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Laser Ablation for Removal of Chemical Agent Resistant Coatings (CARC) and Corrosion on Common Army Substrates

by Thomas A. Considine and Alicia A. Farrell

NOTICES

Disclaimers

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14. ABSTRACT
U.S. Army assets require frequent repainting to repair physical damage and environmental degradation. This requires the removal of coatings, which is almost exclusively performed using hazardous chemicals or mechanical abrasion and puts personnel at increased health risk. An upcoming technology, laser ablation, can be used to mitigate these health risks while also decreasing the amount of hazardous waste generated and the cost of its removal. This technology can be used with similar or greater effectiveness to the chemical and mechanical removal means, further reducing labor costs. The goal of this research is to prove the efficacy of laser ablation on an array of commonly used armor substrates and investigate potential detrimental effects to the repaintability of the surface imparted by the energy of the laser. Successful testing performed as part of this program is used to justify revisions to Army paint specifications to allow unrestricted use of laser ablation as a cleaning method. With the restriction on the use of laser ablation lifted, Army depots will be allowed to use this cleaning method that generates less waste leading to decreased operational costs. Two depots have already switched to laser ablation, leading to an estimated $279,000 in savings per year.

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Executive Summary

Army assets require frequent repainting to repair physical damage and environmental degradation. This requires the removal of the paint coatings, which is almost exclusively performed using hazardous chemicals or mechanical abrasion and puts personnel at increased health risk. An upcoming technology, laser ablation, can be used to mitigate these health risks while also decreasing the amount of hazardous waste generated and the cost of its removal. This technology can be used with similar or greater effectiveness to the chemical and mechanical removal means, further reducing labor costs. The goal of this program is to prove the efficacy of laser ablation on an array of commonly used armor substrates and investigate any potentially detrimental effects to the repaintability of the surfaces impacted by the energy of the laser. Successful testing performed as part of this program has been used to justify revisions to the Army paint specifications to allow unrestricted use of laser ablation as a cleaning method. With the restriction on the use of laser ablation lifted, Army depots will be allowed to use this cleaning method that generates less waste leading to decreased operational costs. Two depots have already switched to laser ablation, leading to an estimated $279,000 in savings per year. Extrapolating for all nine Army depots, an estimated $1.2 million could be saved while eliminating over one million pounds of hazardous dust and debris from the waste stream and reducing the overall environmental footprint. For these reasons, laser ablation will prove to be an effective, cost-saving method for coatings removal.

1. Introduction and Project Overview

Laser ablation is a mature technology, first seeing experimental application in the 1960s and early industrial adoption through the mid-1980s. Today laser ablation is used in multiple applications across the medical, industrial, and automotive industries, including those serving the DoD. Laser ablation technology uses a controlled wavelength, high-power laser to vaporize surface contaminants, including corrosion products and coatings, by reflecting light off the substrate. The U.S. Air Force (USAF) has performed multiple studies[1,2] on the health, safety, efficiency, and effectiveness of laser ablation for coatings removal, and has already begun to implement both portable and fully automated units in their facilities. The laser ablation process removes the need for the masking, as specific areas can be directly targeted by the laser. Additionally, the laser can be dialed in to only remove coating to a specific depth, allowing primer layers to stay in place while the topcoat is removed. This process results in significant savings in terms of labor costs, which are estimated at approximately $140,000 annually per Army depot.

The U.S. Army relies almost entirely on chemical methods and/or mechanical abrasion to remove Chemical Agent Resistant Coatings (CARC) during maintenance cycles on ground vehicle assets. Chemicals such as methylene chloride are often used in paint-stripping applications, exposure to which has been identified by the Occupational Safety and Health Administration as being able to damage the skin, brain, respiratory system, and other internal organs. Even the greener, less hazardous but still effective chemical depainting options typically come with their own health concerns. Furthermore, chemical stripping operations often have a high energy demand to 1) heat and circulate the large baths they are contained in as well as 2) operate the ventilation systems associated with such processes. Mechanical methods such as abrasive blasting are known to generate fine particulates that can be transported by the air to the lungs of individuals both operating and around the blast cabinets. These mechanical methods are often used to remove corrosion products occurring on the substrate as well. Both methods generate hundreds of thousands of pounds of hazardous waste and man hours related to masking and house cleaning, incurring additional costs to the facilities that employ them.

The purpose of this report is to evaluate the efficacy of laser ablation for preparing the surface of a given substrate versus established cleaning methods such as abrasive blasting and chemical etching used routinely at most Army depots. A selection of test items representative of common armor alloys such as aluminum alloy (AA) 2024, cold rolled steel (CRS), and high hard armor (HHA) will be prepared in accordance with traditional cleaning methods and assessed against a set of test items prepared with laser ablation prior to CARC application. If all requirements of the TT-C-490, *Chemical Conversion Coatings and Pretreatments for Metallic Substrates (Base for Organic Coatings)*,[3] and MIL-DTL-53072, *Chemical Agent Resistant Coating (CARC) System Application Procedures and Quality Control Inspection*[4] specifications are met, then these specifications will be revised to allow laser ablation to be performed on Army hardware. This program will rely on a battery of standard tests from these specifications to demonstrate the effectiveness of laser ablation on these substrates while also determining if there are any detrimental, unseen effects to subsequent coatings application and adhesion. Testing will consist of visual comparisons using Society for Protective Coating (SSPC)/National Association of Corrosion Engineers International (NACE) standards SP5,[5] SP10,[6] and VIS-3[7]; surface cleanliness and contamination testing; repaintability/adhesion testing; and both laboratory and real-world corrosion testing.

The recent successes[*] in demonstrations and implementations by the USAF has created interest in and around the U.S. Army to allow laser ablation to be used as a cleaning method on ground vehicle systems for coatings and rust removal. To facilitate this, a study of the effectiveness of laser ablation on representative panels and parts is needed.

2. Focus of Effort

Test coupons of 4- × 6-inch 2024 aluminum, CRS, and HHA were cleaned and primed, primed and top coated, or primed and double top coated with CARC paint at the U.S. Army Combat Capabilities Development Command Army Research Laboratory in Aberdeen, Maryland. The CARC primer used in this process was MIL-DTL-53022[8] Type IV (Figure 1), and the CARC topcoats were MIL-DTL-53039[9] Type VI. The first topcoat color used was Brown and the second topcoat color used was Green 383.[10] MIL-DTL-53072,[4] the main specification for CARC primer and topcoat application, was followed for all coating applications.

