# Final Report

# Technology Demonstration Plan

# Demonstration/Validation of a Zero-VOC Waterborne Polyurethane Topcoat

## Naval Air Warfare Center Aircraft Division
## Patuxent River Maryland

## 31 January 2001

DRAFT

## TABLE OF CONTENTS


**Page**

1. Introduction ..... 4
   1.1 Background Information ..... 4
   1.2 Official DOD Requirement Statements ..... 5
   1.3 Objectives of the Demonstration ..... 5
   1.4 Regulatory Issues ..... 5
   1.5 Stakeholder/End-User Issues ..... 6
   1.6 Previous Testing of the Technology ..... 6
2. Technology Description ..... 6
   2.1 Description ..... 6
   2.2 Strengths, Advantages, and Weaknesses ..... 8
   2.3 Factors Influencing Cost and Performance ..... 8
3. Site/Facility Description ..... 9
   3.1 Background ..... 9
4. Demonstration Approach ..... 10
   4.1 Performance Objectives ..... 10
   4.2 Physical Setup and Operation ..... 10
   4.3 Testing Procedures ..... 11
   4.4 Evaluation Procedures ..... 11
5. Performance Assessment ..... 11
   5.1 Performance Data ..... 11
   5.2 Data Assessment ..... 15
   5.2 Technology Comparison ..... 15
6. Cost Assessment ..... 16
   6.1 Cost Performance ..... 16
   6.2 Cost Comparisons to Conventional and Other Technologies ..... 17
7. Regulatory Issues ..... 17
   7.1 Approach to Regulatory and End-User Acceptance ..... 17
8. Stakeholder/End-User Issues ..... 17
9. Technology Implementation ..... 18
   9.1 DoD Need ..... 18
   9.2 Transition ..... 18
10. Lessons Learned ..... 20
11. References ..... 22
Appendix A ..... 1-A
Appendix B ..... 1-B
Appendix C ..... 1-C
   C.1 Data Format ..... 1-C
   C.2 Data Storage and Archiving Procedures ..... 1-C
Appendix D ..... 1-D
Appendix E ..... 1-E




DRAFT

## LIST OF FIGURES

**FIGURE 1. Schematic diagram of a polymer micelle in a water-reducible coating. Neutralized carboxylic groups and surfactants stabilize the particle. Excess amine and solvent distribute between the phases. ..... 7**
**FIGURE 2. Condemned C-141 aft cowlings exposed at WR-ALC for 14 months. ..... 12**
**FIGURE 3. Zero-VOC topcoat application to (A) outer wing panel of C-2 and (B) F/A-18D at NADEP NORIS ..... 13**
**FIGURE 4. CH-60S helicopter painted with zero-VOC topcoat at Sikorsky Aircraft. ..... 14**
**FIGURE 5. Tow bars painted with zero-VOC topcoat at NAVAIRSEFAC, Solomons, MD. Tow bars are deployed on USS Harry S Truman. ..... 14**
**FIGURE 6. RDT&E portion of the Technology Transition Plan for the Zero-VOC Waterborne Polyurethane Topcoat. ..... 19**
**FIGURE 7. Logistics, engineering, and facilities management portion of the technology transition plan for the zero-VOC waterborne polyurethane topcoat. ..... 19**
**FIGURE 8. Deployment portion of the technology transition plan for the zero-VOC waterborne polyurethane topcoat. ..... 20**

## LIST OF TABLES

**TABLE 1. Demonstration Site Details. ..... 10**
**TABLE 2. Color Change Data for the Zero-VOC Topcoats and Other Coatings After Exposure to QUV-B and Xe-Arc Artificial Weathering ..... 15**
**TABLE 3. Cure response of the zero-VOC topcoat as a function of temperature and relative humidity ..... 21**
**TABLE 4. Cure response of zero-VOC topcoat at elevated temperatures. ..... 22**



DRAFT

# Demonstration/Validation of a Zero-VOC Waterborne Polyurethane Topcoat

# Naval Air Warfare Center Aircraft Division Patuxent River Maryland

# 31 January 2001

## 1. Introduction

### 1.1 Background Information

Aircraft painting is a significant source of hazardous waste for the DOD and one of Naval aviation's top generators. The Tri-Service Environmental Quality R&D Strategic Plan (Pillar 3: Pollution Prevention, Requirement Thrust: 3.I.4.h: Non-Hazardous Aircraft Paints and Coatings) has identified the finding of replacement materials for painting operations as a high priority. Organic topcoats are the primary source of barrier-type protection against environmental degradation for Navy aircraft, weapon systems (WS) and support equipment (SE). In addition, these materials provide passive countermeasures against many enemy threats. There is a large number of different coating systems currently used by the Navy due to the diverse nature of their functions, the variety of substrates and alloys to which they are applied, and the severe nature of their operational environment. Unlike other DOD applications, Naval aviation topcoats must provide superior protection in a harsh environment with a thin barrier as to minimize weight for proper payload or operations. These coatings contain high volatile organic compound (VOC) contents; VOCs are released during painting operations as hazardous air pollutants (HAPs).



DRAFT

A solution to the problem of using high VOC topcoats has been found. This new topcoat incorporates resins based on novel polymer chemistries into its formulation. These resins are water-dispersible; no organic solvents (i.e. VOCs, HAPs) are necessary for viscosity reduction and subsequent spray application.

### 1.2 Official DOD Requirement Statements

This project addresses the following requirements:

- Army 2.1.a.(2.1.e) Volatile Organic Compound (VOC) Emission Control (Air Emissions Reduction Initiatives)
- Army 3.2.d Hazardous Paint Elimination
- Navy 3.I.11.d Hazardous Materials Substitution
- Air Force 96-204 Reduced Volatile Organic Compound (VOC) Emissions from Paint-Application Systems
- Air Force T2700.02 New Technologies for Clean Air Act Compliance

The technology will satisfy all of the above requirements because the coating contains no volatile organic compounds (VOCs) in the formulation and the resulting films formed contain no hazardous materials. The zero-VOC topcoat was developed from novel resin chemistry to be applied using conventional or high-volume-low-pressure (HVLP) application equipment.

### 1.3 Objectives of the Demonstration

The object of this proposal is to transfer the zero-VOC topcoat technology information into the hands of future DOD users associated with the painting of military aircraft and ground support equipment. This demonstration/validation stage will be full-scale service demonstrations on various aircraft at the NADEPs through coordination with the Lead Maintenance Technology Center for the Environment. These materials will be transitioned to the fleet through technical manual revisions, specification revisions (MIL-PRF-85285C), and aircraft finishing specification (e.g. MIL-STD-7179, T.O. 1-1-8) modifications through Integrated Product Teams (IPT) and the Acquisition Environmental Product Support Team (AEPST). Additional changes will be promulgated through the services' corrosion control manuals (NAVAIR 01-1A-509, T.O. 1-1-691, TM 1-1500-344-23).

