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Final Report: Demonstration and Validation of Siloxane-Based Aircraft Topcoats that are Isocyanate-Free and Provide a Reduced Environmental Impact (ESTCP WP-201506)

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Polyurethane topcoats for aircraft and support equipment are qualified to MIL-PRF-85285 performance requirements. However, these topcoats contain hazardous isocyanate-functional molecules, which result in health issues for individuals who are exposed during paint operations. During this project, NRL-developed polysiloxane topcoats, which are free of isocyanates and lower in volatile solvents, demonstrated they can provide equivalent, and in some instances improved, laboratory and field performance compared to polyurethanes.

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LIST OF ACRONYMS

1K – Single-Component
2K – Two-Component
AA – Aluminum Alloy
AFB – Air Force Base
AFRL – Air Force Research Laboratory
AFT - Rear
AGE – Aerospace Ground Equipment
ASTM – American Society for Testing and Materials
ATT – Aircraft Tow Tractor
BUNO – Bureau Number
CAA – Clean Air Act
CIE – International Commission on Illumination
CVN – Carrier Version Nuclear
Delta E (ΔE) – Color Change
DFT – Dry Film Thickness
DoD – Department of Defense
DoM – Date of Manufacture
EPA – Environmental Protection Agency
EPCRA – Emergency Planning and Community Right-to-Know Act
ESOH – Environmental Safety and Health
ESTCP – Environmental Security Technology Certification Program
Fp – Flash Point
FRC – Fleet Readiness Center
FWD – Forward
GLP – Good Laboratory Practice
GSE – Ground Support Equipment
GU – Gloss Unit
HAP – Hazardous Air Pollutant
HAZMAT – Hazardous Material
HDI – Hexamethylene Diisocyanate
HVLP – High Volume Low Pressure
IgG – Immunoglobulin G
IH – Industrial Hygiene
IITRI – Illinois Institute of Technology Research Institute
IPDI – Isophorone Diisocyanate
JTP – Joint Test Protocol
LC50 – Limit Concentration at 50% Deaths
LCA – Life Cycle Analysis
MALS – Marine Aviation Logistics Squadron
MCAB – Marine Corps Air Base

MCAS – Marine Corps Air Station
MDMC – Marine Depot Maintenance Command
MEK – Methyl Ethyl Ketone
Mg-RP – Magnesium Rich Primer
MRTT – Mid Range Tow Tractor
NAS – Naval Air Station
NAVAIR – Naval Air Systems Command
NAWC-AD – Naval Air Warfare Center – Aircraft Division
NESHAP – National Emission Standards for Hazardous Air Pollutants
NCP – Niles Chemical Paint
NIOSH – National Institute for Occupational Safety and Health
NRL – Naval Research Laboratory
OML – Outer Mold Line
ONR – Office of Naval Research
OSHA – Occupational Safety and Health Administration
PEL – Permissible Exposure Limit
PMB – Plastic Media Blast
POTS – Pull Off Test Strength
PPA – Pollution Prevention Act
PPE – Personal Protective Equipment
PPS – Paint Preparation System
PUD – Polyurethane Dispersion
RH – Relative Humidity
REL – Recommended Exposure Limit
SDS – Safety Data Sheet
TDS – Technical Data Sheet
TLV – Threshold Limit Value
TPOC – Technical Point of Contact
TRI – Toxic Release Inventory
TSCA – Toxic Substance Control Act
TWA – Time Weight Average
TYCOM – Type Commander
USMC – United States Marine Corps
UV – Ultraviolet
VOC – Volatile Organic Compound
WFT – Wet Film Thickness
WOM – Weatherometer
WP – Weapons Systems and Platforms

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ABSTRACT

For over 30 years, the Department of Defense (DoD) has utilized solvent-borne polyurethane topcoats on the outer mold line (OML) (i.e., outer surface) of aviation assets and support equipment. However, these topcoats contain isocyanate-functional molecules and other chemicals that are hazardous to the environment. Exposure to isocyanates during polyurethane topcoat spray applications can result in numerous health issues, such as watery eyes, difficulty breathing, and sensitization, and assets must be isolated to prevent individuals from exposure to isocyanates in airborne mists (from spraying) and while the topcoat cures. Traditional polyurethane aerospace topcoats also possess hazardous air pollutants (HAPs), which are carcinogenic, including high levels (i.e., up to 420 g/l) of volatile organic compounds (VOCs), which evaporate into the atmosphere and pollute the air.