[*] Use of handheld lasers for corrosion and coating removal and surface pretreatment.

Figure 1. Test panels being coated with primer.

Another set of test samples of the same substrates were corroded for 24, 72, and 168 h to establish samples displaying "light," "medium," and "heavy" grades of corrosion in ASTM B117[11] neutral salt fog chambers. The matrix for this program is in Table 1.

Table 1. Test matrix.

Material	Coated samples			Bare samples		
	Primer MIL-DTL-53022 TIV	+Top coat 1 MIL-DTL-53039 TVI	+Top coat 2 MIL-DTL-53039 TVI	Light corrosion	Medium corrosion	Heavy corrosion
AA2024	5	5	5	1	2	2
CRS	5	5	5	1	2	2
HHA	5	5	5	1	2	2

Test samples were sent to the Penn State University Applied Research Laboratory (PSU ARL) to undergo laser ablation. PSU ARL used an Adapt CL-300, 300-W, laser to ablate the coatings and corrosion from each test sample. PSU ARL ran an optimization process using extra panels provided by DEVCOM Army Research Laboratory to establish the optimum operating parameters for the CARC system. By using a pulse intensity of 1 kHz and a spot size of 685 µm with a 65% overlap, a removal rate of 8.6 cm^2/s was established for 1-mil of coating. This can be extrapolated to show that a similarly set up 1000-W laser could remove 23.8 cm^2/s per pass to remove 3–4 mil of coating thickness. The stripping time for a 4- × 6-inch panel bearing both primer and topcoat took four passes and 72 s to fully remove the coating to the substrate using the 300-W laser. This would only require 6.5 s per panel when using a 1000-W laser. Upon completion of coating and corrosion ablation, the panels were wrapped in Vapor Corrosion Inhibitor paper and placed in individually labeled bags to be shipped back to ARL for additional testing and processing.

Upon return to ARL, the panels were inspected visually in accordance with the visual standard for cleanliness, SSPC-VIS 3, as called for in TT-C-490.[3] The panels that were previously coated with CARC all easily met these criteria (Figure 2). The panels that were previously corroded, particularly the steel panels, did have corrosion dust all over the surfaces that needed to be wiped off. Since only the front surface of the panels was ablated, this left corrosion on the sides and backs of the panels to contaminate the fronts during shipment back in bags. However, the dust did not preclude the visual assessment from being performed and these panels were cleaned to the base substrate.

Figure 2. **Representative ablated samples (left to right: AA2024, CRS, and HHA).**

Surface conductivity measurements were made using a Positector with a soluble salt tester (SST) probe on each ablated panel. A base measurement was made in the untouched deionized (DI) water before testing each set of panels to limit the potential for contamination. Conductivity measurements in excess of 70 μS/cm constituted failure. The color-coded results of these tests are given in Table 2, where green is a pass, yellow is a marginal failure, and red is failure.

Table 2. Surface conductivity results.

baseline		163					183					189				
AP	1	133	30		CP	1	160	23		HP	1	206	17			
	2	152	11			2	204	21			2	206	17			
	3	147	16			3	207	24			3	208	19			
	4	204	41			4	204	21			4	206	17			
	5	200	37			5	206	23			5	207	18			
baseline		197					201					202				
AT	1	210	13		CT	1	205	4		HT	1	206	4			
	2	206	9			2	175	26			2	206	4			
	3	208	11			3	192	9			3	208	6			
	4	210	13			4	204	3			4	207	5			
	5	210	13			5	202	1			5	208	6			
baseline		200					204					197				
ATT	1	181	19		CTT	1	188	16		HTT	1	207	10			
	2	178	22			2	204	0			2	207	10			
	3	207	7			3	179	25			3	206	9			
	4	209	9			4	204	0			4	206	9			
	5	210	10			5	195	9			5	207	10			
baseline		204					180					186		205	Rinsed	
Al light	1	168	36		CRS light	1	204	24		HHA light	1	281	84	219	14	
Al med	1	188	16		CRS med	1	292	112		HHA med	1	237	40	203	2	
Al med	2	206	2		CRS med	2	260	80		HHA med	2	301	104	292	87	
Al heavy	1	208	4		CRS heavy	1	384	204		HHA med	3	237	40	289	84	
Al heavy	2	209	5		CRS heavy	2	230	50		HHA med	4	279	82	224	19	
										HHA heavy	1	477	280	323	118	
										HHA heavy	2	424	227	290	85	
										HHA - very low SE, surface would not wet						

As Table 2 shows, there was no evidence of surface contamination on any of the samples coated with CARC (the top three sets of rows). The bottom rows in the chart are the corroded samples. These were initially tested without wiping off any of the dusty corrosion product that had spread around inside the bags in which the panels were shipped. This proved fine for the aluminum panels, but the corrosion products proved to have more of a detrimental effect on the steel substrates. A quick wipe proved effective in bringing the surface contamination measurements significantly down, but there were still several marginal failures remaining. To correct for this unintentional contamination that occurred during shipping, which would not be typical of any coatings process to include laser ablation as a cleaning method, the surface conductivity measurements will be done immediately following the laser ablation in the demonstration phase of this program and all sides of the parts will be ablated of corrosion/coatings.

Following these assessments for cleanliness and surface contamination, the panels were again recoated with CARC. Most panels were primed with MIL-DTL-53022 TIV.

To create a worst-case scenario, the panels initially used for the corrosion portion of the laser ablation assessment were selected to be used for coating adhesion given that they would generally be expected to perform worse than one of the more pristine-appearing panels from the coatings-only ablations. Crosshatch adhesion testing was performed with a claw-style adhesion tester and consisted of two intersecting sets of six scribe lines at 2-mm spacing. Six crosshatch tests were performed per panel, and the ratings were averaged. The results are given in Table 3 with examples shown in Figure 3. The requirements for adhesion as per TT-C-490[3] is a rating greater than or equal to 4. Given these requirements, all substrates tested performed as required by TT-C-490,[3] even in a worst-case scenario.

Table 3. Crosshatch adhesion results.