### 1.4 Regulatory Issues

Federal, state and local environmental agencies like the EPA and California Air Quality Management Districts (AQMD) classify many VOCs as hazardous and restrict their emissions through regulations such as the Clean Air Act, Clean Water Act, Resource Conservation and Recovery Act (RCRA) as well as local EPA and AQMD rules. Also, CNO directives require significant reductions in the amount of hazardous waste generated by the Navy.

The Environmental Protection Agency (EPA) has proposed a reduction in low-level ozone non-attainment levels within the National Ambient Air Quality Standards (NAAQS). Because VOCs from topcoats contribute to the generation of low-level ozone, state and local agencies may



DRAFT

require VOC reductions beyond those listed in the aerospace National Emission Standards for Hazardous Air Pollutants (NESHAPs).

VOCs are a serious problem with regards to military coating processes. For example, one Naval Aviation Depot (NADEP) typically discharges 20,000 pounds of solvent per year from coatings operations. Painting is the second largest overall generator of hazardous waste at NADEP Jacksonville. Hazardous waste cost per pound has increased by more than 20% per year at one NADEP. A reduction in paint waste is necessary to meet the requirements of Executive Order 12856.

### 1.5 Stakeholder/End-User Issues

The use of a zero-VOC topcoat is expected to have several benefits that will be applicable to any DOD facility or subcontractor engaged in the painting of aircraft or support equipment. Some of the regulatory, economic, and readiness benefits will include the following:

- Avoidance of fines (up to $25K/day/facility)
- Avoidance of hard emission controls (up to $1M/hangar)
- Reduced waste and disposal costs (more than 15,000 lbs. of solvent/NADEP)
- Improved work space/facility environment

Decreased downtime because of compliance means improved operational readiness. Appendix A contains a joint test report (JTR). This JTR summarizes the results from testing as directed by the joint test protocol[1] (JTP), which was developed through tri-service participation and contains the critical technical and performance requirements and tests necessary to qualify potential alternatives to selected target HAZMATs and processes for a particular application.

### 1.6 Previous Testing of the Technology

The technology has been developed and tested in the laboratory under the Strategic Environmental Research and Development Program (SERDP), project PP65: Organic Protective Coatings and Application Technology. The material was tested to MIL-PRF-85285C, Coating: Polyurethane – High Solids. Preliminary results showed deficiencies in pot life and flexibility. These issues have since been resolved. Future testing will continue as tests are added to the JTP described in Reference 1.

## 2. Technology Description

### 2.1 Description

The zero-VOC topcoat offers the potential for the DOD to go beyond environmental compliance in its painting operations. This coating evolved from two previous efforts: the first was the development of a waterborne topcoat that had a VOC content of 210 g/l (one-half the maximum



DRAFT

allowed VOC for aircraft topcoats) and the other was the investigation of less viscous binder systems for aircraft coatings.

Waterborne or water-reducible coatings are unique in the way that they contain resins that are usually not soluble in water. The resin exists in its own micellar phase. Figure 1 illustrates the resin micelle in a waterborne coating. Since the polymer exists as its own organic phase surrounded by water, the solvent distributes between the organic phase and the aqueous phase. This solvent, called the coalescing solvent, aids in film formation as the water evaporates by allowing binder and pigment particles to fuse into a continuous film.

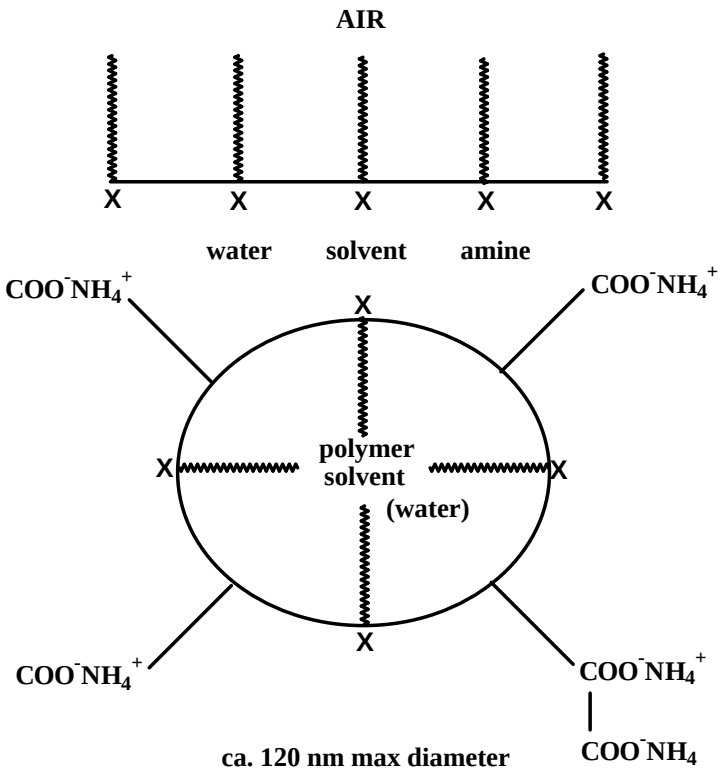


**FIGURE 1. Schematic diagram of a polymer micelle in a water-reducible coating. Neutralized carboxylic groups and surfactants stabilize the particle. Excess amine and solvent distribute between the phases.**

Formulations based on emulsion, water-reducible, and aqueous colloidal dispersions collectively represent one of the most popular alternatives to conventional solventborne coatings. Since water is used as the primary liquid medium or as a diluent, formulations based on waterborne resins have much lower VOC levels than their solventborne counterparts. Recent advances in polymer chemistries have eliminated the need for a coalescing solvent resulting in the formulation of coatings containing no VOCs and substantially less amounts of hazardous materials.



DRAFT

The Sherwin-Williams Company (formerly Pratt & Lambert) has performed engineering studies to investigate the above resins, formulate coatings from these resins, test, and demonstrate low VOC waterborne topcoats. This study came out of a Strategic Environmental Research and Development Program (SERDP) project initiated by the Navy in October, 1992. Laboratory evaluations of this topcoat at the Naval Air Warfare Center Aircraft Division (NAWCAD) have indicated that the topcoat meets all the specification requirements. Field demonstrations were initiated on a Navy CH-46 and continue today.

An in-house engineering study at NAWCAD investigated epoxy resins and reactive diluents for formulation into low VOC topcoats. This study also came out of a SERDP project initiated by the Navy in September 1993. Two formulations were determined to meet all the specification requirements for an epoxy topcoat for use on Naval aircraft; the results of this study are published in a technical report.[2]

The results from both of these studies indicated that high-performance topcoats could be developed from water-dispersible, novel polymer resins. The former study validated the use of waterborne technology for formulating coatings and the latter determined that improvements could be achieved through manipulation of polymer backbone chemistry. The success obtained from both projects attests to the feasibility of a zero-VOC topcoat for Naval aircraft applications.

### 2.2 Strengths, Advantages, and Weaknesses

The zero-VOC topcoat offers many advantages; the greatest of these is the elimination of VOCs from the topcoating process. Other advantages include the avoidance of hard emission controls and fines, reduced waste generated costs and waste disposal costs, improved work space/facility environment, and maintenance of the operational readiness of the Fleet.

