Engineering and Technical Services for Joint Group on Acquisition Pollution Prevention (JG-APP) Projects

Technology Survey

for Alternatives to High Volatile Organic Compound (VOC) Topcoats and Primers

October 31, 1997

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EXECUTIVE SUMMARY

Concurrent Technologies Corporation (*CTC*) was tasked to perform a technology survey to identify alternatives to high-VOC topcoats and primers used at Lockheed Martin Electronics & Missiles and Information Systems Companies in Orlando, Florida. Specifically, the reduction or elimination of methyl ethyl ketone (MEK), methyl isobutyl ketone (MIBK), toluene, and xylene is desired. The following eight categories of alternative coating materials and technologies were identified during the technology survey:

- High-solids coatings
- 100% solids liquid coatings
- Waterborne coatings
- Ion vapor deposition
- Powder coating
- Radiation-curable coatings
- Self-priming topcoats
- Supercritical carbon dioxide (CO_2) spraying

This report contains a description of the search strategy used to identify the alternative materials and technologies, a brief description of each identified alternative, and bibliographic citations of the relevant articles that were identified during literature searches.

1.0. INTRODUCTION

To identify alternatives to solventborne topcoats and primers, Concurrent Technologies Corporation (*CTC*) was tasked to perform a technology survey. Eight commercially available materials and technologies were identified, including high-solids coatings, 100% solids liquid coatings, waterborne coatings, ion vapor deposition, powder coating, radiation-curable coatings, self-priming topcoats, and supercritical CO_2 spraying.

Conventional paint formulations typically consist of finely divided pigment dispersed in a liquid composed of a resin (binder) and an organic solvent. The function of the solvent is to reduce paint viscosity and facilitate application by wetting the substrate surface and controlling the material flow and drying time of the paint. However, many organic solvents, that are used in conventional paints and primers such as MEK, MIBK, toluene, and xylene, are hazardous chemicals and are subject to environmental and worker protection regulations.

Lokheed Martin Electronics and Missiles and Information Systems Companies (Lockheed Martin) apply several military specification primers and topcoats that contain a high concentration of VOCs (greater than 3.5 lb/gal). Furthermore, some of the qualified products for these specifications contain MEK, MIBK, toluene, or xylene. Some of these MIL-SPEC coatings are as follows:

Primers:

- **MIL-P-23377G** (*High-Solids Epoxy Primer Coatings,* issued September 30, 1994)
- **MIL-P-53022B** (*Lead and Chromate Free Corrosion Inhibiting Epoxy Primer Coating*, issued June 1, 1988)
- **MIL-P-53030A** (*Lead and Chromate Free Water Reducible Epoxy Primer Coating*, issued August 20, 1992)

Topcoats:

- **MIL-C-22750F** (*High-Solids Epoxy Coating*, issued May 31, 1994)
- **MIL-C-46168D** (*Chemical Agent Resistant Aliphatic Polyurethane Coating*, issued May 21, 1993)
- **MIL-C-53039A** (*Chemical Agent Resistant Single-Component Aliphatic Polyurethane Coating*, issued May 19, 1993)
- **MIL-C-83286B** (*Aliphatic Isocyanate Urethane Coating for Aerospace Applications*, last amended January 21, 1994, canceled January 19, 1995)
- **MIL-C-85285B** (*High-Solids Polyurethane Coating*, issued October 22, 1990)
- **TT-C-542F** (*Moisture Curing Oil-Free Polyurethane Coating*, issued October 17, 1995)

- **TT-E-527D** (*Low VOC Content Lusterless Alkyd Enamel*, issued August 26, 1992)
- **TT-E-529G** (*Low VOC Content Semigloss Alkyd Enamel*, issued August 26, 1992)
- **TT-P-2756A** (*Low Volatile Organic Compound (VOC) Content Polyurethane Topcoat: Self-Priming Topcoat*, issued February 29, 1996)

Low-solvent or no-solvent primers and topcoats and alternative coating technologies are desired by Lockheed Martin due to the environmental, health, and safety issues associated with these military specification coatings. Alternative topcoats, primers, and coating technologies have the potential to reduce or eliminate VOC emissions and solvent wastes generated by conventional paints and painting technologies.

This report contains a description of the search strategy used to identify the initial list of technologies (Section 2.0), a brief description of the identified alternative technologies (Section 3.0), and the bibliographic citations of the relevant articles that were identified during literature searches (Section 4.0).

2.0. DESCRIPTION OF SEARCH

Among the information sources used to identify low-VOC or no-VOC topcoats, primers, and alternative coating technologies are database searches, internet searches, vendor contacts, *CTC* Information Resource Centers, and personal contacts.

Eleven main searches were performed on electronic databases. Seven of these searches were performed using DIALOG®, which has access to over 370 individual databases. DIALOG® databases contain over 260 million records, all of which are available using a variety of search strategies. The DIALOG® search strategies used to identify low-VOC topcoats and primers are named Search A through Search G and are provided in Tables 1 through 7.

The remaining four database searches were performed on the Air & Waste Management Association (AWMA) database (Search H), Environmental Protection Agency's Enviroene database (Search I), Department of Energy Pollution Prevention Information Clearinghouse (EPIC) database (Search J), and National Technology Transfer Center (NTTC) database (Search K). Searches H through K are described in Tables 8 through 11.

Table 1. Search A – DIALOG® Databases

Search Sequence	Search Term	Number of Matches
A1	organic	1,172,098
A2	coat?	777,189
A3	Search A1_Search A2	5,290
A4	paint?	110,052
A5	Search A3 *or* Search A4	114,204
A6	alternat?	502,254
A7	substitut?	440,881
A8	replac?	355,017
A9	Search A5 *within 5 words of* Search A6 *or* Search A7 *or* Search A8	1,022
A10	reduc?	1,950,806
A11	emission?	699,880
A12	Search A10 *within 2 words of* Search A11	25,316
A13	Search A9 *and* Search A12	34
	Applicable Articles	9

Within DIALOG®, the following databases contained relevant information for Search A:

- Chemical Business Newsbase (1984-1994)
- Chemical Engineering & Biotechnology Abstracts (1971-1994)
- Chemical Industry Notes (1974-1994)

- Chemical Safety Newsbase (1981-1994)
- Ei Compendex*Plus™ (1970-1994)
- Newsletter Database™ (1988-1994)