Substrate	1	2	3	4	5	6	Avg	
Al l	5	5	5	5	5	5	5	
Al m1	5	5	5	5	5	5	5	
Al m2	5	5	5	5	5	5	5	5
Al h1	5	5	5	5	5	5	5	
Al h2	5	5	5	5	5	5	5	
CRS l	5	5	5	5	5	5	5	
CRS m1	5	4	5	4	4	3	4.166667	
CRS m2	3	4	4	4	4	4	3.933333	4.233333
CRS h1	4	5	4	4	4	4	4.166667	
CRS h2	4	4	4	4	3	5	4	
HHA l	4	4	4	4	4	4	4	
HHA m1	5	5	5	5	4	5	4.833333	
HHA m2	4	5	4	4	4	4	4.166667	4.066667
HHA h1	4	4	3	3	4	3	3.5	
HHA h2	4	4	4	3	4	4	3.833333	

Notes: Al = aluminum, l = light corrosion, m = medium, and h = heavy

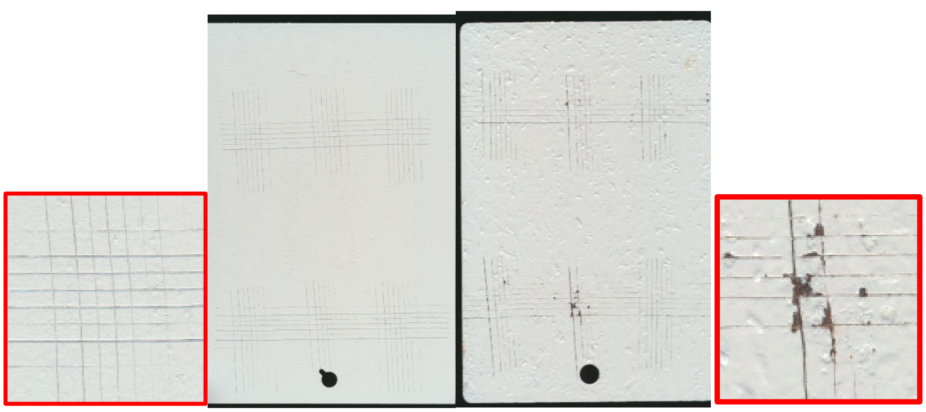

Figure 3. Crosshatch adhesion on AA2024 (left) and CRS (right).

Cyclic corrosion testing was performed in accordance with GMW14872.[12] One set of each substrate primed with MIL-DTL-53022 TIV were X-scribed and placed in printed circuit board (PCB) racks at a 15° angle and rated every 10 cycles for a duration of 30 cycles. Ratings were performed in accordance with ASTM D1654.[13] The requirements for scribe creep in cyclic corrosion as per TT-C-490[3] are ratings greater than or equal to 7. As such, there were no failures in cyclic corrosion, as shown in Table 4. Examples of each substrate are given in Figure 4.

Table 4. Cyclic corrosion results.

Manufacturer		N/A			**Test Method**		GMW14872										
Product		Laser ablation			**Product Details**												
Customer		DLA			**Coating System**		Laser ablated substrate, MIL-DTL-53022 Type IV primer										
	Scale:		**10**	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**0**				
	Steel		<------------------------PASS------------------------>					<------------------------------FAIL------------------------------>									
	Aluminum		<------------PASS------------>			<--------------------------------------FAIL-------------------------------------->											
Creep from Scribe		**#**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**Avg**	**Rating**	**Rating Avg**
	Al	**1**	3	1	4	3	4	6	5	7	6	0	4	0	1.791667	**7**	**7.4**
		2	3	4	4	2	0	0	1	3	3	3	3	0	1.083333	**7**	
		3	2	2	0	0	0	0	2	3	2	1	4	0	0.666667	**8**	
		4	2	2	0	2	0	0	0	2	2	1	0	0	0.458333	**8**	
		5	1	6	0	2	3	0	4	0	1	0	2	5	1	**7**	
	CRS	**1**	4	3	3	4	4	3	3	4	3	4	4	4	1.791667	**7**	**7.2**
		2	3	5	4	4	4	5	4	4	3	4	3	3	1.916667	**7**	
		3	4	2	4	5	4	5	2	3	3	2	3	3	1.666667	**7**	
		4	6	2	3	3	5	3	1	2	1	2	3	2	1.375	**7**	
		5	4	1	2	2	3	1	2	1	1	2	2	2	0.958333	**8**	
	HHA	**1**	4	1	2	1	4	3	2	2	2	3	2	3	1.208333	**7**	**7.25**
		2	3	2	2	2	2	2	2	2	2	3	2	3	1.125	**7**	
		3	2	2	2	2	2	2	2	2	2	2	2	2	1	**7**	
		4	1	2	1	1	1	1	1	1	1	3	3	3	0.791667	**8**	
		5															

Figure 4. Representative samples from cyclic corrosion; AA2024 (left), CRS (center), and HHA (right).

Neutral salt fog testing was performed in accordance with ASTM B117. One set of each substrate primed with MIL-DTL-53022 TIV were X-scribed and placed in PCB racks at a 15° angle and rated every 336 h for a duration of 1008 h. Ratings were performed in accordance with ASTM D1654. The requirements for scribe creep in neutral salt fog corrosion as per TT-C-490[3] are ratings greater than or equal to 6 for steel substrates and 8 for aluminum substrates. These results, all passing, are shown in Table 5. No blistering was observed (all ratings 10). Examples of each substrate are given in Figure 5.

Table 5. Neutral salt fog results.

Manufacturer	N/A				**Test Method**		ASTM B117										
Product	Laser ablation				**Product Details**												
Customer	DLA				**Coating System**		Laser ablated substrate, MIL-DTL-53022 Type IV primer										
	Scale:		**10**	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**0**				
	Steel		<---------------------------PASS--------------------------->					<--------------------------------FAIL----------------------------------->									
	Aluminum		<--------------PASS--------------->			<---FAIL--->											
Creep from Scribe		**#**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**Avg**	**Rating**	**Rating Avg**
	Al	**1**	0	3	0	1	0	0	2	2	1	0	0	0	0.375	**9**	**8.6**
		2	0	2	2	1	1	2	3	2	0	3	1	0	0.708333	**8**	
		3	2	2	0	0	0	0	1	2	0	0	0	3	0.416667	**9**	
		4	0	0	3	0	0	2	2	0	1	3	2	1	0.583333	**8**	
		5	0	0	0	0	1	0	1	0	3	2	2	0	0.375	**9**	
	CRS	**1**	1	2	2	1	4	3	7	3	3	4	2	2	1.416667	**7**	**7.2**
		2	2	3	2	3	5	5	3	2	2	3	2	3	1.458333	**7**	
		3	1	1	1	2	2	2	3	1	1	1	3	2	0.833333	**8**	
		4	2	2	3	4	3	4	3	3	2	3	2	3	1.416667	**7**	
		5	2	1	1	2	4	5	1	1	1	6	4	3	1.291667	**7**	
	HHA	**1**	3	4	4	4	4	5	3	4	4	4	3	3	1.875	**7**	**6.5**
		2	3	6	3	4	4	3	3	4	3	4	5	3	1.875	**7**	
		3	3	4	2	3	5	4	4	6	4	6	5	3	2.041667	**6**	
		4	3	4	6	4	3	5	7	5	5	3	5	3	2.208333	**6**	
		5	4	4	3	6	6	5	4	3	5	8	4	4	2.333333	6	