To address these environmental issues, the Naval Research Laboratory (NRL) developed two novel and environmentally friendly topcoat technologies: 1) a single-component (1K) polysiloxane topcoat, which is an all-in-one can system that does not require the metering and mixing of components, and 2) a two-component (2K) polysiloxane topcoat, which requires metering and mixing of components. These polysiloxane topcoats are free of hazardous isocyanates, free of HAPs, and lower in VOCs compared to DoD-qualified polyurethane aerospace topcoats. The polysiloxane technology was licensed to Niles Chemical Paint and Coatings (NCP Coatings) for optimization and commercialization, and multi-gallon quantities of camouflage (i.e., low-gloss) gray, semi-gloss gray, and gloss white topcoats were produced for testing to MIL-PRF-85285, MIL-PRF-32239, MIL-PRF-81352, and extended laboratory performance requirements, including application on scrap aircraft components and the entire OML of active DoD assets. These assets were then utilized in the field (e.g., at depots, aboard aircraft carriers) under normal operating conditions for a period of 1-2 years, and assets painted with a MIL-PRF-85285 qualified 2K polyurethane topcoat were used for comparative purposes. During all demonstrations, the isocyanate-free and HAP-free polysiloxane topcoats demonstrated equivalent, and in a few instances better, field performance (e.g., corrosion resistance, weatherability) compared to the qualified polyurethane topcoat. Use of the polysiloxane topcoats on assets also resulted in reduced VOC emissions, reduced preparation and application times, and a reduction in the generation of hazardous paint waste. These performance characteristics validated that the polysiloxane topcoats can be an environmentally friendly drop-in replacement for MIL-PRF-85285 qualified 2K polyurethane topcoats without sacrificing performance.

The 1K camouflage gray and 2K gloss white polysiloxane topcoats, as produced by NCP Coatings, where approved by the Naval Air Systems Command (NAVAIR) and listed on the qualified products database (QPD) as MIL-PRF-85285F, Type I/IV, Class NH, Form S, Grade N and Type II, Class NH, Form M, Grade N products, respectively, on August 19, 2022. Plans to revise MIL-PRF-81352 are also underway so the 1K camouflage gray polysiloxane topcoat can be fully qualified and listed on the QPD as an aircraft touch-up topcoat. Currently, the cost of the polysiloxane topcoats are similar to qualified Type IV polyurethanes.

This project was a collaboration between individuals at NRL, Naval Air Warfare Center – Aircraft Division (NAWC-AD), Air Force Research Laboratory (AFRL), NCP Coatings, Navy and Marine Corps installations, and Air Force bases. Funding for this project (WP-201506) was provided by the Environmental Security Technology Certification Program (ESTCP), Weapons Systems and Platforms (WP) Office.

EXECUTIVE SUMMARY

Polyurethane topcoats have been used on the outer mold line (OML) of DoD aircraft (i.e., fixed and rotary wing) and ground support equipment (GSE) for several decades. These topcoats are two-component (2K) systems that provide visual camouflage, protect the underlying anti-corrosive epoxy primer against degradation from sunlight and hydrocarbons (e.g., fuel, engine oil), and provide an initial barrier to permeation by water and corrosive salts. Since the 1980s, these topcoats have been governed by the performance requirements found in MIL-PRF-85285, which superseded the requirements in MIL-C-85285(AS). Polyurethane topcoats provide exception performance, although they contain hazardous isocyanate-functional molecules, such as 1,6-hexamethylene diisocyanate (HDI) and homopolymers of HDI, including hazardous air pollutants (HAPs) in the form of volatile molecules. Exposure to isocyanates during polyurethane topcoat spray applications can result in severe health issues, such as watery eyes, coughing, shortness of breath, and sensitization, and HAP solvents, such as xylenes, are known or suspected carcinogens. Furthermore, these polyurethane topcoats possess high levels (i.e., up to 420 g/l) of volatile organic compounds (VOCs) in the form of organic solvents, which evaporate into the atmosphere and pollute the air.