Table 2. Search B – DIALOG® Databases

Search Sequence	Search Term	Number of Matches
B1	coatings *and* reduc? *and* emissions *and* organic	19
	Applicable Articles	6

Table 3. Search C – DIALOG® Databases

Search Sequence	Search Term	Number of Matches
C1	organic *and* coating *and* (replac? *or* substitut? *or* alternative?)	62
	Applicable Articles	13

Table 4. Search D – DIALOG® Databases

Search Sequence	Search Term	Number of Matches
D1	coating?	665,844
D2	paint?	110,236
D3	Search D1 *or* Search D2	717,019
D4	complian?	99,270
D5	Search D3 *within 3 words of* Search D4	517
D6	*limit* Search D5 *to 1990-1994*	162
D7	*Printed first 50 abstracts*	50
	Applicable Articles	5

Within DIALOG®, the following databases contained relevant information for Search D:

- INSPEC (1969-1994)
- Enviroline® (1971-1994)
- Pollution Abstracts (1970-1994)
- Scisearch® (1974-1994)

Table 5. Search E – DIALOG® Databases

Search Sequence	Search Term	Number of Matches
E1	coating?	665,844
E2	paint?	110,236
E3	Search E1 *or* Search E2	717,019
E4	waterborne	6,340
E5	water	1,808,428
E6	borne	53,316
E7	Search E5 *and* Search E6	3,135
E8	high	3,935,476
E9	solids	421,028
E10	Search E8_Search E9	4,796
E11	Search E3 *and* (Search E4 *or* Search E7 *or* Search E10)	7,132
E12	*limit* Search E11 *to 1990-1994*	2,012
E13	*Printed first 50 abstracts*	50
	Applicable Articles	16

Within DIALOG®, the following databases contained relevant information for Search E:

- Enviroline® (1971-1994)
- Pollution Abstracts (1970-1994)
- Scisearch® (1974 - 1994)

Table 6. Search F – DIALOG® Databases

Search Sequence	Search Term	Number of Matches
F1	coating?	665,844
F2	paint?	110,236
F3	Search F1 *or* Search F2	717,019
F4	alternat?	503,407
F5	substitut?	441,458
F6	replac?	356,119
F7	solvent	337,942
F8	(Search F4 *or* Search F5 *or* Search F6) *within 5 words of* Search F7	5,552
F9	Search F3 *and* Search F8	698
F10	*limit* Search F9 *to 1990-1994*	332
F11	*Printed first 50 abstracts*	50
	Applicable Articles	9

Within DIALOG®, the following databases contained relevant information for Search F:

- Ei Compendex*Plus™ (1970-1994)
- Enviroline® (1971-1994)
- INSPEC (1969-1994)

- NTIS (1964-1994)
- Pollution Abstracts (1970-1994)
- Scisearch® (1974-1994)

Table 7. Search G – DIALOG® Databases

Search Sequence	Search Term	Number of Matches
G1	low	1,176,501
G2	no	817,797
G3	volatile	27,823
G4	organic	324,572
G5	compound?	1,165,051
G6	chemical?	760,955
G7	Search G3_Search G4_(Search G5 *or* Search G6)	6,130
G8	VOC	2,582
G9	coat?	226,745
G10	primer?	8,248
G11	(Search G1 *or* Search G2) *within 3 words of* (Search G7 *or* Search G8) *and* (Search G9 *or* Search G10)	138
G12	*Remove duplicates in* Search G11	118
G13	*Limit* Search G12 *to 1980-1996*	113
G14	Search G13 *and not* canceled	113
G15	*Limit* Search G14 *to English only*	113
G16	Applicable Articles	74
G17	waterborne	1,666
G18	Search G17_(Search G9 *or* Search G10)	156
G19	*Requested that* Search G18 *terms should be in the title*	68
G20	*Remove duplicates within* Search G19	65
G21	*Compare* Search G15 *to* Search G20 *and remove duplicates*	63
G22	*Limit* Search G21 *to English only*	59
G23	*Limit* Search G22 *to 1980-1996*	51
G24	Search G23 *and not* canceled	51
G25	Applicable Articles	26
	Total Applicable Articles	100

Within DIALOG®, the following databases contained relevant information for Search G:

- Aerospace Database (1962-1996)
- Ei Compendex*Plus™ (1970-1996)
- Federal Research in Progress (1996)
- IHS International Standard and Specifications (1996)
- INSPEC (1969-1996)
- NTIS (1964-1996)

Table 8. Search H – AWMA Database

Search Sequence	Search Term	Number of Matches
H1	paint *or* alternative	13
	Applicable Articles	0

Table 9. Search I – EPA Enviroene Database

Search Sequence	Search Term	Number of Matches
I1	22750 *or* 46168 *or* 83286 *or* 23377	2
I2	paint *and* alternative	509
I3	Search I2 *and not* (clean *or* strip)	5
	Applicable Articles	2

Table 10. Search J – EPIC Database

Search Sequence	Search Term	Number of Matches
J1	paint *and* alternative	36
	Applicable Articles	18
	Downloaded Articles	7

Table 11. Search K - NTTC Database

Search Sequence	Search Term	Number of Matches
K1	paint?	74
K2	alternative?	276
K3	Search J1 *and* Search J2	6
	Applicable Articles	1

The bibliographic citations of the relevant articles from searches A13, B1, C1, D7, E13, F11, G16, G25, and J1 are provided in Section 4.0.