The main disadvantage of this material is the learning curve associated with the application of a new coating. Waterborne systems have different rheological properties than their solventborne predecessors and application procedures must be modified or changed completely. Therefore, periods of initial downtime will be experienced as workers attend training sessions to become familiar with the new coatings. Also, because most surface contaminants are organic, waterborne systems are more susceptible to pre-paint surface preparation. A zero-VOC coating system would be even more vulnerable to contaminants than previous waterborne systems because the latter contained small amounts of organic solvents. Much more care would have to be taken when preparing an aircraft for painting.

Some earlier versions of waterborne coatings experienced poor drying characteristics, including leveling, gloss, and use time (pot life). However, new dispersing agents and rheology additives have been able to rectify these problems.

### 2.3 Factors Influencing Cost and Performance

The new technology was developed to be a “drop-in” replacement for the standard system; standard operational conditions should have no negative effects. However, greater detail must be



DRAFT

given to surface preparation (see Section 2.2). Currently, the new material costs approximately 25% more than the standard topcoat, due to its experimental nature. Once the material is approved for use, the cost should be comparable to the existing polyurethane topcoat. Because the water is denser than most organic solvents, there is less overspray when using the new topcoat. In addition, two sites reported using approximately 20% less zero-VOC topcoat by volume when painting similar assets with the conventional solventborne topcoat.

# 3. Site/Facility Description

## 3.1 Background

Technology demonstrations will be conducted at NADEPs in Jacksonville, FL; Cherry Point, NC; North Island, CA; and NAVAIRSEFAC in Solomons, MD. Additionally, Warner-Robins Air Logistics Center, Warner Robins, GA (WR-ALC) will be utilized for demonstrations on USAF weapon systems component parts. Current aircraft painting at military depots requires compliance with federal and state environmental regulations. Incorporation of a zero-VOC waterborne topcoat will significantly reduce the VOC evolution from painting operations at these and other sites.

Rework activities utilize aircraft hangars, which provide a controlled environment of the weapon system that is undergoing overhaul. NADEP Jacksonville, FL, for instance, overhauls/reworks cargo-sized aircraft such as the P-3 Orion and the EA-6B Prowler. NADEP Jacksonville processes approximately 50 P-3 aircraft annually. Other military rework activities listed in the above paragraph, process other Type Model Series (TMS) such as the F/A-18, S-3, E-2, and F-14 aircraft at rates equal to or greater in number than the Jacksonville activity. NAVAIRSEFAC is the largest SE rework facility for the Navy and Marine Corps. Implementation of this new technology will eliminate the need for installation of extremely expensive control equipment (i.e. $1M per spray booth for VOC emission control and multi-filter systems for airborne HAPs).

Zero-VOC Topcoat has been applied to an H-46 at NADEP Cherry Point, the outer wing panel (OWP) of a C-2 and an F/A-18 at NADEP North Island, condemned aft cowlings from C-141 aircraft at WR-ALC, and an H-60 at Sikorsky Aircraft (Statford, CT). The OWP was painted at North Island and placed on an aircraft at NAS Norfolk, VA. Also, the following pieces of support equipment were painted at NAVAIRSEFAC, Solomons, MD: an electric-powered cart, a tow tractor, eight tow bars, a forklift, and a storage van. Zero-VOC Topcoat will be applied to a second F/A-18 at NADEP North Island, an EA-6B at NADEP Jacksonville, and off-aircraft components (TBD) at WR-ALC.



DRAFT

# 4. Demonstration Approach

## 4.1 Performance Objectives

The new material must, at a minimum, perform comparably to aircraft painted with the standard finishing system at approximately the same time frame. This overall objective was confirmed through coupon testing and in-flight testing as described in the JTP. For the in-flight evaluation, Navy and Air Force assets were painted with the zero-VOC topcoat at the Naval Aviation Depots (NADEPs) and WR-ALC. Periodic inspections for performance were scheduled with NAWCAD and facility representatives. The zero-VOC topcoat was substituted for the standard topcoat when the asset was scheduled for its final painting at the facility.

## 4.2 Physical Setup and Operation

An aircraft or target area of the aircraft (as determined by the JTP) was selected. The chosen asset will observe a significant amount of operational exposure to the environment representative of the demonstration site. See Table 1 below for details.

**TABLE 1. Demonstration Site Details.**

| Site | Asset | Areas to be Coated |
|---|---|---|
| NADEP Jacksonville | EA-6B | Entire aircraft |
| NADEP Cherry Point | H-46 | Access doors and ramp (approximately 100 sq. ft.) |
| NADEP North Island | OWPs for C-2 | Entire wing panel (assembled at NAS Norfolk) |
| | F/A-18 (2) | Entire aircraft |
| NAVAIRSEFAC, Solomons | Tow bars<br>Tow tractor<br>Storage van<br>Electric cart<br>Forklift | Entire assets |
| Warner Robins ALC | C-141 aft cowlings (6)<br>C-130 | Entire assets<br>TBD |
| Sikorsky Aircraft | H-60 | Entire aircraft |



DRAFT

The aircraft should be entering the "Standard Depot Level Maintenance" (SDLM) cycle (or equivalent) to minimize impact to operational readiness and costs for removing aircraft from service. The candidate topcoat will be applied by the high-volume-low-pressure (HVLP) method. The pressure was set at a minimum of 90 p.s.i., resulting in the maximum pressure of 10 psi at the gun tip.

The aircraft or target areas are being inspected at approximate intervals of three months, six months, one year, and two years in accordance with applicable maintenance requirement cards (MRCs). The inspections can be performed at natural breaks in service such as periods of pre- or post-deployment corrosion inspection, or phase/isochronal maintenance inspections. The areas coated with the candidate system will be compared to areas coated with the standard coating system. In the case of an entire aircraft, the comparison will be to similar aircraft coated with the standard system at approximately the same time and exposed to a similar environment. Verification such as historical corrosion records, maintenance data reports, and prevention and treatment documentation (MDR-11) may be used for comparison. Acceptable performance shall be at least two years of operational service, including a minimum of two squadron carrier deployments (Navy aircraft), with the candidate material performing at least as well as the standard system (JTP Section 3.26).

### 4.3 Testing Procedures

For laboratory testing, a high-gloss white and a low-gloss gray formulation were evaluated as per the JTP; the results are summarized in the Joint Test Report (JTR) in Appendix A for each manufacturer of a potential alternative. In this case, only Deft Inc. produces a fully formulated zero-VOC topcoat. Manufacturers have their choice of shade of the above colors to submit; however, the gray is usually federal standard color number 36375 and the white is 17925 because these colors are most widely utilized. These were the colors submitted by Deft.

Once the alternatives passed the majority of testing described above and the stakeholders were comfortable with the results, the in-service testing began (JTP Section 3.21). The decision as to what assets (and portion thereof) is up to the particular service/activity.