To address these issues, the U.S. Naval Research Laboratory (NRL) developed two novel and environmentally friendly topcoat technologies: 1) a single-component (1K) polysiloxane topcoat, which is a user-friendly, all-in-one can system that does not require the metering and mixing of components, and 2) a two-component polysiloxane topcoat, which requires metering and mixing of components in a 4:1 mix ratio (by volume). The 1K topcoat is an isocyanate-free and HAP-free solvent borne system that is based on moisture-curable organosilane polymers, and it contains either 286 g/l VOCs (for camouflage gray finish) or 98 g/l VOCs (for semi-gloss gray finish) depending on the formulation. The 2K topcoat is an isocyanate-free and HAP-free solvent borne system that is based on an epoxy-functional polysiloxane polymer and amine-functional oligomers, and it contains 65 g/l VOCs when formulated as a gloss white finish. The technology was licensed to NCP Coatings, LLC for commercialization, and under this project NRL collaborated with chemists at NCP to optimize the various topcoat formulations and produce multi-gallon quantities. A gallon can of manufactured 1K camouflage gray polysiloxane topcoat, in FED-STD-595 #36375 medium gray color, is shown in Figure E1a, whereas a gallon kit of 2K gloss white polysiloxane topcoat, in FED-STD-595 #17925 color, is shown in figure E1b.

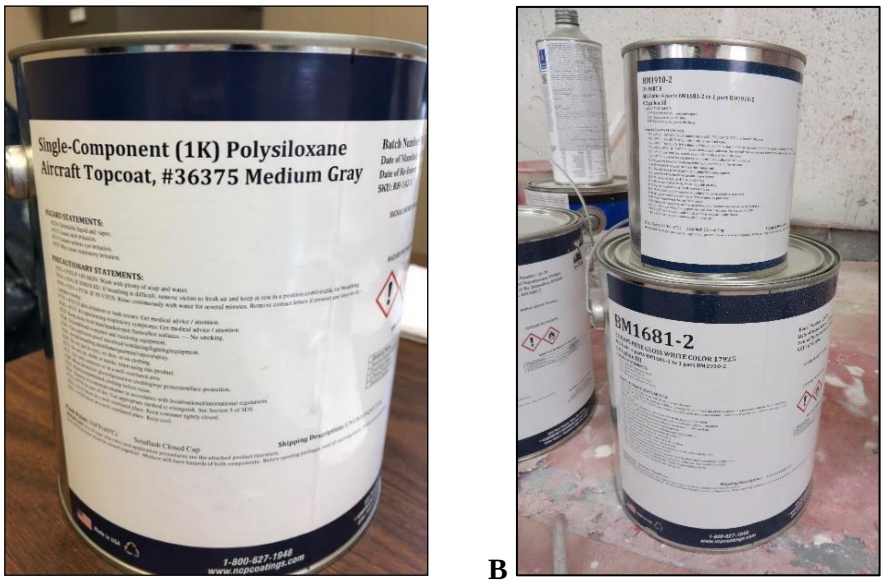

Fig. E1 — Polysiloxane topcoats from NCP Coatings: a) gallon can of 1K camouflage gray and b) gallon kit of 2K gloss white.

The objectives of this project were four-fold: 1) the main objective was to validate that the polysiloxane topcoats could provide equivalent, or enhanced, field performance compared to MIL-PRF-85285 qualified polyurethane topcoats when demonstrated on active aircraft and support equipment, 2) prove that the polysiloxane topcoats were free of hazardous isocyanates and possessed reduced inhalation toxicity compared to polyurethane topcoats, 3) demonstrate that applications of the polysiloxane topcoats at end-user facilities would result in reduced preparation times, reduced paint consumption, and reduced VOC emissions compared to qualified polyurethane topcoats, and 4) demonstrate that the single-component polysiloxane topcoat was user-friendly and would generated minimal-to-zero hazardous paint waste compared to qualified polyurethane topcoats.

Isocyanate-based polyurethane topcoats were the main target Hazardous Material (HazMat) to be eliminated during this project. Table 1 summarizes the target HazMat, including the process, current specifications, affected programs, and areas of application for the polysiloxane topcoats. The isocyanate-free, HAP-free, and lower VOC polysiloxane topcoats were tested to numerous laboratory performance requirements over chromate and non-chromate epoxy primers, then applied in the field on active DoD aircraft and support equipment using the same equipment and processes that are commonly used to apply qualified polyurethane topcoats.

Table E1 — Target HazMat Summary.