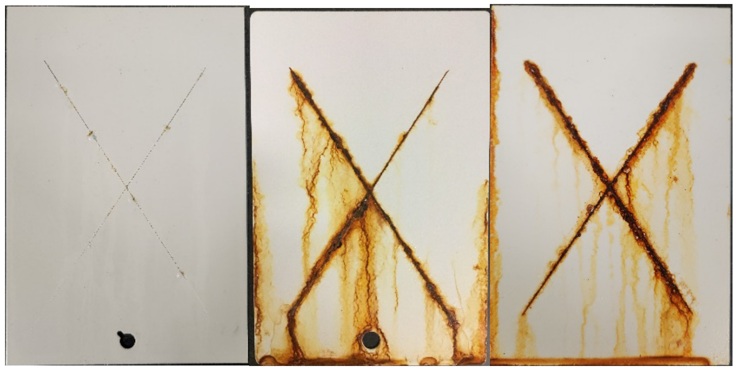

Figure 5. Representative samples from salt fog corrosion; AA2024 (left), CRS (center), and HHA (right).

Outdoor exposure testing began in December 2022 following two failed deployments in September due to extreme weather. Outdoor testing was completed in December 2024, with panels receiving their final evaluations on December 3, 2024. The results are shown in Table 6 with representative samples shown in Figure 6. No failures were observed on any substrate tested, either in terms of corrosion creep from scribe or blistering in field. As expected, the mill finish surface profile of the CRS samples was more susceptible to corrosion than the rougher surface profile imparted by the abrasive blast to HHA steel samples. The minimum acceptable rating of 6 for steel was exceeded by both CRS and HHA. Three of the five aluminum samples observed were nearly perfect in terms of corrosion inhibition after 2 years exposure.

Table 6. Outdoor exposure results at 24 months.

Manufacturer		N/A			**Test Method**		Outdoor										
Product		Laser ablation			**Product Details**												
Customer		DLA			**Coating System**		Laser ablated substrate, MIL-DTL-53022 Type IV primer, MIL-DTL-53039 Type VI topcoat (Brown)										
	Scale:		**10**	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**0**				
	Steel		<--------------------------PASS-------------------------->					<-------------------------------FAIL--------------------------------->									
	Aluminum		<--------------PASS-------------->			<--FAIL-->											
Creep from Scribe		**#**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**Avg**	**Rating**	**Rating Avg**
	Al	**1**	0	0	0	0	0	0	0	0	0	0	0	0	0	**10**	
		2	0	0	6	4	0	0	0	0	0	0	0	0	0.416667	**9**	
		3	6	0	0	0	0	0	0	0	0	0	0	0	0.25	**9**	**9.6**
		4	0	0	0	0	0	0	0	0	0	0	0	0	0	**10**	
		5	0	0	0	0	0	0	0	0	0	0	0	0	0	**10**	
	CRS	**1**	3	2	3	3	4	3	3	2	2	3	3	2	1.375	**7**	
		2	2	5	5	4	3	5	3	2	2	3	3	2	1.625	**7**	
		3	2	3	2	3	4	3	2	3	2	2	2	2	1.25	**7**	**7**
		4	2	2	2	2	3	5	2	2	2	2	2	3	1.208333	**7**	
		5	2	2	3	3	0	2	3	2	3	2	2	2	1.083333	**7**	
	HHA	**1**	0	0	1	0	1	0	0	0	0	0	0	0	0.083333	**9**	
		2	0	0	0	0	0	0	0	0	0	0	0	0	0	**10**	
		3	0	0	1	0	0	1	0	0	0	0	0	0	0.083333	**9**	**9.25**
		4	0	0	0	0	1	2	0	0	0	0	2	2	0.291667	**9**	
		5	0	0	0	0	0	2	0	0	0	1	0	1	0.166667	**9**	

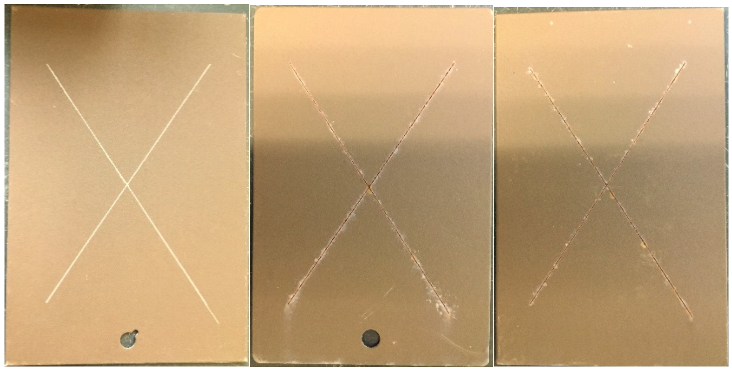

Figure 6. Representative samples from outdoor corrosion; AA2024 (left), CRS (center), HHA (right) at 24 months.