### 4.4 Evaluation Procedures

Refer to the individual test descriptions in the JTP in Reference 1.

## 5. Performance Assessment

### 5.1 Performance Data

Once the majority of the JTP tests were passed, the Navy and the Air Force chose to coat condemned C-141 aft cowlings with the zero-VOC topcoat, the standard aircraft topcoat (MIL-



DRAFT

PRF-85285), and an advanced performance fluoro-urethane topcoat. The cowlings were exposed on the south side of the materials building at WR-ALC for 14 months, as shown in Figure 2. The cowlings were washed every 60 days according to the Air Force's T.O. 1-1-8. After the 14 months, chalking was observed on the standard system and the zero-VOC; the worst chalking was present on the zero-VOC. The cause of the chalking had to be determined before applying the coating to deployed assets. Deft believed the chalking was due to the small amount of resin

**FIGURE 2. Condemned C-141 aft cowlings exposed at WR-ALC for 14 months.**

at the surface (necessary for low gloss coatings). A new version was formulated to raise the gloss to just below 5 (maximum gloss allowed for camouflage coatings, see JTP Section 3.8); this version is designated ZVOC2.

A stakeholder meeting was called to propose additional laboratory testing to test the Deft hypothesis. Two tests were proposed: UV-B/condensation cycles (QUV-B) and extended Xe-Arc weathering (JTP Section 3.5). The QUV-B was chosen because of its severity in the hope that the problem would manifest itself quickly. Xe-Arc weathering more closely resembles natural weathering, but takes a longer period of time to show any discrepancies. Panels exposed to QUV-B were also washed according to T.O. 1-1-8 to determine any deleterious effects from the washing procedure; Xe-Arc-exposed panels were not washed. The three coating systems described in the paragraph above were exposed to both the QUV-B and the Xe-Arc along with ZVOC2.

Although QUV-B exposed panels showed color differences among the standard, zero-VOC, and ZVOC2 after 1000 hours, it did not represent the behavior observed on the cowlings at WR-ALC



DRAFT

after 14 months of outdoor exposure. Values obtained from panels that were subjected to the wash procedure did not vary appreciably (more than 0.3) from those that were unwashed, so it appears that any effects due to cleaning are negligible. However, at 1500 hours of Xe-Arc exposure, a significant color change was observed on panels coated with the original zero-VOC, indicative of chalking. Much smaller differences were observed after Xe-Arc exposure on the panels coated with the original zero-VOC after 1500 hours; even smaller color differences were observed on panels coated with the advanced performance topcoat. This behavior did mimic the outdoor exposure of the cowlings at WR-ALC. The standard topcoat and ZVOC2 panels had substantially less color changes after 1500 hours of Xe-Arc exposure, with ZVOC2 performing somewhat better. It was decided to go forward with the ZVOC2 formulation because the data suggest that it will exhibit less chalking outdoors that the standard material. A summary of the color-change data (see Section 3.5 in Reference 1) after exposure to QUV-B and Xe-Arc artificial weathering is given in Table 2.

ZVOC2 has been used at the other demonstration sites. The high-gloss white was used at NAVAIRSEFAC Solomons, MD and on the C-2 outer wing panels. After the assets are coated, they will be tested according to Section 3.26 of the JTP. The test criteria and proposed test assets are summarized in Section 5.2 of this document. The service POCs are responsible for making arrangements with the paint shop and program office personnel, as well as coordinating with the principal investigator for the actual painting of the asset and follow-up inspections. Figures 3, 4, and 5 show some assets painted to date with the zero-VOC topcoat.

**(A)**

**(B)**

**FIGURE 3. Zero-VOC topcoat application to (A) outer wing panel of C-2 and (B) F/A-18D at NADEP NORIS**



DRAFT

**FIGURE 4. CH-60S helicopter painted with zero-VOC topcoat at Sikorsky Aircraft.**

**FIGURE 5. Tow bars painted with zero-VOC topcoat at NAVAIRSEFAC, Solomons, MD. Tow bars are deployed on USS Harry S Truman.**



DRAFT

## 5.2 Data Assessment

The results summarized in the JTR in Appendix A and those summarized above should provide the stakeholders the confidence that the zero-VOC waterborne polyurethane topcoat will perform as expected and meet the objectives of the demonstration. Also, all laboratory testing was performed at the Organic Coatings Laboratory, which is located in the Aerospace Materials Division at the Naval Air Warfare Center, Patuxent River. The Aerospace Materials Division is an ISO 9001 certified organization.

**TABLE 2. Color Change Data for the Zero-VOC Topcoats and Other Coatings After Exposure to QUV-B and Xe-Arc Artificial Weathering**

| **Primer ®** | **Exposure Time (hrs.)** | **MIL-PRF-23377[a]** | | **MIL-PRF-85582, C2, TI[b]** | | **MIL-PRF-85582, C1, TII[c]** | | **TT-P-2760[d]** | |
|---|---|---|---|---|---|---|---|---|---|
| | | QUV-B | Xe-Arc | QUV-B | Xe-Arc | QUV-B | Xe-Arc | QUV-B | Xe-Arc |
| **Topcoat** | | | | | | | | | |
| | | | | | | | | | |
| **Original Zero-VOC** | 500 | 0.33 | 0.40 | 0.33 | 0.47 | 0.73 | 0.59 | 0.44 | 0.37 |
| | 1000 | 2.10 | 2.41 | 3.72 | 2.09 | 4.14 | 2.52 | 4.33 | 3.64 |
| | 1500 | — | 6.36 | — | 5.25 | — | 5.02 | — | 7.37 |
| | | | | | | | | | |
| **ZVOC2** | 500 | 1.81 | 0.71 | 1.91 | 0.61 | 1.97 | 0.71 | 0.55 | 0.30 |
| | 1000 | 1.81 | 1.33 | 2.11 | 1.40 | 2.11 | 1.41 | 0.66 | 0.58 |
| | 1500 | — | 1.91 | — | 1.81 | — | 1.91 | — | 1.27 |
| | | | | | | | | | |
| **MIL-PRF-85285** | 500 | 3.44 | 2.12 | 3.68 | 0.83 | 3.44 | 1.71 | 2.65 | 1.31 |
| | 1000 | 4.55 | 2.50 | 4.16 | 2.30 | 4.85 | 2.20 | 4.26 | 2.21 |
| | 1500 | — | 3.01 | — | 2.62 | — | 2.71 | — | 2.51 |
| | | | | | | | | | |
| **Advanced Performance Coating** | 500 | 0.25 | 0.32 | 0.51 | 0.32 | 0.32 | 0.33 | 0.23 | 0.17 |
| | 1000 | 0.56 | 0.46 | 0.92 | 0.37 | 0.62 | 0.46 | 0.56 | 0.37 |
| | 1500 | — | 0.45 | — | 0.41 | — | 0.42 | — | 0.24 |

[a,d]Refer to JTR in Appendix A for description of primers.
[b]Primer is Class C2, Type I from Deft, Inc. Product number is 44-GN-72.
[c]Primer is Class C1, Type II from Deft, Inc. Product number is 44-GN-8A.

