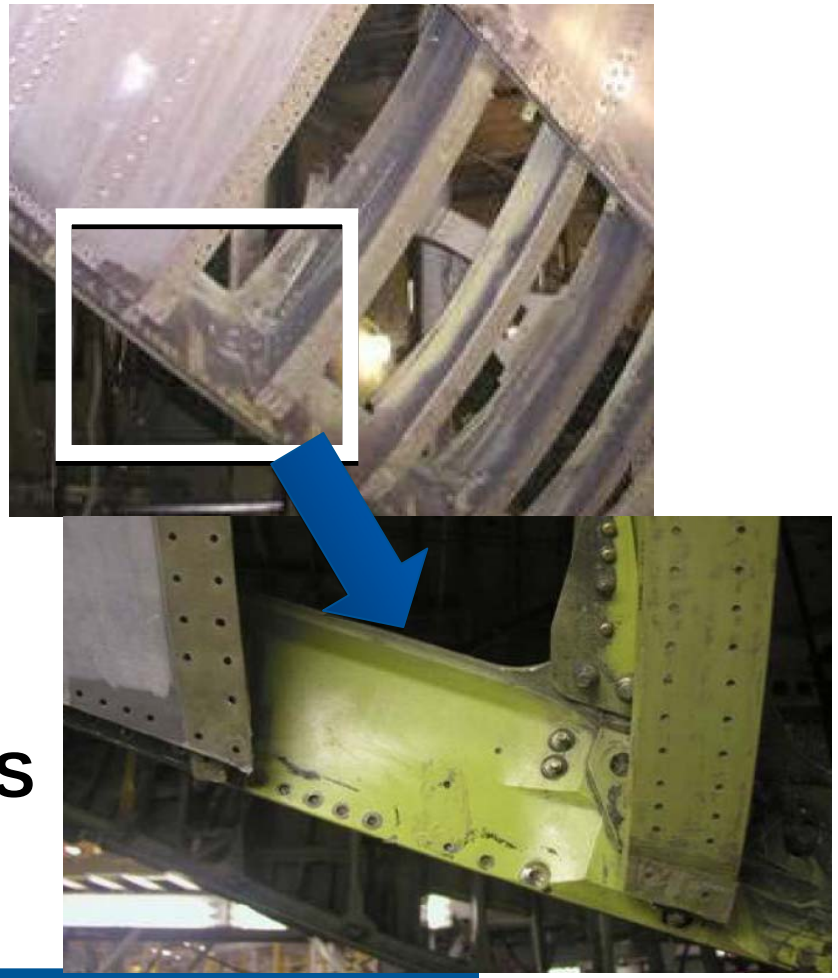
- Sandwich Corrosion: No corrosion observed on 2024 and 7075 coupons
- Hydrogen Embrittlement: Four test specimens exceeded 75% NFS sustained load for 200 hours
- Effects on Painted Surfaces: Product performed complete coating removal within 30 minutes
- Total Immersion Corrosion: Product met corrosion limits as specified

Test	Specification	Results
Sandwich Corrosion	ASTM F1110	✓
Hydrogen Embrittlement	ASTM F519	✓
Effects on Painted Surfaces	ASTM F502	✗
Total Immersion Corrosion	ASTM F484	✓

PolyGone 310 AG now being considered as compliant coating remover by USAF

Demonstration/Validation Activities

- Phase I (FY06, FY07)
  - Polysulfide sealant focus
  - Dem/Val 1 at **Hill AFB**
    - F-16 Wing Spar/Pylons
    - C-130 Sloping Longeron
    - A-10 Wing IML
  - Dem/Val 2 at **FRCSE**
    - P-3 OML
  - P-3 Wing tank components
  - EA-6B Canopy Structure
- Phase II (FY08, FY09)
  - Polythioether sealant focus
  - Dem/Val 3 at **New River MCAS**
    - V-22 Osprey



OO-ALC Demonstration/Validation Summary

- **F-16**
  - When coupled with Cold Jet, both removers showed potential to reduce stripping operations by 50%
  - Easier clean-up with SkyKleen 2000
- **C-130**
  - Both products worked adequately, but did not improve the current method (methylene chloride – 2 hr. dwell); however, PPE and evacuation of area is required with current method
- **A-10**
  - Center wing spar tested, but neither stripper was preferred to the current method due to dwell time requirement and methodology
- **All**
  - Viscosity is key to successful removal of sealant from vertical surfaces and seems to aid in clean-up

FRC-SE JAX Demonstration/Validation Summary

- **Applied Poly-Gone 300 to OML of P-3 Aircraft**
  - Used varying viscosities (Gel;Liq - 2:1, 1:1, 0:1)
  - Dwell time ~4 hrs.
  - Removal using pressurized water not as effective as anticipated
- **SkyKleen 2000 applied at later date by USN personnel**
  - Dwell time ~5-6 hrs.
  - Greater viscosity than Poly-Gone slurry
  - Removal using pressurized water not as effective as Poly-Gone 300
- **Lessons Learned**
  - When possible, apply when longer dwell time can be taken advantage of (possibly overnight)
  - Refine viscosities for greater effectiveness
  - Refine removal method, possibly with knife edge water jet nozzle, to increase effectiveness of pressurized removal