Finally, a selection of Beyond Economic Repair (BER) aviation parts were obtained from Corpus Christi Army Depot (CCAD):

- UH-60 tail rotor gearbox inboard retention plate (1), P/N 70358-06612-042, titanium 6AL-4V, two coats of CARC MIL-PRF-22750[14] (Figure 7)
- AH-64 main rotor head bearing retainer (2), 7-311411207, aluminum, one coat of CARC MIL-DTL-53039 (Figure 8)
- AH-64 main rotor head nut retention bracket (2), 7-114111016, CRES 301 steel, one coat of CARC MIL-DTL-53039 (Figure 9)

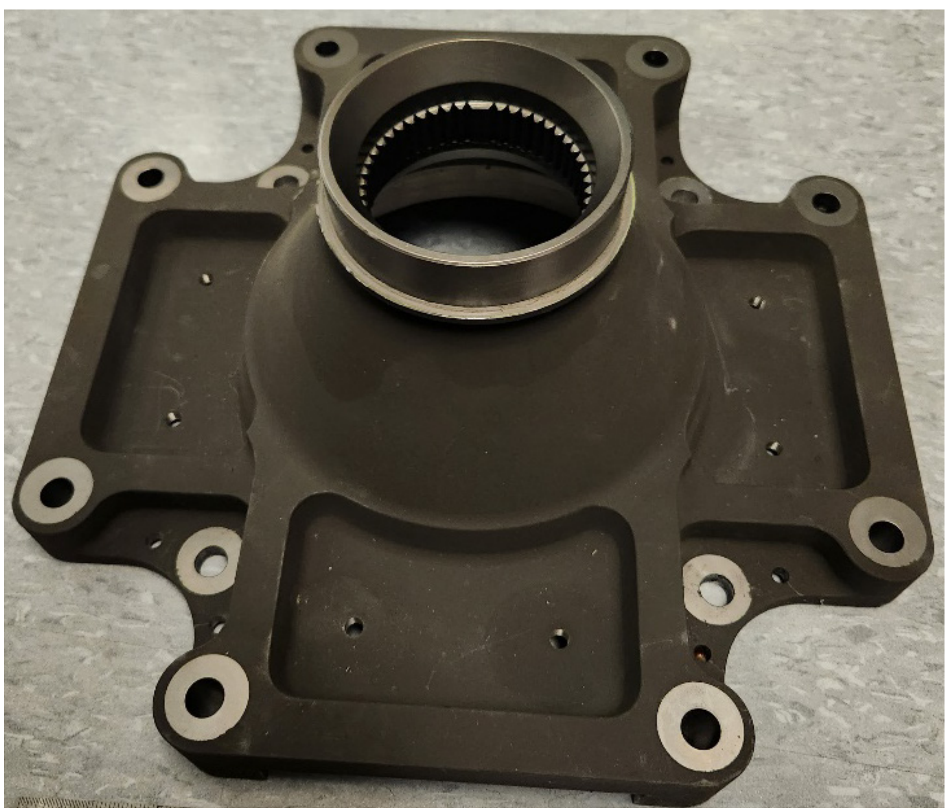

Figure 7. UH-60 tail rotor gearbox, as received.

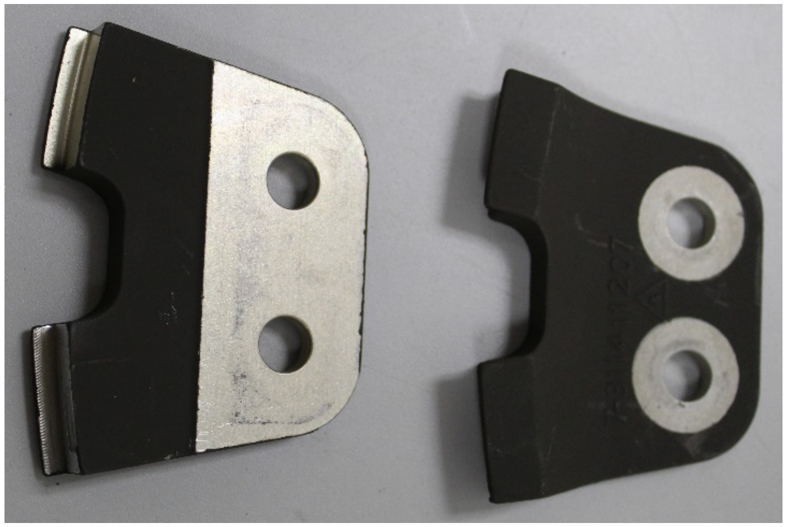

Figure 8. AH-64 main rotor head bearing retainers, as received.

Figure 9. AH-64 main rotor head nut retention brackets, as received.

These parts, along with a steel M1 fuel cap (Figure 10) to represent ground vehicle systems, were subjected to laser ablation and recoating to further validate the efficacy of laser ablation as a cleaning system over parts with complex geometries within the constraints of TT-C-490.[3]

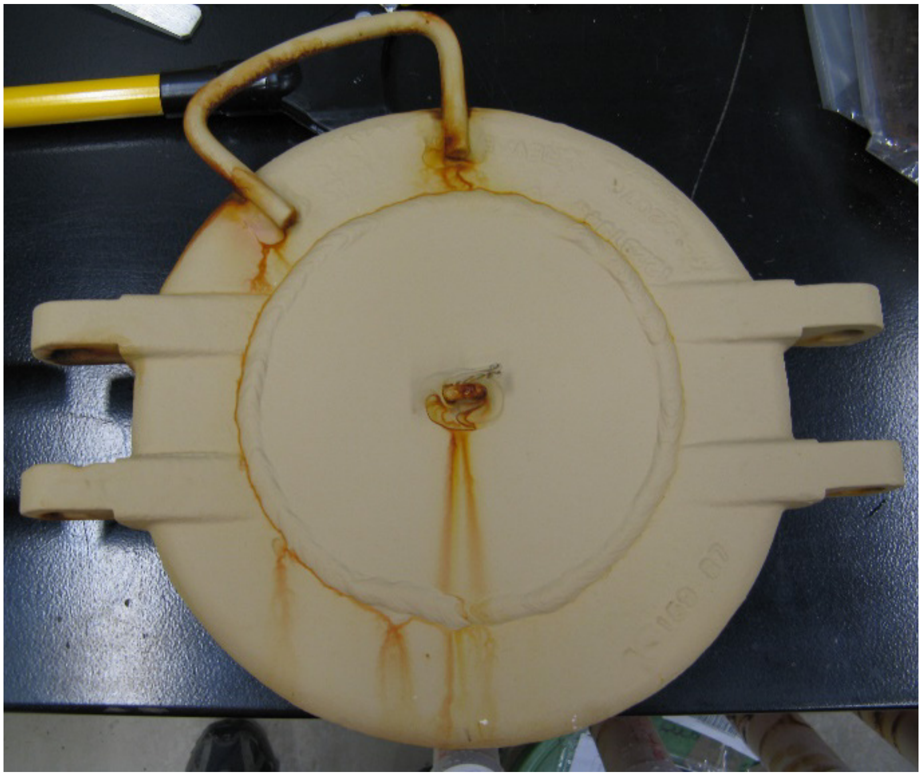

Figure 10. Steel M1 fuel cap prior to ablation.