## 5.2 Technology Comparison

The technical performance of the zero-VOC topcoat was compared to the standard aircraft topcoat, which conforms to MIL-PRF-85285. Results are summarized in the JTR found in Appendix A.



DRAFT

The zero-VOC topcoat was also compared to an advanced performance topcoat (APC), which is based on novel fluoro-urethane resin chemistry. The APC exhibited superior resistance to artificial weathering, as shown in Table 2, and is expected to extend the life of aircraft topcoats from three to four years to eight years. The environmental benefit to the APC is reduced number of repaint cycles and field touch-up.

Presently, the APC is formulated at 420 g/L (maximum VOC allowed for compliance). MIL-PRF-85285 specification testing at NAWCAD revealed some discrepancies with the APC. Gloss white specimens: A) became heavily stained when subjected to lubricating oil (JTP Section 3.12), B) blistered when exposed to humidity resistance test (JTP Section 3.11), and C) underwent a significant color change when subjected to heat ($\Delta E$ of 4.8, JTP Section 3.9). Camouflage gray specimens: A) exhibited poor cleanability (JTP Section 3.6) and B) marginal flexibility with a 20% elongation in impact flexibility (JTP Section 3.14). NAWCAD has proposed a five-year project under the Future Naval Capabilities – Total Ownership Cost Program to improve this promising technology and take advantage of its superior resistance to UV while lowering the VOC content.

# 6. Cost Assessment

## 6.1 Cost Performance

The cost performance criteria shall address economic as well as environmental issues and must be performed from a corporate point-of-view (i.e., how does this technology impact all of DOD). These analyses shall include, at a minimum; cost benefit analysis (CBA), hazardous materials data, and hazardous waste data. Our plan is outlined below.

Cost performance information is essential to keep current project funding levels and, more importantly, to program for current and future P2 projects. Furthermore, the impact analysis will support the Acquisition Support Process as outlined in the NAVAIR Corporate Environmental Management Plan. Phase 2 of the Acquisition Support Process requires the establishment of solutions and to set a course of action in addressing operational requirements. In Phase 3, the sponsor will support the proposed solutions that will have the greatest benefit to the acquisition community. Impact studies and analysis will support both phases of the decision making process. This approach will streamline the project line built on a firm justification foundation, ultimately providing better products and better serving the end customer.

SAIC, Inc. performed a CBA for the zero-VOC topcoat based on the ECAM methodology.[3] The preferred analytical methods are payback (months/years), return on investment (ROI), and net present value (NPV). The payback analysis can be used for initial budget estimates, while the ROI and NPV are more detailed and suitable for large investments. The full CBA is attached as Appendix E.



DRAFT

### 6.2 Cost Comparisons to Conventional and Other Technologies

Refer to the CBA in Appendix E.

## 7. Regulatory Issues

### 7.1 Approach to Regulatory and End-User Acceptance

Numerous federal and state environmental regulations apply to paints and coatings. The largest drivers are Executive Orders 12586 and 13148. Enacted by President Clinton in August 1993, Executive Order 12586 requires DOD activities to reduce the transport of hazardous materials from their activity by 50% from their activity by 1999. Enacted in April 2000, Executive Order 13148 requires "Greening the Government" by additional 40-50% reductions in toxic/hazardous chemical use and emissions by the end of 2006. Also, the California SCAQMD and California air resources Board (CARB) rulings have eliminated the utilization of chromium in manufacturing/industry. Follow-on rulings are anticipated to be even more stringent than those previously enacted. Use of a zero-VOC topcoat goes beyond compliance with these and future regulations because the material is non-toxic and generates no hazardous emissions and/or waste.

## 8. Stakeholder/End-User Issues

The end users for this technology will be all DOD weapons systems that incorporate MIL-PRF-85285 polyurethane topcoat in their finishing system. Because the technology is a replacement for MIL-PRF-85285, the majority of the testing is based on this specification. Successful laboratory testing followed by favorable field demonstrations (addressed in the JTP Section 3.26) will allow for transition of this technology to the user community. JTP endorsements were received from NAVAIR 4.3.4 (Aerospace Materials Division), all NADEPs, and the following Air Force program offices: Corrosion Program Office, C-130, C-141, C-5, Vehicles, F-15, and helicopters.



DRAFT

# 9. Technology Implementation

## 9.1 DoD Need

Painting and depainting operations are a significant source of hazardous waste for the Department of Defense (DoD).[4] The environmental impact results largely from the emission of heavy metal compounds and VOCs that are contained in primer and topcoat formulations, which are released during painting operations as HAPs. Despite an 80% reduction in VOC emissions over the four-year period from 1993-1997, the NADEPs typically discharge 60,000 pounds of VOCs per year from coatings operations. The costs related to hazardous waste have also risen dramatically - by more than 20% per year at one NADEP. Hard controls can cost up to $1M/hangar and fines up to $25K/day/facility. Downtime due to non-compliance would significantly affect force readiness. Army Research Laboratory documented the Army's hazardous waste generation from coating related operations to be even higher: 680 tons of painting wastes at 28 operation sites and a staggering 2,000 tons associated with depainting at 16 locations. Their Marine Corps estimation of VOC emissions from primers and topcoats was 80 tons. Air Force estimates indicate that painting operations cost over $150M per year, and hazardous materials comprise a significant percentage of that amount.[5] Hazardous ingredients in primer and coatings formulations must be reduced to meet new environmental regulations and protect worker safety.

## 9.2 Transition

Ongoing and near future demonstrations will be evaluated as per Section 3.26 of the JTP. After successful completion of JTP Section 3.26, the transition of technology will be accomplished through technical manual revisions, specification revisions (MIL-PRF-85285C), and aircraft finishing specification (e.g. MIL-STD-7179) modifications through Integrated Product Teams (IPT) and the Acquisition Environmental Product Support Team (AEPST). Additional changes will be promulgated through the services' corrosion control manuals (NAVAIR 01-1A-509, T.O. 1-1-691, TM 1-1500-344-23) and to the Air Force's paint application manual T.O. 1-1-8.

Potential transition to the OEM community has been identified. Sikorsky Aircraft contacted NAWCAD in April 1998 for information regarding the proposed demonstrations under the ESTCP project. Sikorsky Aerospace coated an H-60 helicopter with the zero-VOC topcoat on 14 November 2000. Also, Hamilton Standard developed specification HS 7136 Rev F for use of this technology on aircraft propeller blades.