Target HazMat	**Current Process**	**Current Specifications**	**Candidate Parts & Substrates**	**Affected Programs**	**Application Areas**
Isocyanate-containing polyurethane topcoats	Spray application	MIL-PRF-85285; MIL-PRF-32239	Chromate & non-chromate stack-ups consisting of a primer, pretreatment, and metal substrate	DoD aviation platforms and support equipment	Entire exterior surface of aircraft and support equipment

Multi-gallon quantities of a 1K camouflage gray polysiloxane topcoat, a 1K camouflage gray polysiloxane touch-up topcoat, a 1K semi-gloss gray polysiloxane topcoat, and a 2K gloss white polysiloxane topcoat were produced by NCP Coatings during this project. A 1K gloss white polysiloxane topcoat was also produced by NCP Coatings, but only in quart quantities. Topcoat spray applications and limited testing were conducted by NCP Coatings, followed by topcoat spray applications and testing to the majority of MIL-PRF-85285, MIL-PRF-32239, and MIL-PRF-81352 performance requirements, including extended performance requirements, at the Naval Air Warfare Center – Aircraft Division (NAWC-AD) and Air Force Research Laboratory (AFRL). Laboratory test results showed that the 1K camouflage gray polysiloxane topcoat over a chromate-containing primer met MIL-PRF-85285, Type IV performance requirements and was similar to a MIL-PRF-85285, Type IV qualified 2K camouflage gray polyurethane topcoat over the same primer. However, the 1K camouflage gray polysiloxane topcoat over a non-chromate primer did not meet all MIL-PRF-32239 performance requirements as a coating system, yet provided slightly better performance overall than a MIL-PRF-85285, Type IV qualified 2K camouflage gray polyurethane topcoat over the same primer. Furthermore, a fast-curing 1K camouflage gray polysiloxane topcoat, when packaged as a touch-up kit, met all MIL-PRF-81352 (aircraft touch-up) performance requirements. Additionally, laboratory test results showed that the 2K gloss white polysiloxane topcoat had slightly better performance than a MIL-PRF-85285, Type II qualified 2K gloss white polyurethane topcoat. Topcoats that met laboratory performance requirements were then used by DoD painters to tune spray gun parameters and

paint scrap components (e.g., aircraft engine inlets), followed by application on Navy, Marine Corps, and Air Force assets for field demonstration and validation.

The 1K camouflage gray polysiloxane topcoat, in #36375 medium gray and #35237 blue gray colors, was applied on the entire OML of three AH-1Z Viper helicopters at Marine Corps Base Camp Pendleton, California, including the entire OML of two UH-1Y Venom helicopters at Marine Corps Air Station New River, Jacksonville, North Carolina (figure E2). The 1K camouflage gray polysiloxane touch-up topcoat, in #36375 medium gray, was used on small areas of a F/A-18E Super Hornet and other aircraft at Naval Air Station (NAS) Oceana, Virginia Beach, Virginia and NAS Whidbey, Washington. The 1K semi-gloss gray polysiloxane topcoat, in #26173 dark gray color, was applied on two B4 maintenance stands at MacDill Air Force Base, Tampa, Florida. The 2K gloss white polysiloxane topcoat, in #17925 white color, was applied on the entire exterior of one Mid-Range Tow Tractor (MRTT) at NAS Oceana, one aircraft tow tractor (ATT) at Fleet Readiness Center (FRC) Solomon's, and one mobile facility unit at Marine Depot Maintenance Command (MDMC) Albany, Georgia. These assets were then operated under normal conditions in the field (i.e., at depots, aboard an aircraft carrier) for a period of 1-2 years, and periodic inspections of the topcoats were conducted to assess qualitative (e.g., mechanical damage, blisters, visual comparison to assets painted with qualified polyurethane topcoats) and quantitative (e.g., color and gloss change) performance requirements.

Fig. E2 — AH-1Z Viper at Camp Pendleton after the entire exterior was painted and stenciled with single-component (1K) camouflage gray polysiloxane topcoats.

After approximately 2 years of service, the 1K camouflage gray polysiloxane topcoats on the exterior of three AH-1Z and two UH-1Y aircraft were in good condition with minimal mechanical damage (e.g., scratches) and no signs of blistering, delamination, cracking, damage due to fluids, or facial corrosion. All aircraft were contaminated with soot and grease during inspections, especially on area behind the engines (e.g., top of tail boom, horizontal stabilizers), yet the UH-1Ys were significantly more contaminated than the AH-1Zs because they had not been washed. Minor staining was observed on a few of the aircraft, although it was difficult to determine if this was due to the use of unapproved cleaners, leaking engine oil, and/or degradation due to heat. The 1K camouflage gray polysiloxane topcoats on the AH-1Zs were successful at meeting the quantitative in-service weatherability criteria with a color change (ΔE) of ≤ 2.0 after 2 years of service, in addition to retaining their gloss (figure E3). The 1K camouflage gray topcoats on the UH-1Zs retained their gloss, but demonstrated a color change of 2.6-2.8 and 3.8-4.9 for the medium gray and blue gray colors, respectively. However, the degree of color change due to surface contamination remains unknown. Nevertheless, the topcoats on these aircraft were visually similar to AH-1Z and UH-1Y