In addition to the database searches, internet sources were scanned with search engines such as InfoSeek, Lycos, Savvy Search, Web Crawler, and Yahoo. Search strategies on these search engines are provided below. The actual syntax for performing searches varies for each search engine, so Boolean search descriptors are listed for simplicity:

- 22750 *or* 23377 *or* 83286 *or* 46168 *or* 85285 *or* 85582
- paint alternative
- primer alternative
- waterborne paint
- high solids

3.0. IDENTIFIED ALTERNATIVE TECHNOLOGIES

Several potential low-VOC or no-VOC primers and topcoats and alternative coating technologies are currently available. These alternatives may generate less hazardous waste and have fewer health and safety risks than current high-VOC topcoats and primers that contain Hazardous Materials (HazMats). Identified alternatives for high-VOC primers and topcoats include:

Alternative	Topcoat	Primer	Section
High-Solids Coatings	X	X	3.1
MIL-C-53039A	X		3.1.1
MIL-C-85285B	X		3.1.2
MIL-P-53022B Type II		X	3.1.3
100% Solids Liquid Coatings	X	X	3.2
Waterborne Coatings	X	X	3.3
MIL-P-85582B		X	3.3.1
Ion Vapor Deposition		X	3.4
Powder Coating	X	X	3.5
High Gloss CARC Epoxy Powder	X		3.5.1
Airborne Weapon Epoxy Powder	X	X	3.5.2
Radiation-Curable Coatings	X		3.6
Self-Priming Topcoat (Unicoat)	X		3.7
TT-P-2756A	X		3.7.1
Supercritical CO_2 Spraying	X	X	3.8

3.1. High-Solids Coatings

Conventional solventborne paints typically contain 8 to 30 percent solids. High-solids paints contain an increased amount of non-volatiles, resulting in formulations that range from 40 to nearly 100 percent solids. These paint formulations use low-molecular-weight resins (500 to 2,000 as compared to 20,000 for conventional resins), which require less solvent to attain the desired application viscosity. These resins have highly reactive sites to aid in coating polymerization. High-solids paints may be one- component or two-component systems based on acrylic, alkyd, epoxy, polyester, or urethane resins. High-solids coatings can be cured in conditions ranging from ambient air dry to a high-temperature bake (above 180°C [350°F]).

The reduced solvent content in high-solids coatings presents some potential difficulties. Surface preparation is more critical because oils, greases, and other surface contaminants normally dissolved by solvents in conventional formulations may affect paint adhesion. Although some high-solids paints may be applied by conventional application techniques (e.g., air spraying, curtain coating, dip coating, electrostatic spraying, or flow coating), special equipment may be required for others, especially those approaching 100 percent solids. For high-viscosity materials, it may be necessary to heat the paint to maintain a workable paint consistency, increase the pressure in spray applications, or use two-component formulations and plural component equipment that meters and mixes the materials at the spray gun. Since thicker coatings do not blend as well as thinner coatings, color matching may be more complicated. In addition, the reduced solvent content may make clean-up more difficult.

3.1.1. MIL-C-53039A (Chemical Agent Resistant Single-Component Aliphatic Polyurethane Coating)

MIL-C-53039A, a one-component aliphatic polyurethane epoxy chemical agent resistant coating (CARC), is a potential alternative to MIL-C-46168D, a two-component aliphatic polyurethane CARC. MIL-C-46168D is currently applied for at least six programs at Lockheed Martin, including Comanche, Javelin, Longbow FCR, Longbow Missile, TADS, and PNVS.

Laboratory testing of the two CARC paints (MIL-C-53039A and MIL-C-46168D) has been conducted by Lockheed Martin for the Javelin program. Specifically, compatibility and adhesion testing was performed with various substrates. Topcoats were applied to a thickness of 3 to 5 mils. Adhesion testing was performed in accordance with Method 6301 of FED-STD-141, Adhesion (Wet) Tape Test. This method is a wet tape scratch adhesion test. Both paints failed the adhesion test on a urethane adhesive substrate. MIL-C-46168D also failed on an aluminum surface. Both coatings adhered to a curing adhesive, epoxy adhesive, non-conductive polythioether, conductive polythioether, polyetherimide, and copper paint. No substrate attack was noted on the eight substrates that were evaluated.

References

- MIL-C-46168D. “Chemical Agent Resistant Aliphatic Polyurethane Coating.” May 21, 1993.
- MIL-C-53039A. “Chemical Agent Resistant Single-Component Aliphatic Polyurethane Coating.” May 19, 1993.

3.1.2. MIL-C-85285B: High-Solids Polyurethane Coating

MIL-C-85285B is a potential alternative to MIL-C-22750F and MIL-C-83286B (canceled). MIL-C-85285B coatings are polyurethane coatings that have a high solids content. They are grouped by Type I (aircraft applications; 420 grams VOCs per liter maximum) or Type II (ground support equipment applications; 340 grams VOCs per liter). These formulations do not contain lead. The qualified products list of

MIL-C-85285B (QPL-85285-6) records at least 28 products that meet the performance requirements of this specification.

High-solids paints produce finishes that closely resemble conventional solventborne coatings. The performance requirements of the conventional MIL-C-22750F and MIL-C-83286B are compared to the alternative MIL-C-85285B below:

	Requirements of MIL-C-22750F	**Requirements of MIL-C-83286B**	**Requirements of MIL-C-85285B**
VOC content	2.8 lb/gal	not specified	3.5 lb/gal (Type I) 2.8 lb/gal (Type II)
Compatibility with MIL-T-81772 Type I thinner	Not in spec	Compatible	Compatible
Compatibility with MIL-T-81772 Type II thinner	Compatible	Not in spec	Compatible
Drying time	0.5 hour maximum set-to-touch 3 hours dry hard 4 hours dry through	1 hour dry-to-recoat max. 2 hours set-to-touch 6 hours dry hard	4 hours set-to-touch 8 hours dry hard
Pot life	8 hours	6 hours	8 hours
Settling (no curdling, precipitation, or separation)	Not in spec	6 hours	8 hours
Storage stability of unopened package	1 year between 35°F and 115°F	1 year between 0°F and 115°F	1 year between 35°F and 115°F
FED-STD-595B Colors	All colors allowed	Available	Available
Gloss, 60° specular, gloss	90 minimum	90 minimum	80 minimum
Gloss, 60° specular, semi-gloss	15 minimum; 30 maximum	Not in spec	15 minimum
Gloss, 60° specular, camouflage	5 maximum	7 maximum	5 maximum
Wet tape adhesion	Pass	Pass	Pass
Impact flexibility (elongation)	Not in spec	60% min. (gloss); 20% min. (flat)	40% min. (Type I); 5% min. (Type II)
Flexibility	Pass over 1 inch mandrel	Not in spec	Pass over 1 or 2 inch mandrel
Hiding power (contrast ratio)	0.9 minimum	0.85 minimum	0.9 minimum (white)
Salt spray resistance	336 hours (with primer)	500 hours	2,000 hours (with MIL-P-85582B)
Humidity resistance	Not in spec	30 days at 95% RH and 120°F	30 days at 100% RH and 120°F
Heat resistance	1 hour at 250°F	4 hours at 300°F	1 hour at 250°F
Cold resistance	Not in spec	4 hours at -65°F	4 hours at 60°F
Fluid resistance: Lubricating oil	24 hours at 250°F	24 hours at 250°F	24 hours at 250°F
Fluid resistance: Hydrocarbon	7 days, standard conditions	7 days, standard conditions	Not in spec
Fluid resistance: Hydraulic fluid	24 hours at 150°F	7 days, standard conditions	24 hours at 150°F
Fluid resistance: Skydrol 500B	Not in spec	7 days, standard conditions	Not in spec
Fluid immersion resistance: Distilled water	4 days at 120°F	4 days at 100°F	4 days at 120°F (MIL-P-85582B)
Accelerated weathering	500 hours	500 hours	500 hours