Through the LMTCE, a detailed technology transition plan was developed that includes the revisions and modifications summarized above. The plan is in an MS Project file with a work breakdown structure format and divided into four main elements: technology area (coatings); RDT&E (laboratory/field testing, etc.); logistics, engineering, and facilities management (manual and specification revision, supply, facilities, training course development, packaging, etc.); and



DRAFT

deployment (local process/engineering specifications, HAZMAT management, training, permits, etc.). The RDT&E portion of the technology transition plan for the zero-VOC waterborne polyurethane topcoat is shown in Figure 6. The logistics, engineering, and facilities management portion is shown in Figure 7. The deployment portion is shown in Figure 8.

| ID | Topcoat | Duration | Start | Finish |
|---|---|---|---|---|
| 1 | | **2813 days** | **Mon 1/1/96** | **Sat 3/27/04** |
| 2 | Zero VOC Topcoat Demonstration & Testing | 450 days | Mon 1/1/96 | Sat 6/7/97 |
| 3 | Low VOC Topcoat Field Evaluation | 715 days | Wed 8/19/98 | Sat 9/30/00 |
| 4 | AV-8B testing at Cherry Point | 534 days | Wed 8/19/98 | Sat 9/30/00 |
| 5 | Inspect AV-8B doors coated with Low VOC Tpct. – 8/99 | 5 days | Mon 8/30/99 | Fri 9/3/99 |
| 6 | Zero VOC Topcoat Evaluation | **2332 days** | **Mon 1/1/96** | **Mon 12/2/02** |
| 7 | Complete Joint Test Protocol – 10/98 | 1 day | Mon 1/1/96 | Mon 1/1/96 |
| 8 | Issue first draft Joint Test Report to Stakeholders – 2/99 | 1 day | Fri 2/26/99 | Fri 2/26/99 |
| 9 | Conduct Test and Evaluation Program | **1263 days** | **Tue 6/1/99** | **Mon 12/2/02** |
| 10 | Paint C-2 Outer Wing Panel @ NADEP NORIS | 5 days | Tue 6/1/99 | Sat 6/5/99 |
| 11 | Paint CH-46 Components @ NADEP Cherry Point | 5 days | Wed 12/1/99 | Sun 12/5/99 |
| 12 | Environmental Testing at NAWC-AD Pax | 60 days | Sat 4/1/00 | Tue 5/30/00 |
| 13 | Paint fleet-traceable SE at NAVAIRSEFAC | 5 days | Sat 4/15/00 | Wed 4/19/00 |
| 14 | Paint H-60 @ Sikorsky | 2 days | Tue 11/14/00 | Wed 11/15/00 |
| 15 | Paint EA-6B @ NADEP Jax | 2 days | Thu 2/15/01 | Fri 2/16/01 |
| 16 | Paint F/A-18 @ NADEP NORIS | 2 days | Tue 12/5/00 | Wed 12/6/00 |
| 17 | Paint C-130 @ WR-ALC | 2 days | Mon 6/4/01 | Tue 6/5/01 |
| 18 | Inspect CH-46 painted components | 5 days | Wed 6/6/01 | Sun 6/10/01 |
| 19 | Continuing Inspections | 365 days | Wed 6/6/01 | Wed 6/5/02 |
| 20 | Test Data Evaluation | 180 days | Thu 6/6/02 | Mon 12/2/02 |
| 21 | MIL-PRF-85285 Spec Revision Engineering Approval | 60 days | Fri 10/4/02 | Mon 12/2/02 |
| 22 | **R&D Transition** | 1 day | Tue 12/3/02 | Tue 12/3/02 |

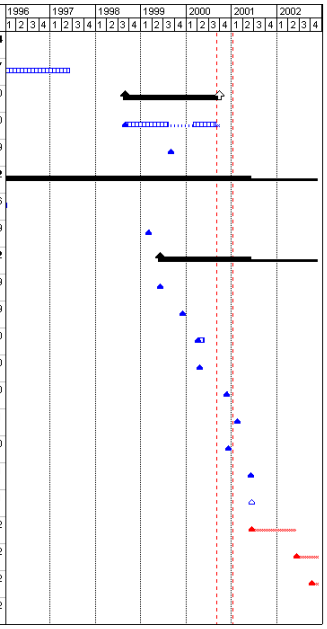


**FIGURE 6. RDT&E portion of the Technology Transition Plan for the Zero-VOC Waterborne Polyurethane Topcoat.**

| ID | Topcoat | Duration | Start | Finish |
|---|---|---|---|---|
| 23 | OMN BAM for FY01 | 30 days | Tue 2/1/00 | Wed 3/1/00 |
| 24 | Site/System Customer Development | 180 days | Thu 3/2/00 | Mon 8/28/00 |
| 25 | Coatings Transition Workshop | 1 day | Wed 1/5/00 | Wed 1/5/00 |
| 26 | MIL-PRF-85285 Spec Revision Coordination/Release | 210 days | Tue 12/3/02 | Mon 6/30/03 |
| 27 | Establish Supply Support | 30 days | Tue 7/1/03 | Wed 7/30/03 |
| 28 | Modify Qualified Parts List 85285 | 60 days | Thu 7/31/03 | Sun 9/28/03 |
| 29 | Update -509 Manual for MIL-PRF-85285 | 60 days | Thu 7/31/03 | Sun 9/28/03 |
| 30 | Update -509 Manual HMAUL for MIL-PRF-85285 | 60 days | Mon 9/29/03 | Thu 11/27/03 |
| 31 | NATEC Training Course Development/Change | 60 days | Tue 7/1/03 | Fri 8/29/03 |
| 32 | Environmental, Safety, and Health | 869 days | Fri 5/1/98 | Wed 11/29/00 |
| 33 | Compliance and Planning Assessment | 77 days | Sun 11/1/98 | Fri 1/29/99 |
| 34 | Pollution Prevention Impact Analysis | 50 days | Fri 5/1/98 | Sat 6/27/98 |
| 35 | Occupational Safety and Health Evaluation | 60 days | Sun 10/1/00 | Wed 11/29/00 |
| 36 | User, stakeholder and technical evaluation | 90 days | Tue 7/1/03 | Sun 9/28/03 |
| 37 | **NAVAIR Transition** | 1 day | Mon 9/29/03 | Mon 9/29/03 |

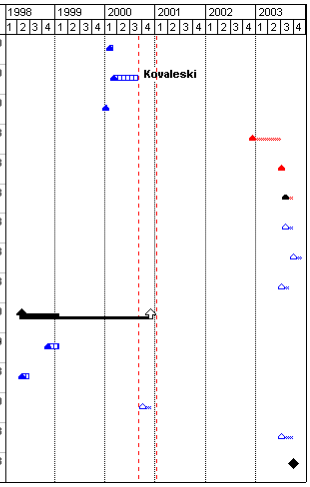


**FIGURE 7. Logistics, engineering, and facilities management portion of the technology transition plan for the zero-VOC waterborne polyurethane topcoat.**