aircraft on the flight line and in hangers that were painted with MIL-PRF-85285 qualified 2K polyurethane topcoats, and maintainers for the squadrons stated they could not visually distinguish between aircraft painted with the 1K polysiloxane topcoat and those with a 2K polyurethane topcoat, nor did they observe a difference in performance between the two topcoats. These results validated that the 1K camouflage gray polysiloxane topcoat can be an isocyanate-free drop-in replacement for MIL-PRF-85285, Type I and IV qualified polyurethane topcoats that are currently used on tactical aircraft.

Fig. E3 — Single-component (1K) camouflage gray polysiloxane topcoats on an AH-1Z Viper at Camp Pendleton after 2 years of service.

The camouflage gray polyurethane topcoat on several aircraft at NAS Oceana and NAS Whidbey was repaired using NCP's Smart Touch® touch-up kits, which contained a fast-curing 1K camouflage gray polysiloxane topcoat, a solvent reducer, a Preval® spray gun, and two brushes. Two small areas of a Navy F/A-18E Super Horner were repaired, one by spraying and one by brushing the 1K topcoat. The topcoat required less than 5 minutes to mix (i.e., once reduced for spraying), as opposed to up to 30 minutes to meter and mix a small volume of MIL-PRF-85285 qualified 2K polyurethane topcoat. Once applied, the 1K polysiloxane touch-up topcoat covered the underlying epoxy primer and blended well with the surrounding polyurethane topcoat. Squadron personnel stated the 1K camouflage gray polysiloxane touch-up kit was easy-to-use, did not require training, and had a more pleasant odor than the legacy polyurethane topcoats. To date, none of the squadrons have reported adhesion issues with the polysiloxane topcoat.

A 1K semi-gloss gray polysiloxane topcoat was spray-applied on two Air Force B4 maintenance stands at MacDill AFB. After 14-15 months of service, there was corrosion in areas where the coating system was mechanically damaged during maintenance activities, although the topcoat showed no signs of blisters, cracking, delamination, damage due to heat and fluids, or loss of semi-gloss appearance. An Air Force service member stated the adhesion and color stability of this 1K polysiloxane topcoat was superior to the MIL-PRF-85285 qualified 2K semi-gloss gray polyurethane topcoat that is routinely applied on these stands, thus exceeding the visual in-service weatherability criteria. The enhanced performance of the 1K polysiloxane topcoat may increase the service life of B4 stands and reduce paint intervals, thereby reducing maintenance costs for the Air Force.

The 2K gloss white polysiloxane topcoat was demonstrated on the entire exterior of a Navy aircraft tow tractor (a.k.a. spotting dolly) aboard the flight deck of the USS Nimitz (CVN-68) for 25 months, a Navy mid-range tow tractor (MRTT) on the flight line at NAS Oceana for a period of 1 year, and a Marine Corps mobile facility at MDMC Albany for a period of 1 year. In all cases, the polysiloxane topcoat showed no signs of blistering, cracking, damage due to fluids, or damage due to heat during service. There was moderate mechanical damage to the polysiloxane topcoat on the spotting dolly due to chains being dropped on and dragged across the top of the asset, and corrosion was found on several edges where the coating system was applied thin. However, a MIL-PRF-85285, Type II qualified 2K gloss white polyurethane topcoat on the entire exterior a spotting dolly with 28 months of service, and at twice the film thickness of the polysiloxane topcoat, showed similar mechanical damage and corrosion issues as the 2K polysiloxane. Furthermore, the 2K gloss white polysiloxane topcoat on the spotting dolly had a color change of 0.87 and gloss retention of 76.4% after deployment, which were similar to the spotting dolly with the Type II 2K polyurethane topcoat. For the MRTT, nearly all surfaces painted with the 2K gloss white polysiloxane topcoat showed a color change of ≤2.0 after the 1 year service period, in addition to demonstrating better color and gloss retention than a Type II qualified 2K gloss white polyurethane topcoat on the doors, thereby exceeding both the qualitative and quantitative the in-service weatherability criteria (figure E4). Service members at NAS Oceana stated that the 2K gloss white polysiloxane topcoat was more chip and corrosion resistant than the qualified Type II polyurethane topcoat.