(Continued on next page)

	Requirements of MIL-C-22750F	Requirements of MIL-C-83286B	Requirements of MIL-C-85285B
Outdoor weathering	Not in spec	1 year in Florida	1 year in Florida
Tape resistance without Marring	8 hours	16 hours (except black)	8 hours
DS2 decontamination solution resistance	Pass	Not in spec	Not in spec
Chemical Warfare Agent GD	Pass	Not in spec	Not in spec
Chemical Warfare Agent HD	Pass	Not in spec	Not in spec
MEK Resistance	Pass	Not in spec	Pass
Strippability	90% minimum in 1 hour	Not in spec	90% minimum in 1 hour
Comments	High-solids Revision E and F version - poor quality Chronic problems: Orange peel, gloss, viscosity, cure, adhesion, source of supply High rework (strip) rate - excess emissions	Solventborne Canceled MIL-C-85285B - Future acquisition	Solventborne, high-solids Used on LAMPS III FLIR, Tomahawk, and JSOW

References

- MIL-C-22750F. “Coating, Epoxy, High-Solids.” May 31, 1994.
- MIL-C-83286B. “Coating, Urethane, Aliphatic Isocyanate, for Aerospace Applications.” August 19, 1980.
- MIL-C-85285B. “Coating: Polyurethane, High-Solids.” October 22, 1990.
- QPL-85285-6. “Qualified Products List of Products Qualified Under Military Specification MIL-C-85285. Coating: Polyurethane, High-Solids.” July 30, 1996.

3.1.3. MIL-P-53022B Type II: Lead-Free and Chromate-Free Corrosion-Inhibiting Epoxy Primer Coating

MIL-P-53022B states in the “Intended Use” section that it may be used as an alternative to MIL-P-23377. MIL-P-53022B requires that qualifying primers have less than 420 grams of solvent per liter (3.5 pounds of solvent per gallon). In addition, hexavalent chromium is not allowed in the formulation, and no more than 0.06 weight percent of lead or lead compounds is allowed in the formulation.

MIL-P-53022B groups these epoxy coatings into two types. Type I coatings are a lead- and chromate-free formulation that meets Rule 102, South Coast Air Quality Management District. Type II coatings are a lead- and chromate-free formulation that have a maximum of 420 grams per liter (3.5 pounds per gallon) VOC content. Type II coatings, which are discussed in this section, are considered to be high-solids coatings. The qualified products list of MIL-P-53022B lists twelve products that meet the minimum performance requirements.

The requirements of the conventional MIL-P-23377F Type I, Class 1 coating and the superseding MIL-P-23377G, Type I, Class C coating, are compared to the alternative MIL-P-53022B Type II coating below:

	Requirement of MIL-P-23377F, Type I, Class 1	**Requirement of MIL-P-23377G, Type I, Class C**	**Requirement of MIL-P-53022B, Type II**
VOC content	Solvent quantities suitable for air or airless spray application	2.8 lb/gal	3.5 lb/gal
Compatibility with MIL-T-81772 Type II thinner	Compatible	Compatible	Not in spec
Storage stability of unopened package	1 year between 35°F and 115°F	1 year between 35°F and 115°F	1 year between 72°F and 80°F
Drying time	1 hour tack-free 6 hours dry hard	5 hours tack-free 8 hours dry hard	0.5 hour set to touch 4 hours dry hard 6 hours dry through
Pot life	8 hours	4 hours	4 hours
Strippability using MIL-R-81294 Type I Class 1	90% stripped in 1 hour	90% stripped in 1 hour	Not in spec
Wet tape adhesion	Pass after 24 hours	Pass after 24 hours	Not in spec
Tape adhesion	Not in spec	Not in spec	Pass
Impact flexibility (elongation)	10% minimum	10% minimum	Not in spec
Flexibility	Not in spec	Not in spec	Pass (no cracking or flaking)
Filiform corrosion resistance	Pass	Pass	Not in spec
Salt spray resistance	1000 hours (aluminum, scored) 500 hours (aluminum/ graphite-epoxy, scored)	2000 hours (aluminum, scored) 500 hours (aluminum/ graphite-epoxy, scored)	336 hours (steel and aluminum, unscored)
Fluid immersion resistance: lubricating oil	24 hours at 250°F	24 hours at 250°F	Not in spec
Fluid resistance: hydraulic fluid	24 hours at 150°F	24 hours at 150°F	Not in spec
Fluid resistance: distilled water	4 days at 120°F	4 days at 120°F	7 days at 23°C
Fluid resistance: hydrocarbon fluid	Not in spec	Not in spec	Pass ASTM D 1308
DS2 resistance	Not in spec	Not in spec	30 minutes at 70°F

(Continued on next page)

	Requirement of MIL-P-23377F, Type I, Class 1	Requirement of MIL-P-23377G, Type I, Class C	Requirement of MIL-P-53022B, Type II
Lifting	None visible	None visible	Not in spec
Knife test	Not in spec	Not in spec	Pass
Solvent resistance (cure)	50 passes rubbing with MEK	50 passes rubbing with MEK	Not in spec
Specular gloss, 60°	Not in spec	Not in spec	10 minimum 30 maximum
Comments	Solventborne MIL-P-23377F canceled	Solventborne High-solids MIL-P-23377G does not work as well as preceding revision F	Solventborne High-solids

References

- MIL-P-23377F. "Primer Coatings: Epoxy, Chemical and Solvent Resistant." May 5, 1989.
- MIL-P-23377G. "Primer Coatings: Epoxy, High-Solids." September 30, 1994.
- MIL-P-53022B. "Primer, Epoxy Coating, Corrosion Inhibiting, Lead and Chromate Free." June 1, 1988.
- QPL-53022-11. "Qualified Products List of Products under Military Specification MIL-P-53022. Primer, Epoxy Coating, Corrosion Inhibiting, Lead and Chromate Free." September 25, 1995.