The demonstration was held at PSU ARL using an Adapt 500-W handheld laser (HHL). Optimization was first performed on the M1 fuel cap. Initially set for 26 kHz, the extreme coating thickness (ranging from 11 to 22 mil) of the fuel cap required changing to 18 kHz as well as adjusting the overlap width from 50% to 65% to efficiently remove the paint. The initial settings left some bluing on the cap, but the adjusted settings rectified this issue. The top, the flatter of the two sides, took about an hour to ablate with the HHL. The bottom side has a large, recessed area encircling the outer rim of the fuel cap (Figure 11), which required much contortion of the HHL operator and took approximately an additional hour to completely ablate. It is estimated that with a 1000-W laser, this process could be done 1.5× quicker and could be further improved upon with the use of robotics.

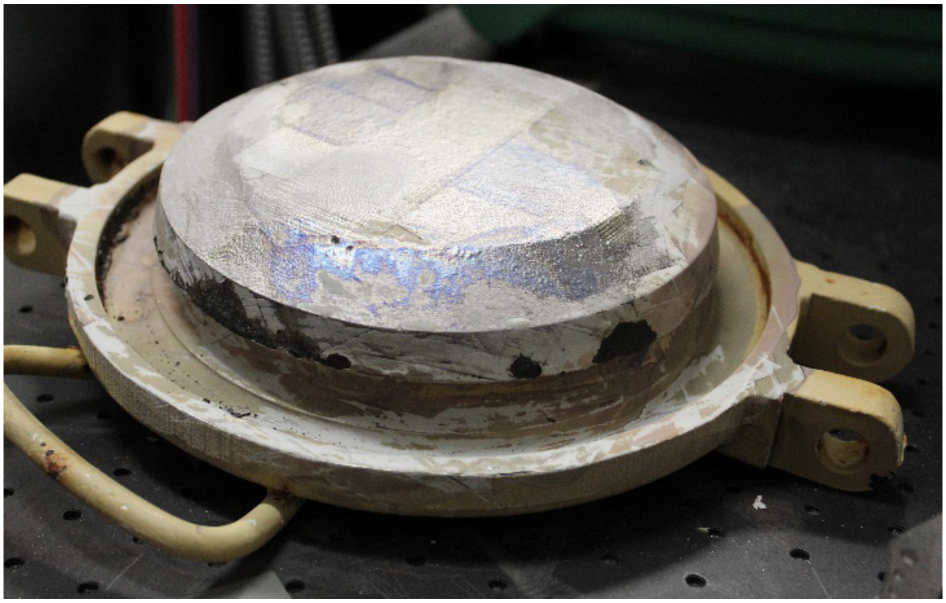

Figure 11. Bottom of fuel cap showing recessed area (mid ablation).

The settings had to be adjusted when moving to the aluminum and titanium items with the much thinner coating films. The beam was narrowed and power adjusted to 28 kHz, the idea being that fewer pulses gives each one more power. This resulted in the coating blowing off the part in sheets as it was ablated. The entire rotor mount, much larger than the fuel cap, only took 25 min from start to finish to fully ablate to pristine condition (Figure 12).

Figure 12. UH-60 tail rotor gearbox following ablation.

The sets of retainers and brackets ablated just as quickly, taking only 7 min in total for both sides of all four items to be ablated. Their images are shown in Figures 13 and 14.

Figure 13. AH-64 main rotor head bearing retainers following ablation.

Figure 14. AH-64 main rotor head nut retention brackets following ablation.

Following the completion of the ablation procedure, the parts were assessed for contamination prior to recoating operations at ARL. The process for surface contamination was the same as previously performed, using the same Positector unit with SST probe and measured versus virgin DI water. A difference of more than 70 µS/cm constitutes failure. No failures were observed. The color-coded results are given in Table 7.

Table 7. Surface contamination vs. DI water.

Conductivity Δ µS/cm			
UH-60 rotor	**AH-64 retainer**	**AH-64 bracket**	**M1 fuel cap**
4	2	26	5
4	1	7	3
8	4	5	2
6	5	10	6
4			1
7			1
4			11
7			4

The parts were then recoated at ARL in accordance with MIL-DTL-53072.[4] Primer used was again MIL-DTL-53022 Type IV; however, no topcoat was applied in this instance since the parts would only be exposed in ASTM B117 neutral salt fog testing. Again, no pretreatments were applied to keep the testing similar to the panels and the inclusion of a titanium substrate would complicate the selection process. After recoating and a 168-h air cure, the parts were placed again into ASTM B117 for 1008 h. Parts were evaluated unscribed for visual performance and coating adhesion versus previous testing. The UH-60 tail rotor gearbox (Figure 15) exhibited no signs of coating delamination nor corrosion (as to be expected from a titanium item) and came out in pristine condition. The AH-64 main rotor head bearing retainers (Figure 16) and rotor head nut retention brackets (Figure 17) performed similarly, with no visual corrosion or coating delamination. The steel M1 fuel cap with only primer performed similarly to an abrasive blasted fuel cap with a full coating stack up (Figure 18). Both caps had corrosion evident along the handle and from the faying surfaces, as well as the hinge holes. Interestingly, the ablated and primed fuel cap had almost no corrosion on the underside, whereas the abrasive blasted and pretreated, primed and top-coated fuel cap had significant corrosion on the underside recessed areas. Much of the orange coloration seen in Figure 19 is staining from above and along the grid pattern that was the bottom of the racking it was exposed on.