Fig. E4 — Two-component (2K) gloss white polysiloxane topcoat on MRTT at NAS Oceana after 1 years of service.

Coating applicators were able to paint an entire Marine Corps mobile facility, which is a large shipping container, by applying the 2K gloss white polysiloxane topcoat in two successive coats. Each coat was applied at 3-4 mils wet film thickness (WFT) via cross-coating, yet the topcoat did not sag, run, or drip. The painters stated that the same thickness cannot be achieved with a MIL-PRF-85285, Type II 2K gloss white polyurethane topcoat because it sags after 2 mils WFT. Additionally, the painters stated that the 2K gloss white polysiloxane topcoat was “one of the best coatings we have ever sprayed”, including the statement “we could have painted the entire mobile facility with just one coat”. Gloss measurements of the cured 2K polysiloxane topcoat showed an average gloss of 85.0 GU at 60 degrees, whereas a mobile facility that was painted with a Type II 2K gloss white polyurethane topcoat on the same day showed an average gloss of 75.0 GU at 60 degrees. These results validated that the 2K polysiloxane topcoat can meet, and likely exceed, the in-service performance of MIL-PRF-85285, Type II gloss white polyurethane topcoats.

During all field demonstrations, use of the polysiloxane topcoats resulted in reduced times for preparation and application, reduced volumes of applied material, and reduced VOC emissions compared to when using MIL-PRF-85285 qualified 2K polyurethane topcoats. For example, spray application of the 1K camouflage gray polysiloxane topcoat on an AH-1Z at Camp Pendleton consumed 6 gallons of material and emitted 14.3 pounds of VOCs, compared to 6.25 gallons and 21.9 pounds of emitted VOCs for a MIL-PRF-85285, Type I or IV qualified 2K camouflage gray polyurethane topcoat. With over 60 active AH-1Z aircraft (not including reserve aircraft) at Camp Pendleton this equates to a reduction of over 450 pounds of VOCs emitted into the air if all aircraft were painted with the 1K camouflage gray polysiloxane topcoat. In another example, spray application of the 2K gloss white polysiloxane topcoat on a mobile facility at MDMC Albany consumed approximately four gallons of topcoat and emitted 2.16 pounds of VOCs, compared to 5.0 gallons and 14.0 pounds of emitted VOCs for a MIL-PRF-85285, Type II qualified 2K gloss white polyurethane topcoat. This is a difference of 11.84 pounds, or about 7.5 times less emitted VOCs, by applying the polysiloxane topcoat. Furthermore, the 1K camouflage gray topcoat demonstrated that unused liquid material can be recovered from pressure pots and returned to the original containers for future use (e.g., stenciling), unlike mixed and unused 2K polyurethane topcoats that must be discarded as hazardous paint waste.

The NCP Coatings produced 1K camouflage gray and 2K gloss white polysiloxane topcoats where approved by NAVAIR and listed on the QPD as MIL-PRF-85285F, Type I/IV, Class NH, Form S, Grade N and Type II, Class NH, Form M, Grade N products, respectively, on August 19, 2022. NAVAIR also plans to revise MIL-PRF-81352 (aircraft touch-up topcoat) by adding a new "Type" for polysiloxane chemistry. Currently, the cost of the polysiloxane topcoats are similar to MIL-PRF-85285, Type IV qualified 2K polyurethane topcoats.

Throughout this project, the polysiloxane topcoats have demonstrated they can meet, and in several instances exceed, the laboratory and field performance requirements necessary for use on the exterior of DoD aircraft and support equipment. These results validate that the polysiloxane topcoats can be an environmentally friendly replacement for MIL-PRF-85285 polyurethane topcoats without sacrificing appearance or performance.