3.2. 100% Solids Liquid Coatings

A new group of coatings, 100% solids liquid coatings, are currently being developed. These paints do not contain solvents or water, but are still sprayable. They are very viscous, yet pourable, when at rest, and become much less viscous when under sheer. Although the paints can be air atomized, it is recommended that they be heated prior to spraying to approximately 60°C (140°F) with an in-line heater. In addition, the coatings may be applied electrostatically with disc-shaped or bell-shaped applicators at room temperature. However, heating the paint to approximately 40°C (100°F) will insure uniform coating results. Coatings may also be formulated for roller or dip application. Curing is required after coating application. Curing requires 3 to 40 minutes, depending on the heat of the cure (>150°C [300°F]), coating hardness desired, type of substrate, and thickness of coating. Coatings can be applied to thicknesses between 0.7 and 1.2 mils.

The transfer efficiency of 100% solids liquid coatings are higher than conventional coatings, at 90 percent if an electrostatic bell is used for coating application. Any overspray can be collected with a recovery system and then filtered, blended, and tinted to a reusable coating, since solvent or water evaporation is not an issue.

At least one 100% solids liquid coating is commercially available, which is referred to as TioTech™ 20 and is manufactured and distributed by Tioga Coatings Corporation. TioTech™ 20 coatings have passed crosshatch adhesion tests and flexibility tests over a 1/8 in. mandrel. They can withstand direct impact of 120 in.-lb_f. Salt spray tests for 500 hours resulted in a 1/8 in. to 3/16 in. creep. In addition, the coatings are resistant to MEK, xylene, Gasohol, brake fluid, antifreeze, and motor oil. Shelf life exceeds six months in an unopened container.

A capital investment will be required to convert existing solventborne coating spray equipment to 100% solids liquid coatings equipment. Identified commercially available products are limited to application on metal substrates. In addition, adhesion to the substrate may not be adequate if the coating materials are not heated to the correct temperature.

References

- Baker, John S. *Lead- and Chromate-Free Anticorrosive Primers, High Solids, 100 Percent Solids, and Waterborne Coatings as Environmentally Sound Coatings for Reclamation Infrastructures.* United States Department of Interior, Bureau of Reclamation Publication. September 1994.
- Jarzomek, Rich. Tioga Coatings Corporation. Telephone Conversation. July 10, 1996.
- Tioga Coatings Corporation. "Generic TioTech™ 20." *Material Safety Data Sheet*.
- Tioga Coatings Corporation. Product Literature.

3.3. Waterborne Coatings

Another alternative to solventborne topcoats and primers is waterborne topcoats and primers. Waterborne coatings are formulated with water as the main solvent (dispersal medium), but still may contain 5 to 20 percent organic solvent to aid in wetting, viscosity control, and pigment dispersion. Waterborne paints, which may be classified as either emulsions (latexes), colloidal dispersions, or solutions, may be applied by air or airless spraying, autodeposition, curtain coating, dip coating, electrocoating, electrostatic spraying, flow coating, or fluidized bed coating. A wide variety of waterborne coatings are commercially available.

Waterborne coatings are available that offer similar performance properties as the traditional solventborne coatings. Water-based paints are also easier to clean up, since overspray can be collected by rinsing with water and then concentrated via evaporation, absorption/recirculation of paint, electrochemical precipitation, or ultrafiltration. Although the material cost is comparable to or lower than solventborne paint, some waterborne paints have a short shelf-life of about six months. Since waterborne paint takes longer to dry, the flash-off/drying area of paint lines may have to be lengthened. In addition, humidity control devices may be required, and some metal equipment surfaces may have to be replaced with stainless steel or other corrosion-resistant materials.

3.3.1. MIL-P-85582B: Waterborne Epoxy Primer Coating

One military specification, which is waterborne, may be applicable as an alternative epoxy primer coating: MIL-P-85582B. Although waterborne primers may contain some solvents, this military specification requires that qualifying primers have less than 340 grams of solvent per liter (2.8 lb/gal). In addition, chlorinated solvents, cadmium, and cadmium compounds are not allowed in the formulation, and no more than 0.06 weight percent of lead or lead compounds is allowed in the formulation. The MIL-P-85582B primers are formulated as sprayable coatings that can be applied by conventional; airless; high-volume, low-pressure (HVLP); or electrostatic spray equipment. They are applied at a dry-film thickness of 0.6 to 0.9 mils (15 to 23 microns).

MIL-P-85582B groups waterborne coatings into two types and two classes, as listed below.

Type	Class
Type I - Standard pigments	Class C1 - Barium chromate-based corrosion inhibitors
Type II - Low infrared reflective pigments	Class C2 - Strontium chromate-based corrosion inhibitors
	Class N - Non-chromate-based corrosion inhibitors

Unless a specific type and/or class is referenced in the contract or purchase order, MIL-P-85582B Type I, Class C1 or C2 is the default. The qualified products list of MIL-P-85582B lists 12 products for Type I, Class C1 or C2 coatings.

The requirements of the conventional MIL-P-23377F Type I, Class 1 coating and the superseding MIL-P-23377G Type I, Class C coating are compared to the alternative MIL-P-85582B Type I, Class C1 or C2 coating in the following table:

	Requirement of MIL-P-23377F, Type I, Class 1	Requirement of MIL-P-23377G, Type I, Class C*	Requirement of MIL-P-85582B, Type I, Class C1 or C2
VOC content	Solvent quantities suitable for air or airless spray application	2.8 lb/gal	2.8 lb/gal
Compatibility with MIL-T-81772 Type II thinner	Compatible	Compatible	Not compatible; use water in place of thinner
Storage stability of unopened package	1 year between 35°F and 115°F	1 year between 35°F and 115°F	1 year between 35°F and 115°F
Drying time	1 hour tack-free 6 hours dry hard	5 hours tack-free 8 hours dry hard	1 hour tack-free 6 hours dry hard
Pot life	8 hours	4 hours	4 hours
Strippability using MIL-R-81294 Type I Class 1	90% stripped in 1 hour	90% stripped in 1 hour	90% stripped in 15 minutes
Wet tape adhesion	Pass after 24 hours	Pass after 24 hours	Pass after 24 hours
Impact flexibility (elongation)	10% minimum	10% minimum	10% minimum
Filiform corrosion resistance	Pass	Pass	Pass
Salt spray resistance	1000 hours	2000 hours	2000 hours
Fluid immersion resistance: lubricating oil	24 hours at 250°F	24 hours at 250°F	24 hours at 250°F
Fluid resistance: hydraulic fluid	24 hours at 150°F	24 hours at 150°F	24 hours at 150°F
Fluid resistance: distilled water	4 days at 120°F	4 days at 120°F	4 days at 120°F
Lifting	None visible	None visible	None visible
Solvent resistance (cure)	50 passes rubbing with MEK	50 passes rubbing with MEK	50 passes rubbing with MEK
Comments	Solventborne MIL-P-23377F canceled	Solventborne High-solids MIL-P-23377G Type I, Class C coating does not work as well as MIL-P-23377F Type I, Class 1 coating	Water-reducible Not currently used for bare steel or wet installation of fasteners

*MIL-P-23377G Type I, Class C coatings are essentially the same as MIL-P-23377F Type I, Class 2 coatings.

As can be seen in the above table, the requirements of MIL-P-85582B are at least as stringent as MIL-P-23377F and MIL-P-23377G, so qualified MIL-P-85582B coatings will be feasible alternatives.

References

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- MIL-P-23377G. “Primer Coatings: Epoxy, High-Solids.” September 30, 1994.
- MIL-P-85582B. “Military Specification. Primer Coatings: Epoxy, Waterborne.” May 23, 1994.
- QPL-85582-4. “Qualified Products List of Products under Military Specification MIL-P-85582. Primer Coatings: Epoxy, Waterborne.” April 17, 1995

3.4. Ion Vapor Deposition

One alternative to chromate-containing primers (such as Class C MIL-P-23377G primers) is ion vapor deposition (IVD). IVD is a process in which parts to be coated are placed in a chamber, and the chamber is evacuated and backfilled with an inert gas, such as argon. A high negative potential is applied to the substrate and, subsequently, the surrounding inert gas becomes ionized. Positive ions in the ionized inert gas are attracted to the oppositely charged substrate, bombarding it to clean the substrate surface. Next, the coating material (aluminum) is added to the chamber, melted, and vaporized. The vaporized material is ionized. The ionized coating material is attracted to the substrate, and bombards it to form a protective film.

IVD aluminum offers soft, ductile, adherent coatings that are commonly used in corrosive environments. However, it cannot be used when fine tolerances are required or in small diameter openings. In addition, it offers poor lubricity.

<u>*References*</u>

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3.5. Powder Coating

Powder coatings are dry, solid materials composed of pulverized resin, pigment, solid additives, and up to 10 percent trapped volatiles. Powder coating formulations require different types of resins than liquid paints to produce coating materials that are solid at ambient and elevated storage temperatures, yet capable of melting rapidly to low viscosities when heated. Several types of thermosetting and thermoplastic resins, defined below, are available for specific applications.

- *Thermosetting powders*—Thermosetting powders melt and flow to form a coating on the substrate, and then crosslink with other particles in the powder formulation to form high-molecular-weight polymers. Due to crosslinking, these powders may soften, but will not melt if heat is applied after curing. Some examples of thermosetting powders are acrylic, epoxy/polyester hybrid, functional epoxy, thin film epoxy, and urethane polyester.

- *Thermoplastic powders*—Thermoplastic powders are melted for application onto the substrate, but, unlike thermosetting powders, they will melt during any subsequent heating in the substrate's lifetime, because no chemical change (i.e., crosslinking) occurs in the polymers during the coating process. These powders have a higher molecular weight than thermosetting powders. Some examples of these polymers are cellulose esters, polyamides (such as Nylon-11), polyester, polypropylene, and polyvinyl chloride (PVC).

In general, powder coating eliminates problems associated with running and sagging, liquid mixing or pumping, and liquid viscosity monitoring. Powder coatings are also superior to liquid coatings in their ability to cover sharp edges. The process offers low energy consumption and reduced labor requirements. In addition, for coating an equivalent substrate, material use is lower for powder coating than conventional spray painting, since powder coating yields are typically greater than 95 percent, versus approximately 35 percent for conventional techniques.

Powder coating is used to deposit coatings between 1.5 and 60 mils, with uniform coatings less than 1 mil typically unobtainable. This process may be used to coat substrates, such as aluminum or steel, for various applications. Depending on the formulation, powder coatings can provide decorative appeal, corrosion and abrasion resistance, electrical insulation, and ultraviolet light resistance. However, some performance problems exist, such as film appearance and powder handling (e.g., changing colors during the process).

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3.5.1. High Gloss CARC Epoxy Powder

One possible alternative for MIL-C-22750F is a high gloss CARC epoxy powder coating. These systems are compared in the following table:

	Requirements of MIL-P-22750F	Requirements of High Gloss CARC Epoxy Powder Coating
VOC content	2.8 lb/gal	0
Compatibility with MIL-T-81772 Type II thinner	Compatible	No thinner required
Drying time	0.5 hour maximum set-to-touch 3 hours dry hard 4 hours dry through	Oven-cure @ 250°F for 30 minutes
Pot life	8 hours	N/A
Storage stability of unopened package	1 year between 35°F and 115°F	> 1 year
FED-STD-595B Colors	All colors allowed	Only 17925 gloss white approved at this time
Gloss, 60° specular, gloss	90 minimum	90 minimum
Gloss, 60° specular, semi-gloss	15 minimum 30 maximum	not tested
Gloss, 60° specular, camouflage	5 maximum	not presently available
Wet tape adhesion	Pass	Pass
Flexibility	Pass over 1 inch mandrel	Not in spec
Hiding power (contrast ratio)	0.9 minimum	Not in spec
Salt spray resistance	336 hours (with primer)	1,000 hours (scribed and unscribed)
Heat resistance	1 hour at 250°F	Will not solidify until it reaches 250°F
Recoatability	Recoatable	Touch-up with appropriate Color MIL-C-22750F
Fluid resistance: Lubricating oil	24 hours at 250°F	24 hours at 250°F
Fluid resistance: Hydrocarbon	7 days, standard conditions	7 days, standard conditions
Fluid resistance: Hydraulic fluid	24 hours at 150°F	24 hours at 150°F
Fluid immersion resistance: Distilled water	4 days at 120°F	7 days, standard conditions
Accelerated weathering	500 hours	To be tested
Tape resistance without Marring	8 hours	Not in spec
DS2 decontamination solution resistance	Pass	Pass