DRAFT

| ID | Topcoat | Duration | Start | Finish |
|---|---|---|---|---|
| 38 | Update Aircraft Specs for MIL-PRF-85285 | 90 days | Tue 7/1/03 | Sun 9/28/03 |
| 39 | Local Process/Engineering Specifications - Revise | 30 days | Mon 9/29/03 | Tue 10/28/03 |
| 40 | Revise Shipboard HM List | 60 days | Wed 10/29/03 | Sat 12/27/03 |
| 41 | Update Hazardous Material AULs | 30 days | Sun 12/28/03 | Mon 1/26/04 |
| 42 | Revise AIMD/Squadron HM AUL | 60 days | Tue 1/27/04 | Fri 3/26/04 |
| 43 | Order/Receive Material | 90 days | Wed 10/29/03 | Mon 1/26/04 |
| 44 | Update Air Permits | 60 days | Wed 10/29/03 | Sat 12/27/03 |
| 45 | Technical Assessment - Final | 60 days | Tue 1/27/04 | Fri 3/26/04 |
| 46 | **Navy Transition** | 1 day | Sat 3/27/04 | Sat 3/27/04 |

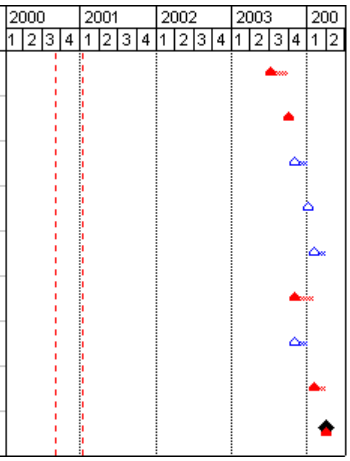


**FIGURE 8. Deployment portion of the technology transition plan for the zero-VOC waterborne polyurethane topcoat.**

## 10. Lessons Learned

The new coating is designed as a substitute for the high-solids polyurethane topcoat that conforms to MIL-PRF-85285. A one-for-one substitution is proposed; however, the following preparation is required before the material can be applied successfully.

The zero-VOC topcoat is a two-part system consisting of a pigmented polyol resin and an isocyanate-based curing agent. The two components are combined by hand or low-speed mechanical mixer. No high-speed mixing or paint shakers should be used at any time during the mixing process. After the components are thoroughly blended, the mixture is thinned to a viscosity of 18-20 seconds as measured by a #4 Ford cup with de-ionized water. In the field, the mixture would be thinned to 24-28 seconds as measured by a #2 Zahn cup. Thinning the mixture by approximately 25% by volume should result in the desired viscosity range in either case. The Zahn cup is readily available and can easily be placed in the admixed coating for quick measurement. If the measured viscosity is too high, further reduction with water may be done in 7-ml increments. The water should be de-ionized; tap water may be used only when de-ionized is not available. Thinning too much will result in a coating that runs and sags on application.

The admixed coating may be applied by conventional or high-volume, low-pressure (HVLP) spraying techniques. If HVLP is to be utilized, a high line pressure (about 90 psi) should be used to provide the maximum amount of atomization. Smaller droplets coalesce more easily than larger ones, resulting in a more uniform, smoother finish. Application methods such as plural component should be avoided as they use high shear forces to combine the two parts in the paint line.



DRAFT

Before any activity sprays the zero-VOC coating, the artisans should receive a day's training to effectively apply the material. This training is available from NAWCAD and Deft, Inc. All specifics will be documented in the specification and technical manual updates.

Because the zero-VOC topcoat will be used at sites that exhibit ranges of climates and painting conditions, it was necessary to determine the curing conditions at various temperatures and relative humidities. Table 3 shows the cure response of the zero-VOC topcoat as the time it takes the coating to achieve a tack-free status as a function of cure temperature and humidity. Throughout the temperature and humidity ranges, no changes were noted in the following properties: gloss, water sensitivity, chemical resistance, and physical properties.

**TABLE 3. Cure response of the zero-VOC topcoat as a function of temperature and relative humidity.**

| TEMPERATURE (°F) | RELATIVE HUMIDITY (%) | TACK-FREE TIME (hrs.) |
|---|---|---|
| | | |
| 40 | 90 | 10 |
| 40 | 50 | 10 |
| 40 | 10 | 10 |
| | | |
| 60 | 90 | 8 |
| 60 | 50 | 8 |
| 60 | 10 | 6 |
| | | |
| 77 | 90 | 6 |
| 77 | 50 | 5 |
| 77 | 10 | 4 |
| | | |
| 86 | 90 | 4 |
| 86 | 50 | 4 |
| 86 | 10 | 2 |
| | | |
| 100 | 90 | 1 |
| 100 | 50 | 1 |
| 100 | 10 | 1 |

Elevated temperature cure studies were also conducted to determine a procedure for accelerated curing of the zero-VOC topcoat. These studies are of interest to some component shop and support equipment activities that need to paint and cure in batches within designated shifts. The following procedure should be followed. The assets to be painted are sprayed and placed in a designated area for 30-60 minutes at ambient conditions to allow for water flash-off. This flash-off period prevents popping of the water through the semi-cured film. The temperature can then be elevated to a value shown in Table 4. The painted components must remain at the elevated temperature for the period of time designated for that temperature; this is also shown in Table 4.



DRAFT

After the designated time has elapsed, the components must be allowed to cool before they can be stacked or stored. Following the parameters in Table 4 will achieve a 90% cure.

**TABLE 4. Cure response of zero-VOC topcoat at elevated temperatures.**

| TIME | TEMPERATURE (°F) |
|---|---|
| | |
| 3 Hours | 125 |
| 90 Minutes | 160 |
| 60 Minutes | 200 |
| 15 Minutes | 250 |
| 10 Minutes | 300 |

Following the procedure above for elevated cures may cause the coating to have small runs and drips. If these are unacceptable, it is recommended that accelerated curing not be pursued. The manufacturer is aware of this situation and is working to adjust the formulation to accommodate elevated-temperature curing where necessary.

The planning of demonstrations at military/contractor rework facilities is difficult due to several factors. Issues such as workload, weather, asset availability, and personnel changes can affect the timetables for painting and deployment. The following suggestions are given for those who pursue new coating demonstrations. First, arrange for demonstrations on assets that will give you the widest variety of platforms. This way, the new technology will experience the most possible operating environments. Next, arrange for demonstrations at multiple locations. Not only will this help with the first suggestion, but it will also provide for alternatives should one site not have any available assets or an unusually heavy workload. Lastly, have as many persons available to assist the principal investigator and site point of contact when the demonstration finally is performed. One extra day of preparation, artisan training, and final instructions can make the difference between a successful demonstration and validation of a promising new technology and an uphill battle to repair poor performance perception.

## 11. References


1. *Joint Test Protocol for for Validation of Alternatives to Topcoats Containing Volatile Organic Compounds (VOCs) for Military Aerospace Applications*, developed under ESTCP Project Number 199802, dated 30 October 1998.

2. *High-Performance, Low Volatile Organic Compound Content Epoxy Systems for Naval Aircraft Coatings*, NAWCADPAX--96-41-TR, 28 December 1995.




DRAFT

3. *Environmental Cost Analysis Methodology (ECAM) Handbook*, National Defense Center for Environmental Excellence for the Environmental Security Technology Certification Program, Johnstown, Pennsylvania. November 1997. (To order, contact Mr. Robert Scola, P.E., Director, U.S. Army Industrial Ecology Center, AMSTA-AR-WET, Bldg. 171, Picatinny Arsenal, NJ 07806-5000).