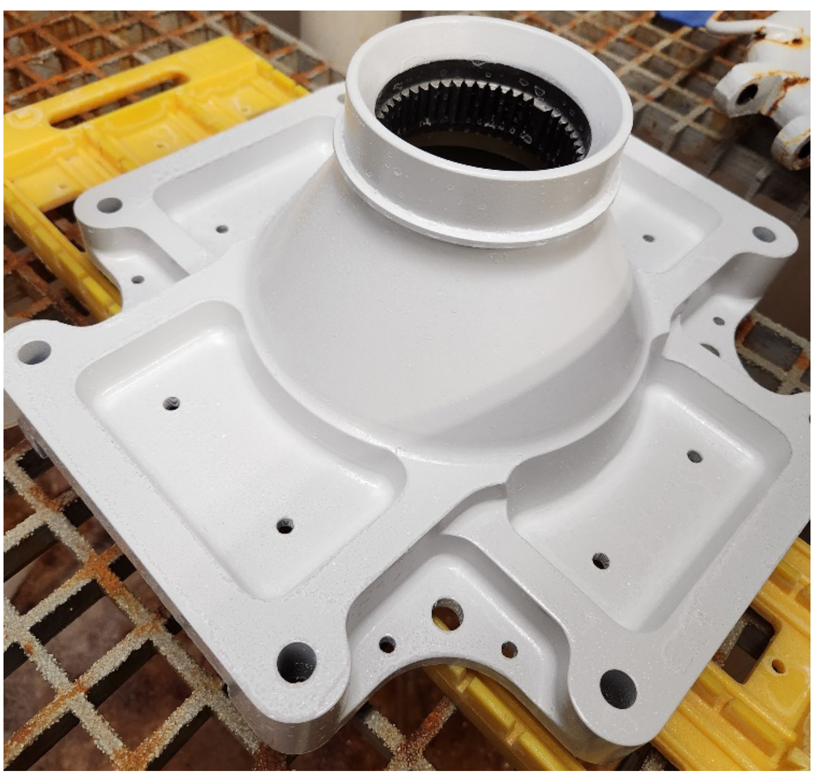

Figure 15. UH-60 tail rotor gearbox at 1008 h (ASTM B117).

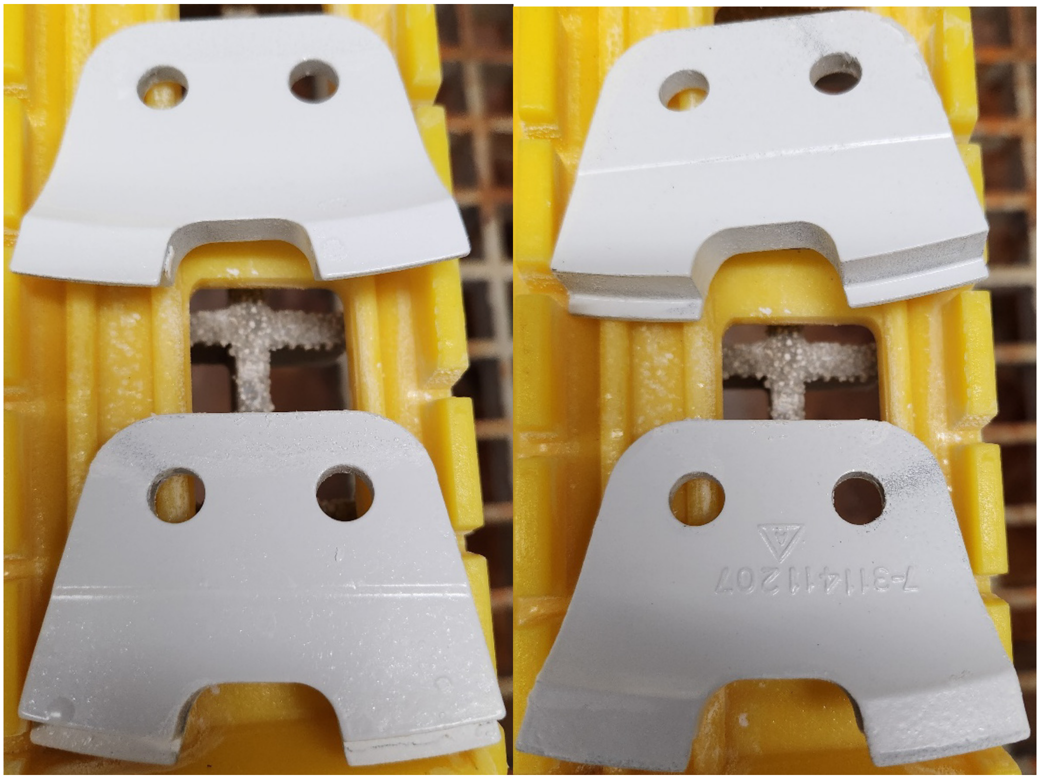

Figure 16. AH-64 main rotor head bearing retainers at 1008 h (ASTM B117).

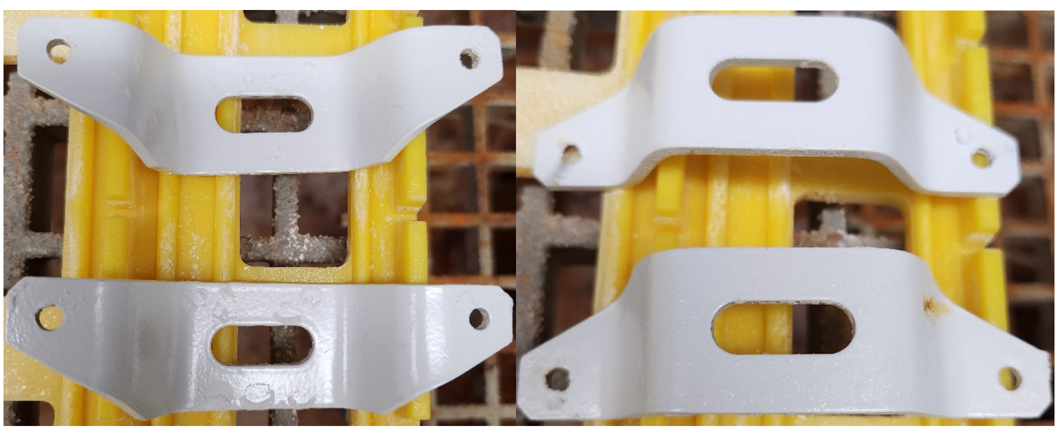

Figure 17. AH-64 main rotor head nut retention brackets at 1008 h (ASTM B117).