(Continued on next page)

	Requirements of MIL-P-22750F	Requirements of High Gloss CARC Epoxy Powder Coating
Chemical Warfare Agent GD	Pass	Pass
Chemical Warfare Agent HD	Pass	Pass

	Requirements of MIL-P-22750F	Requirements of High Gloss CARC Epoxy Powder Coating
MEK Resistance	Pass	Pass
Acetic acid resistance	Not in spec	30 minutes
Strippability	90% minimum in 1 hour	Not in spec
Comments	High-solids Revision E and F version - poor quality Chronic problems: orange peel, gloss, viscosity, cure, adhesion, source of supply	Special Powder Paint Developed for CITV/HTEU

References

MIL-C-22750F. "Coating, Epoxy, High-Solids." May 31, 1994.

3.5.2. Airborne Weapon Epoxy Powder

Another powder paint, referred to as an Airborne Weapon Epoxy Powder, may potentially replace MIL-C-83286B and the interim MIL-C-85285B coatings. These systems are compared in the following table:

	Requirements of MIL-C-83286B	Requirements of MIL-C-85285B	Requirements of Airborne Weapon Epoxy Powder
VOC content	not specified	3.5 lb/gal	0
Compatibility with MIL-T-81772 Type I thinner	Compatible	Compatible	N/A
Compatibility with MIL-T-81772 Type II thinner	Not in spec	Compatible	Not in spec
Drying time	1 hour dry-to-recoat max. 2 hours set-to-touch 6 hours dry hard	4 hours set-to-touch 8 hours dry hard	Applied coating must be cured by baking <45 minutes @ 250°F
Settling (no curdling, precipitation, or separation)	6 hours	8 hours	N/A
Storage stability of unopened package	1 year between 0°F and 115°F	1 year between 35°F and 115°F	> 1 year
FED-STD-595B Colors	Available	Available	Limited selection at this time
Pot life	6 hours	8 hours	N/A
Gloss, 60° specular, gloss	90 minimum	80 minimum	None available at this time

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	Requirements of MIL-C-83286B	Requirements of MIL-C-85285B	Requirements of Airborne Weapon Epoxy Powder
Gloss, 60° specular, semi-gloss	Not in spec	15 minimum	12 maximum
Gloss, 60° specular, camouflage	7 maximum	5 maximum	Not in spec
Wet tape adhesion	Pass	Pass	Pass
Impact flexibility (elongation)	60% min. (gloss); 20% min. (flat)	40% min. (Type I); 5% min. (Type II)	20% min. (all)
Flexibility	Not in spec	Pass over 1 or 2 inch mandrel	Not in spec
Hiding power (contrast ratio)	0.85 minimum	0.9 minimum (white)	N/A
Salt spray resistance	500 hours	2,000 hours (with MIL-P-85582B)	500 hours
Humidity resistance	30 days at 95% RH and 120°F	30 days at 100% RH and 120°F	30 days at 95% RH and 120°F
Heat resistance	4 hours at 300°F	1 hour at 250°F	4 hour at 300°F
Cold resistance	4 hours at -65°F	4 hours at -60°F	4 hours at -65°F
Fluid resistance: Lubricating oil	24 hours at 250°F	24 hours at 250°F	24 hours at 250°F
Fluid resistance: Hydrocarbon	7 days, standard conditions	Not in spec	7 days, standard conditions
Fluid resistance: Hydraulic fluid	7 days, standard conditions	24 hours at 150°F	7 days, standard conditions
Fluid resistance: Skydrol 500B	7 days, standard conditions	Not in spec	7 days, standard conditions
Fluid immersion resistance: Distilled water	4 days at 100°F	4 days at 120°F (MIL-P-85582B)	4 days at 100°F
Accelerated weathering	500 hours	500 hours	500 hours
Outdoor weathering	1 year in Florida	1 year in Florida	Not in spec
Tape resistance without Marring	16 hours (except black)	8 hours	Not in spec
MEK Resistance	Not in spec	Pass	Not in spec
Strippability	Not in spec	90% minimum in 1 hour	Not in spec
Comments	Solventborne Canceled MIL-C-85285B - Future acquisition	Solventborne, high-solids	Epoxy powder coating

References

- MIL-C-83286B. "Coating, Urethane, Aliphatic Isocyanate, for Aerospace Applications." August 19, 1980.
- MIL-C-85285B. "Coating, Polyurethane, High-Solids." October 22, 1990.

3.6. Radiation-Curable Coatings

Traditional methods for curing paints rely on a heat source, such as baking ovens, to speed solvent evaporation and trigger coating polymerization reactions. However, radiation-curable coatings are formulated to cure by exposure to ultraviolet (UV), electron beam (EB), infrared (IR), or microwave radiation. Radiation-curable coatings are formulated with a higher percentage of solids than conventional coatings. Formulations consist of a low-molecular-weight olefin resin (with carbon-carbon double bonds), a reactive solvent containing unsaturated groups, and a photoinitiator. Electromagnetic radiation energy produces a chemical and physical change in the coating by initiating a reaction that forms cross-linked polymer networks.

Although radiation-curable formulations are typically clear (non-pigmented) coatings, pigmented paints can also be cured by radiation. Radiation-curable coatings may be applied by air or airless spraying, curtain coating, dip coating, electrostatic spraying, flow coating, or roller/coil coating. Radiation curing ovens typically require 50 to 75 percent less floor space than thermal curing ovens. Higher production rates can be achieved because radiation curing is faster than thermal curing.

Radiation-curable coatings provide good resistance to abrasion, heat, staining, and weathering. They can be used on temperature-sensitive substrates because they do not require the elevated curing temperatures that conventional coatings require.

Radiation-curable coatings have several technical limitations. Presence of air can retard the polymerization process, thus resulting in a tacky surface. Therefore, blanketing with an inert gas is required in most situations. Due to the reduced solvent content, the formulations have a high viscosity, which may also limit applications.