4. Col. K Cornelius, "DoD Hazardous Waste Minimization Efforts," Presentation at the Fifth Aerospace Hazardous Waste Minimization Conference, Costa Mesa, CA, May 1990.

5. E. H. Kolcum, "USAF Analysis Identifies Cost of Corrosion," *Aviation Week and Space Technology*, p. 67, June 24, 1991.



DRAFT

# Appendix A
## Joint Test Report


DRAFT

# Appendix B

## Points of Contact

| Organization | POC/Phone | Address | E-mail Address |
|---|---|---|---|
| NAWCAD PAX (Financial) | Ms. Karen Baker<br>(301) 342-8063<br>Fax (301) 342-8062 | Commander<br>Comptroller 7612 Bldg 439 Suite F<br>NAWCAD<br>47710 Liljencranz Rd Unit 7<br>Patuxent River MD 20670-1545 | bakerka@navair.<br>navy.mil |
| NAWCAD PAX (Technical POC and PI) | Dr. Kevin Kovaleski<br>(301) 342-8049<br>Fax (302) 342-8062 | NAWCAD Code 4341 Bldg 2188<br>48066 Shaw Rd Unit 5<br>Patuxent River, MD 20670-1908 | kovaleskikj@navair.<br>navy.mil |
| Naval Aviation Depot Jacksonville | Mr. Jack Benfer<br>(904) 542-4516<br>x153<br>Fax (904) 542-4523 | NADEP Jacksonville<br>Code 4344, Bldg 793<br>Jacksonville, FL 32212 | benferje@<br>navair.navy.mil |
| Naval Aviation Depot Cherry Point | Mr. James Whitfield<br>(252) 464-7342<br>Fax (252) 464-8108 | NADEP Cherry Point<br>Code 4342, PSC Box 8021<br>Cherry Point, NC 28533 | whitfieldja@navair.<br>navy.mil |
| Naval Aviation Depot North Island | Mr. Tim Woods<br>(619) 545-9757<br>Fax (619) 545-7810 | NADEP North Island<br>Product Support Directorate<br>Code 43400 Bldg 469-1<br>San Diego, CA 92135-7058 | woodstr@navair.navy.<br>mil |
| Warner-Robins Air Logistics Center | Mr. Randy Ivey<br>(912) 926-4489<br>Fax (912) 926-1743 | WR-ALC<br>420 Second St. Suite 100<br>Robins AFB, GA 31908-1640 | randy.ivey@robins.af.<br>mil |
| NAVAIRSEFAC | Mr. David Semat<br>(410) 326-2000<br>Fax (410) 326-2801 | NAVAIRSEFAC Solomons<br>P.O. Box 54 Building 105<br>Solomons, MD 20688 | sematdl@navair.<br>navy.mil |
| Deft Coatings | Mr. Norm Gaul<br>(949) 476-6740<br>Fax (949) 474-7269 | Deft Coatings<br>17451 Von Karman Avenue<br>Irvine, CA 92714 | Norm@deftfinishes.com |
| Sikorsky Aircraft | Mr. Tom Rose<br>(203) 386-3619<br>Fax (203) 386-7523 | Sikorsky Aircraft<br>Mail Stop S312A2<br>6900 Main St.<br>Stratford, CT 06497-9129 | tcrose@sikorsky.com |



DRAFT

# Appendix C

## Data Archiving and Demonstration Plan

### C.1 Data Format

Factors such as temperature, relative humidity, application technique, and equipment were noted and documented during the paint application process. Utilization of a tape recorder and camera has ensured accurate and timely collection of data.

All data entries for demonstration follow-ups will be dated on the day of entry and signed or initialed by the person entering the data and written clearly in ink. Any change in entries will not obscure the original entry, will indicate the reason for the change, and will be dated and signed at the time of the change.

### C.2 Data Storage and Archiving Procedures

Data will be stored both electronically and as paper reports at the demonstration sites and at NAWCAD Patuxent River, and incorporated and retained as part of the principal investigators turnover file. Interested personnel may obtain demonstration results and the approved demonstration plan via written requests addressed to the author.



DRAFT

# Appendix D

## List of Acronyms

| | |
|---|---|
| AEPST | Aviation Environmental Product Support Team |
| APC | Advanced Performance Topcoat |
| AQMD | Air Quality Management District |
| ASTM | American Society for Testing and Materials |
| CARB | California Air Resources Board |
| CBA | Cost Benefit Analysis |
| CHPT | Cherry Point, NC |
| DOD | Department of Defense |
| ECAM | Environmental Cost Analysis Methodology |
| EPA | Environmental Protection Agency |
| ESH | Environmental, Safety, and Health |
| ESTCP | Environmental Security Technology Certification Program |
| HAP | Hazardous Air Pollutant |
| HASP | Health and Safety Plan |
| HAZMAT | Hazardous Material |
| HVLP | High Volume, Low Pressure |
| IPT | Integrated Product/Process Team |
| ISO | International Organization for Standardization |
| JAX | Jacksonville, FL |
| JTP | Joint Test Protocol |
| JTR | Joint Test Report |
| MRC | Maintenance Requirement Card |
| MDR | Maintenance Data Record |
| MEK | Methyl Ethyl Ketone |
| MIBK | Methyl Isobutyl Ketone |
| MILSPEC | Military Specification |
| NADEP | Naval Aviation Depot |
| NAVAIR | Naval Air Systems Command |
| NAVAIRSEFAC | Naval Air Support Equipment Facility |



DRAFT

## List of Acronyms (continued)

| | |
|---|---|
| NAWCAD | Naval Air Warfare Center Aircraft Division, Warminster, PA or Patuxent River, MD |
| NESHAP | National Emission Standards for Hazardous Air Pollutants |
| NORIS | North Island, CA |
| NPV | Net Present Value |
| OEM | Original Equipment Manufacturer |
| P2 | Pollution Prevention |
| POC | Point of Contact |
| QA/QC | Quality Assurance / Quality Control |
| QUV-B | UV-B/Condensation Cyclic Exposure |
| R&D | Research and Development |
| ROI | Return on Investment |
| SCAQMD | Southern California Air Quality Management District |
| SDLM | Standard Depot-Level Maintenance |
| SE | Support Equipment |
| SERDP | Strategic Environmental Research and Development Program |
| TBD | To Be Determined |
| TM | Technical Manual |
| TMS | Type/Model/Series |
| TO | Technical Order |
| TRI | Toxic Release Inventory |
| VOC | Volatile Organic Compound |
| WR-ALC | Warner Robins Air Logistics Center |
| WS | Weapons System |
| ZVOC2 | Zero-VOC Topcoat Reformulated for Chalking Resistance |



DRAFT

# Appendix E
## Cost Benefit Analysis

..\..\Zero-VOC CBA\ZEROVOCT_FinalJuly00.xls



DRAFT