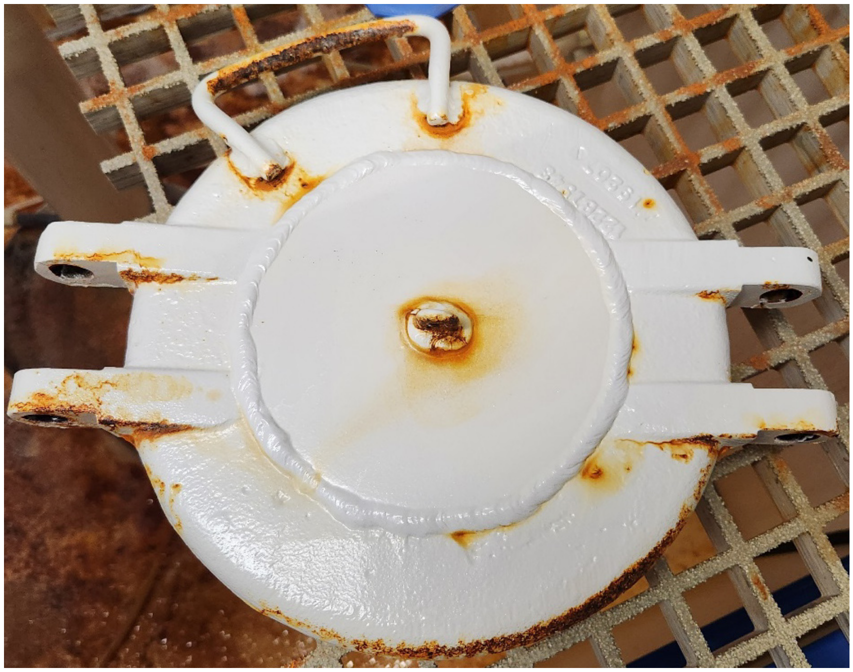

Figure 18. Steel M1 fuel cap at 1008 h (ASTM B117) (top).

Figure 19. Steel M1 fuel cap at 1008 h (ASTM B117) (bottom).

3. Conclusions

The results demonstrated from laboratory testing on curated panels that laser ablation is a viable cleaning method within the framework of TT-C-490.[3] The lone outlier, the surface conductivity and cleanliness testing done on the corroded samples, was due to a sub-optimum process approach that was a result of having to ship panels (which were only ablated on one side) from the laser to the coating-application site. The remaining corrosive product dust was allowed to move about the bag containing each individual panel during shipping and contaminated the surfaces. Even with this accrued contamination, a simple wipe was all that was necessary to get the panels close to conformance, and the panels met all adhesion requirements in TT-C-490[3] when recoated. This conformance was verified during the parts demonstration, where the surface contamination measured never exceeded 26 µS/cm, well under the allowed 70 µS/cm. Following 24 months of outdoor exposure, both the high hard and aluminum panels continue to rate higher than 9, with the CRS panels still passing with 7's. The laboratory and outdoor assessments, combined with the results from the demonstration and further exposures, have given ARL enough supporting data to revise TT-C-490[3] to include full approval for laser ablation as a cleaning method. Several depots, including Letterkenny Army Depot and CCAD, have begun implementing laser ablation in their procedures. This means decreased hazardous waste generation, labor man hours dedicated to cleaning and masking, costs dedicated to personal protective equipment, and an overall increase in health and safety where ablation is used. Between the two depots, they estimate cost savings of $279,000 per year. Extrapolated out, a projected return on investment would occur in 17 months when implemented by these depots but could happen in as soon as 4 months if implemented across every Army depot.

3.1 Deliverables

The deliverables were as follows:

- Test panel procurement and processing (complete)
- Laser ablation of test panels (complete)
- Test panel reprocessing (complete)
- Laboratory and outdoor testing of reprocessed test panels (complete)
- Demonstration of laser ablation on air and ground vehicle parts (complete)
- Vehicle part reprocessing (complete)
- Laboratory testing of reprocessed parts (complete)
- TT-C-490[3] revision for inclusion of unrestricted laser ablation (complete)
- Final report (complete)

3.2 Path Forward

With the revision to TT-C-490[3] to include laser ablation as a new, unrestricted cleaning method, it allowed ARL to update MIL-DTL-53072[4] to include laser ablation as well. This covers every aspect of the CARC system, from cleaning and pretreatments through priming and topcoating. Letterkenny and CCAD are already using laser ablation at their facilities for both aviation and ground support equipment and operating at a net savings. ARL has approached other depots and coatings applicators and has gained several additional interested parties for further adoption of laser ablation. With the adoption rate of this technology on the rise, we expect to see the amount of hazardous waste at these facilities continue to drop, especially as the technology itself continues to develop and become more powerful.

3.3 Key Personnel

Key personnel for this project are included in Table 8.

Table 8. Key personnel.

Contact	Organization	E-mail	Role
Tom Considine	ARL	thomas.a.considine.civ@army.mil	Project Lead
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William Lum	ARL	william.s.lum.civ@army.mil	Specification revision
Brian Placzankis	ARL	brian.e.placzankis.civ@army.mil	Specification revision
Zubin Dutia	AMCOM-G4 (Ctr)	zubin.a.dutia.ctr@army.mil	SME
Fernando Garcia	DEVCOM AvMC (Ctr)	fernando.garcia129.ctr@army.mil	SME
Mark Feathers	AMCOM-G4	mark.g.feathers.civ@army.mil	Sustainment
Maria Labuda	DLA AVN-VB	iris.labuda@dla.mil	Project Management
Andy Shaban	DLA AVN-VB	amad.shaban@dla.mil	Project Management
Fred Tramontin	DLA AVN-VB	fred.tramontin@dla.mil	Project Management

Notes: (U) Ctr = contractor; AMCOM = U.S. Army Aviation and Missile Command; AvMC = DEVCOM Aviation & Missile Center; DLA AVN-VB = DLA Aviation-Vendor Base; SME = subject matter expert

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List of Symbols, Abbreviations, and Acronyms

AA	aluminum alloy
ARL	Army Research Laboratory
ASTM	American Society for Testing and Materials
BER	Beyond Economic Repair
CARC	Chemical Agent Resistant Coatings
CCAD	Corpus Christi Army Depot
CRS	cold rolled steel
DEVCOM	U.S. Army Combat Capabilities Development Command
DI	deionized water
DLA AVN-VB	DLA Aviation-Vendor Base
DoD	Department of Defense
HHA	high hard armor
HHL	handheld laser
NACE	National Association of Corrosion Engineers International
PCB	printed circuit board
P/N	part no.
PSU ARL	Penn State University Applied Research Laboratory
SME	subject matter expert
SSPC	Society for Protective Coating
SST	soluble salt tester
USAF	United States Air Force

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