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3.7. Self-Priming Topcoat (Unicoat)

Self-priming topcoat, or Unicoat, is a chromate-free, low-VOC coating. It was originally developed by the Naval Air Warfare Center (Warminster, Pennsylvania) to replace the standard MIL-P-87112/MIL-C-83286B coating system. Unicoat is recommended as an overcoat on flat coatings. Several military installations, such as Tinker Air Force Base, Oklahoma City, Oklahoma, currently use Unicoat. Some benefits of Unicoat include reductions in coating materials, application time, hazardous material emissions, and maintenance.

A study was performed in 1993 to assess the Unicoat system (Yamaski 1994). A summary of the conclusions regarding Unicoat performance is provided below:

- Unicoat can be applied to aluminum substrates and provide the adhesion and corrosion resistance of the original primer and the chemical resistance, weather resistance, durability, and flexibility of the original topcoat. (Navy)
- Unicoat provides over 2,000 hours of salt spray resistance. (Navy)
- Field tests proved that Unicoat had good durability and cleanability. (Navy)
- Unicoat reduces the amount of corrosion control maintenance required. (Navy)
- Self-priming topcoat (a predecessor to TT-P-2756A) was applied on KC-135 and B-1 aircraft. After six months, the paint passed several tests, including wet and dry tape adhesion tests. (OC-ALC)
- The corrosion protection may not be adequate compared to the conventional coating system. (Wright Laboratories)
- Unicoat may fail tests for pot life and salt spray resistance. (Pensacola NAS)
- Unicoat is easier to clean than MIL-C-85285B. (Naval Aviation Depot Jacksonville)
- Unicoat provides substandard corrosion protection on aluminum or magnesium substrates and steel fasteners. (OC-ALC/LA)
- Inadequate adhesion is provided by Unicoat when applied directly to 3M leading edge tape. (OC-ALC/LA)
- Unicoat provides insufficient Skydrol resistance on KC-10 aircraft. (OC-ALC/LA)

As can be seen, the test results vary from one facility to the next. Some of these differences can be attributed to varied surface preparation and overcoating procedures. For an expanded discussion about field tests of Unicoat, refer to the Yamaksi (1994) reference.

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3.7.1. TT-P-2756A: Low VOC Self-Priming Polyurethane Topcoat Coating

TT-P-2756A describes a lead-free and chromate-free self-priming polyurethane coating material that may be used to replace standard primer/topcoat systems. It is intended to be used on aircraft, weapon systems, and other applications that require protection for aluminum, steel, titanium, magnesium, or polymeric substrates. It may contain a maximum of 420 grams of VOCs per liter. Three products are currently commercially available that meet the performance requirements of this specification, including 03-GY-369 (Deft, Inc.), 26-F30-100/PC223 (Dexter Corporation), and 24-F30-10/PC220 (Dexter Corporation).

Qualified products to TT-P-2756A must have the following performance requirements:

	Requirements of TT-P-2756A
Curing time	2 hours set-to-touch 8 hours dry hard
Gloss, 60° specular gloss	90 minimum
Gloss, 60° specular semi-gloss	15 minimum 45 maximum
Gloss, 60° specular camouflage (low gloss)	6 maximum
Gloss, 85° specular camouflage (low gloss)	9 maximum
Fluid resistance, water	7 days at 66°C
Fluid resistance, lubricating oil	24 hours at 121°C
Fluid resistance, hydraulic fluid	24 hours at 66°C
Flexibility, impact elongation, gloss coatings	40%
Flexibility, impact elongation, camouflage coatings	20%
Humidity resistance	30 days at 100% RH and 49°C
Heat resistance	4 hours at 121°C
MEK Resistance	withstand rubbing
Dry tape adhesion	pass
Strippability with MIL-R-81294	90% of coating in 60 minutes

	Requirements of TT-P-2756A
Filiform corrosion resistance	1,000 hours

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	Requirements of TT-P-2756A
Salt spray resistance, ASTM B117	2,000 hours
Salt spray resistance, ASTM G85	500 hours
Weather resistance	500 hours in 6,000 watt Xenon-arc
Closed container pot life	2 hours
Mixed coating pot life	4 hours
Storage stability	1 year
Accelerated stability	24 hours at 57°C
Comments	Solventborne Combines primer and topcoat

References

- QPL-TT-P-2756-1. "Qualified Products List of Products Qualified Under Federal Specification TT-P-2756: Polyurethane Coating: Self-Priming Topcoat, Low Volatile Organic Compounds (VOC)." February 24, 1993.
- TT-P-2756A. "Federal Specification. Polyurethane Coating: Self-Priming Topcoat, Low Volatile Organic Compounds (VOC)." January 20, 1992.

3.8. Supercritical CO_2 Spraying

The supercritical carbon dioxide (CO_2) spray painting process uses carbon dioxide above its critical temperature and pressure to replace some of the solvents used in coating formulations, resulting in reduced VOCs. Up to 80 percent of the organic solvents can be replaced with supercritical CO_2 without affecting coating performance. Supercritical CO_2 reduces paint viscosity and produces vigorous atomization, yielding a quality finish. This spray technique is an effective alternative to applying conventional paints and high-solids coatings.

A primary disadvantage of supercritical CO_2 spraying is the high capital cost. Current coatings may need to be reformulated to meet supercritical CO_2 requirements, and these coatings are produced by a limited number of manufacturers. Due to the high pressures of supercritical CO_2 painting systems, frequent color changes are not practical. In most cases, existing spray painting production operations can be retrofitted to accommodate supercritical CO_2 spray painting operations. Modifications may include replacing many of the hoses, transfer lines, spray guns, and fittings with custom-designed equipment.

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5.0. SUMMARY

CTC was tasked to perform a technology survey to identify alternatives to high VOC topcoats and primers used at Lockheed Martin Electronics & Missiles and Information Systems Companies in Orlando, Florida. Eight commercially available materials and technologies were identified, including high-solids coatings, 100% solids liquid coatings, waterborne coatings, ion vapor deposition, powder coating, radiation-curable coatings, self-priming topcoats, and supercritical CO_2 spraying. After the advantages and limitations of these technologies are reviewed, specific alternatives may be identified and further evaluated against distinct performance requirements of defense systems manufactured at Lockheed Martin.