FINAL REPORT: DEMONSTRATION AND VALIDATION OF SILOXANE-BASED AIRCRAFT TOPCOATS THAT ARE ISOCYANATE-FREE AND PROVIDE A REDUCED ENVIRONMENTAL IMPACT (ESTCP WP-201506)

1. BACKGROUND

Polyurethane topcoats are used on the outer layer of DoD aviation assets (i.e., fixed and rotary wing aircraft) and ground support equipment (GSE) because they provide visual camouflage, protect the underlying anti-corrosive epoxy primer against degradation from ultraviolet (UV) radiation in sunlight, protect the underlying primer from hydrocarbons (e.g., fuel, engine oil) and abrasive materials, and provide a first layer of protection against the ingress of water and corrosive salts (figure 1). These high-performance topcoats are solvent borne, two-component (i.e., two-part) paints, often referred to as 2K systems, where the "K" represents "component" as translated from the German word komponenten. One part of the system is composed of hydroxyl-functional molecules as a gray or white pigmented base, whereas the other part is composed of isocyanate-functional molecules as a clear activator/hardener. Once these components are mixed in a specific volumetric ratio the molecules react to generate a cross-linked polymeric network with numerous carbamate (i.e., urethane) linkages, hence the name poly(urethane).

Figure 1 — Spay-application of a MIL-PRF-85285 camouflage gray polyurethane topcoat on a F/A-18 Hornet.

Polyurethane topcoats has been used by the DoD since the late 1980s, superseding military specification MIL-C-85285(AS) from December of 1978.[1] Currently, the polyurethane topcoats for Navy, Marine Corps, and Air Force aircraft and support equipment are qualified to the performance requirements found in MIL-PRF-85285.[2] Under this specification, topcoats for use on the exterior skin (a.k.a. outer mold line) of aircraft are qualified to either Type I (≤420 g/l of volatile organic compounds (VOCs)) or Type IV (aircraft with extended weatherability; ≤420 g/l VOC content) requirements, whereas topcoats for use on Navy GSE are qualified to Type II (≤340 g/l VOC content) requirements. Recently, the Air Force adopted MIL-PRF-32239, which is similar to MIL-PRF-85285, yet all polyurethane topcoats are tested and qualified as a coating system (i.e., pretreatment, primer, and topcoat).[3] Although polyurethane topcoats provide a host of unique properties, the main issue with this chemistry is that it requires the use of hazardous isocyanate-functional molecules to form the cross-linked polymeric network, which provides integrity to the pigmented coating. Unfortunately, an isocyanate-free alternative that provides similar performance properties to polyurethanes has not been realized by the coating industry. Thus, the development and implementation of a new coating technology that is environmentally friendly (e.g., isocyanate-free, lower

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in VOCs, reduced environmental toxicity) and provides equivalent, if not improved, performance properties compared to polyurethanes has remained a desire for many within the DoD for the past decade.

To address these issues, NRL developed two novel and environmentally friendly topcoat technologies: 1) a single-component (1K) polysiloxane topcoat, which is an all-in-one can system that does not require metering and mixing of components, and 2) a two-component (2K) polysiloxane topcoat, which requires mixing of components in a specific volumetric ratio. These topcoats are free of hazardous isocyanates, free of hazardous air pollutants (HAPs), lower in VOCs than the qualified 2K polyurethane topcoats, and can be formulated to provide a low-gloss, semi-gloss, or high-gloss finish once cured. Under this project, these topcoats were tested to the majority of MIL-PRF-85285, MIL-PRF-32239, and MIL-PRF-81352 performance requirements using a qualified topcoat as the control. Polysiloxane topcoats that met the performance requirements were then demonstrated on active (in-service) field aircraft and support equipment. The polysiloxane topcoats will enable the DoD to minimize, if not eliminate, the environmental safety and health (ESOH) risks associated with isocyanate-containing polyurethanes, in addition to eliminating the costs attributed to industrial hygiene monitoring and testing during polyurethane applications. Additionally, the polysiloxane topcoats will allow for increased productivity and logistics at DoD facilities by enabling maintenance activities in nearby areas during painting operations. Reduced VOC emissions and the elimination of HAPs from these topcoats will provide the additional ESOH benefits of improved air quality, reduced ozone depletion, and elimination of airborne carcinogens, as well as providing depots and bases with greater flexibility in managing their overall VOC limits when painting assets. The 1K polysiloxane topcoat will reduce errors and application costs associated with improper mixing of 2K systems, in addition to reducing the generation of hazardous waste.

1.1 Demonstration Objectives

The objectives of this project were four-fold: 1) the main objective was to validate that the polysiloxane topcoats could provide equivalent, or enhanced, field performance compared to MIL-PRF-85285 qualified 2K polyurethane topcoats when demonstrated on active aircraft and ground support equipment, 2) prove that the polysiloxane topcoats were free of airborne isocyanates and offered reduced inhalation toxicity compared to polyurethane topcoats, 3) demonstrate that applications of the polysiloxane topcoats at end-user facilities would result in reduced preparation times, reduced paint consumption, and reduced VOCs emissions compared to qualified polyurethane topcoats, and 4) demonstrate that the 1K polysiloxane topcoat was user-friendly and would generate minimal-to-zero hazardous paint waste compared to polyurethane topcoats.