MCAS New River, NC Demonstration/Validation Summary (January 2010)

- Elixair Sky Restore and Solutia SkyKleen 2000 demonstrated on V-22 Osprey components
  - Fixed Wing Structure
  - Outer Mold Line Elements
- Dem/Val conditions affected outcomes
  - Unheated hangar resulted in dwell temperatures <40°F, possibly effecting remover efficiency
  - Sky Restore exceeded performance of SkyKleen 2000 at more desirable dwell times
- **Outcome was negative**. Cause determined to be due to temperature during dwell. This verified with lab testing.

Additional Lab Analysis

Temperature effect on removal activity

- Poor results from field demonstration attained in adverse weather conditions.
- Trouble shooting poor results confirmed temperature as a critical parameter in chemical remover.

Controlled Temperature Test

Test Matrix and Sample Specifications

Sample #	Sealant	Sealant Surface Area (in^2)	Sealant Thickness (mils)	Chemical Remover	Remover (grams)	Remover Dwell (hrs)	Temp. (^oF)	Coverage ($grams/in^2$)
1	PR1826, Class B	7.1875	66.10	Skykleen	11.34	20	35	1.58
2	PR1826, Class B	7.1875	65.87	Skyrestore	11.26	6	35	1.57
3	PR1826, Class B	7.1875	60.33	Skykleen	11.69	20	50	1.63
4	PR1826, Class B	7.1875	65.23	Skyrestore	11.76	6	50	1.64
5	PR1826, Class B	7.1875	65.60	Skykleen	11.67	20	70	1.62
6	PR1826, Class B	7.1875	64.13	Skyrestore	11.75	6	70	1.63

Controlled Temperature Test Results

Removal rates for each test sample according to the subjected temperature

Sample #	Chemical Remover	Remover Dwell (hours)	Temperature (ºF)	Removal Time (min:sec)	Strip Rate (in²/min)
1	Skykleen	20	35	19:53	0.36
2	Skyrestore	6	35	15:41	0.46
3	Skykleen	20	50	5:52	1.23
4	Skyrestore	6	50	5:25	1.33
5	Skykleen	20	70	2:22	3.04
6	Skyrestore	6	70	9:41	0.74

MCAS New River, NC Demonstration/Validation Summary (June 2010)

- Elixair Sky Restore and Solutia SkyKleen 2000 demonstrated on AV-8B Harrier components
  - Fixed Wing Structure

MCAS New River Demonstration/Validation

Summary of Individual Test Areas Along Upper Surfaces of V-22 Wing Section

Test Area Identification	Approximate Length, in.	Condition	Approximate Dwell Time, hr.
Area 1 Skyrestore	9	Scored	2
	9	Unscored	2
Area 2 Skyrestore	9	Scored	4
	9	Unscored	4
Area 3 Skyrestore	12	Unscored	6
Area 1 Skykleen	9	Scored	6
	9	Unscored	6
Area 2 Skykleen	9	Scored	22
	9	Unscored	22

MCAS New River Demonstration/Validation

Sealant Removal Times for Sealants Processed with SkyKleen Remover

Test Area	Approximate Surface Area, in^2.	Condition	Approximate Dwell Time, hrs.	Approximate Removal Rate, in^2/ min.
Area 1	2.25	Scored	6	0.520
	2.25	Unscored	6	0.562
Area 2	2.25	Scored	22	0.843
	2.25	Unscored	22	1.25
Control	2.25	Unscored	N/A	1.58

MCAS New River Demonstration/Validation

MCAS New River Demonstration/Validation

Sealant Removal Times for Sealants Processed with SkyRestore Remover

Test Area	Approximate Surface Area, in^2.	Condition	Approximate Dwell Time, hrs.	Approximate Removal Rate, in^2/min.
Area 1	2.25	Scored	2	.225
	2.25	Unscored	2	.225
Area 2	2.25	Scored	4	2.25
	2.25	Unscored	4	.900
Area 3	3.00	Unscored	6	.901

MCAS Cherry Point, NC Demonstration/Validation Summary (June 2010)

- Dem/Val performed on condemned AV-8B wing
  - Sealant test areas located underneath panels on front section of the wing
  - Sealant thickness: ~1/16”
- Chemical Removers used in combination with mechanical scraping tools
  - Skyrestore and Skywipes
  - SkyKleen
- Hangar Environment Conditions
  - 70-90°F
  - Humidity < 40%
- Control test performed without the aid of a chemical remover:
  - Complete sealant material removal wasn’t possible
  - Residue layer adhered to the substrate was left behind
- Fastest removal rate occurred with a 4 hour dwell period of Skyrestore: 21 in^2/min (25 secs for ~9 in^2)

Cost Analysis of P-3 Aircraft Desealing Process Costs (based on 25 aircraft/yr)

	Baseline Scenario Mechanical Desealing	Alternative Scenario Chemical + Mechanical Desealing
Initial Investment Cost		
Capital Equipment	N/A	N/A
Annual Operating Cost		
Direct Labor	$192,000	$96,000
Direct Materials:	$37,500	$69,500
Aluminum tape/aircraft (unit $)	$25,000	$12,500
Sanding disks/aircraft (unit $)	$5,000	$1,000
Plastic and SS wire scrapers (unit $)	$7,500	$1,000
Desealant chemical (unit $)	$0	$55,000
Total	**$229,500**	**$165,000**
Utilities:		
Electric Steam/Rinse Water		
Total	**$2,400**	**$2,400**
Waste Management:		
Non-Hazardous Waste Disposal	Negligible	Negligible
Wastewater Treatment/Disposal	$85,200	$85,200
Wastewater: Hazardous Waste	$2,936	$2,936
Wastewater: Sludge	$4,607	$4,607
Total	**$92,743**	**$92,743**
Environmental Compliance Recurring Cost	N/A	N/A

Comparison of F-16 Aircraft Lower Wing Desealing Process Costs (based on three aircraft wings/month)

	Baseline Scenario Mechanical + CO_2 Desealing	Alternative Scenario Chemical + CO_2 Desealing
Initial Investment Cost		
Capital Equipment	N/A	N/A
Annual Operating Cost		
Direct Labor	$21,600	$12,960
Direct Materials:	$6,750	$8,100
Aluminum tape/aircraft (unit $)	$0	$0
Rotary brushes/aircraft (unit $)	$0	$0
Plastic scrapers/aircraft (unit $)	$600	$300
Dry ice pellets/aircraft (unit $)	$6,150	$4,500
Desealant chemical/aircraft (unit $)	$0	$3,300
Total	**$28,350**	**$21,060**
Utilities:		
Rinse Water	$0	$0
Waste Management:		
Non-Hazardous Waste Disposal	Negligible	Negligible
Wastewater Treatment/Disposal	N/A	N/A
Hazardous Waste/Disposal	$375	$146
Sludge/Disposal	$0	$300
Total	**$375**	**$581**
Environmental Compliance Recurring Cost	N/A	N/A

Comparison of C-130 Sloping Longeron Desealing Process Costs (based on 4 aircraft/month)

	Baseline Scenario Chemical + Mechanical Desealing	Alternative Scenario Chemical + Mechanical Desealing
Initial Investment Cost		
Capital Equipment	N/A	N/A
Annual Operating Cost		
Direct Labor	$3,840	$3,840
Direct Materials:	$1,090	$2,650
Tarping and rags/aircraft (unit $)	$400	$1,000
Plastic scrapers/aircraft (unit $)	$400	$400
Desealant chemical/aircraft (unit $)	$290	$1,250
Total	**$4,930**	**$7,450**
Utilities: Rinse Water	Negligible	Negligible
Waste Management:		
Non-Hazardous Waste Disposal	$250	$250
Solid Waste Treatment/Disposal	N/A	N/A
Hazardous Liquid Waste/Disposal	$275	$146
Sludge/Disposal	N/A	N/A
Total	**$475**	**$396**
Environmental Compliance Recurring Cost	N/A	N/A

Cost Analysis Phase I Demonstrations Summary

- **P-3 Outer Moldline**
  - Potential to save $64,500 annually (based on throughput of 25 A/C)
  - Annual savings likely less due to depot scheduling requirements
- **F-16 Component Parts (lower wing)**
  - Potential annual savings of $7,046 (based on three aircraft/wings per month)
  - Savings could be significantly greater if throughput is doubled, as data indicate
- **C-130 Sloping Longeron**
  - Increase in annual cost (~$7K) can be recovered through manpower efficiency and possible increased throughput

Transition Plan

- PolyGone 310 AG being promoted as sealant and coatings remover
  - Letter of support from AFRL/RXSA
  - Follow-on project to qualify as compliant paint remover
  - Addition of NSN and addition to DLA “Green Products” List
  - End users include the ANG, AMARC, WR-ALC, OO-ALC and Boeing-Military
- Elixaire Sky Restore
  - Currently in use as aircraft cleaner and solvent
  - Efforts underway to promote as sealant remover
  - NSN 8030-01-466-1649
- Solutia SkyKleen 2000
  - Currently in use as aircraft cleaner and solvent
  - Efforts underway to promote as sealant remover
  - NSN 6850-01-456-7458

Conclusions and Summary

- Down-selected removers (PolyGone 310, SkyKleen 2000, Sky Restore) performed adequately for sealants, adhesives with no damage to substrates
- Down-selected removers varied in effectiveness based on sealant (polysulfide, polythioether, silicone)
  - "Toolbox Approach" confirmed for different scenarios
- Potential efficiency gains identified during demonstration/validation exercises
  - Hill AFB (F-16, C-130)
  - FRCSE-JAX (P-3)
  - MCAS Cherry Point (AV-8B Harrier)