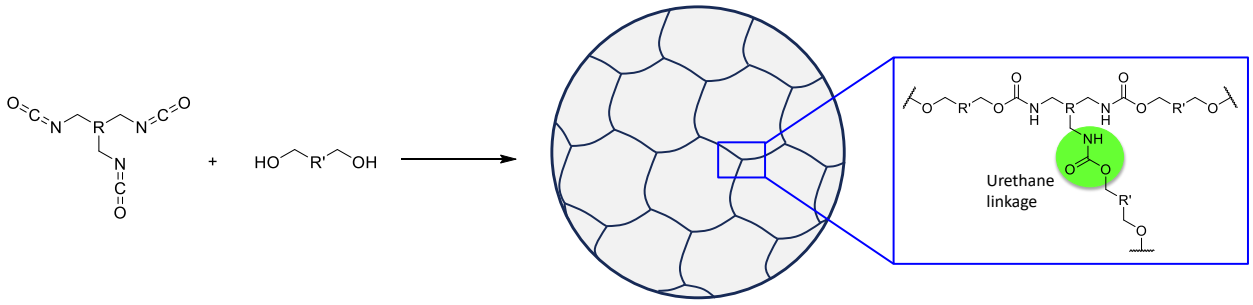
For this project, isocyanate-based polyurethane topcoats were the main target Hazardous Material (HazMat) to be eliminated or reduced. Table 1 summarizes the target HazMat, including the process, current specifications, affected programs, and areas of application for the polysiloxane topcoats. The isocyanate-free, HAP-free, and low-VOC polysiloxane topcoats were applied using the sample spray process and equipment as polyurethane topcoats, tested to MIL-PRF-85285 and MIL-PRF-32239 performance requirements in the laboratory over a chromate or non-chromate coating stack-up (i.e., pretreatment, primer, topcoat), and applied in the field on active DoD aircraft and ground support equipment using the same process as used to apply qualified 2K polyurethane topcoats.

Table 1 — Target HazMat Summary.

Target HazMat	Current Process	Current Specifications	Candidate Parts & Substrates	Affected Programs	Application Areas
Isocyanate-containing polyurethane topcoats	Spray application	MIL-PRF-85285; MIL-PRF-32239	Chromate & non-chromate stack-ups consisting of a primer, pretreatment, and metal substrate	DoD aviation platforms and support equipment	Entire exterior surface of aircraft and support equipment

1.2 Isocyanates and Toxicity

An isocyanate (-N=C=O) is an organic functional group, which consists of nitrogen, carbon, and oxygen, and reacts with a hydroxyl group (-OH) to form a carbamate (i.e., urethane) linkage. When several urethane linkages form a cross-linked network, such as in a coating, the resulting material is referred to as a poly(urethane) (scheme 1). The isocyanate-functional molecules used in polyurethane topcoats for aircraft and GSE possess an aliphatic or cycloaliphatic backbone to provide resistance against oxidative degradation from UV-radiation in sunlight. Common examples include 1,6-hexamethylene diisocyanate (HDI) monomer, isophorone diisocyanate (IPDI) monomer, and homopolymers / oligomers (i.e., polyisocyanates) of these monomers in the form of isocyanurates, uretdiones, and other structures (figure 2). Isocyanates can cause serious health issues for coating applicators and those in proximity to airborne mists during spray (i.e., aerosolized) applications, including the off-gassing of vapors after an aircraft has been painted.[4,5] Exposure to isocyanates can result in watery eyes, dermal sensitivity (e.g., rash, itching, hives, swelling of the extremities), symptoms of asthma (e.g., coughing, shortness of breath and wheezing, tightness of chest), and hypersensitivity pneumonitis, which is a lung disease whose symptoms include a fever, body aches, and cough with phlegm or sputum.[6-9] Furthermore, the Department of Health Services of California estimates that about one in twenty people who work with isocyanates become sensitized, meaning that an individual can experience a variety of adverse health conditions from subsequent exposures, even if the exposure is at extremely low levels.[10]



Scheme 1 — Reaction of isocyanate (-NCO) and hydroxy (-OH) functional molecules to form a network with poly(urethane) linkages.

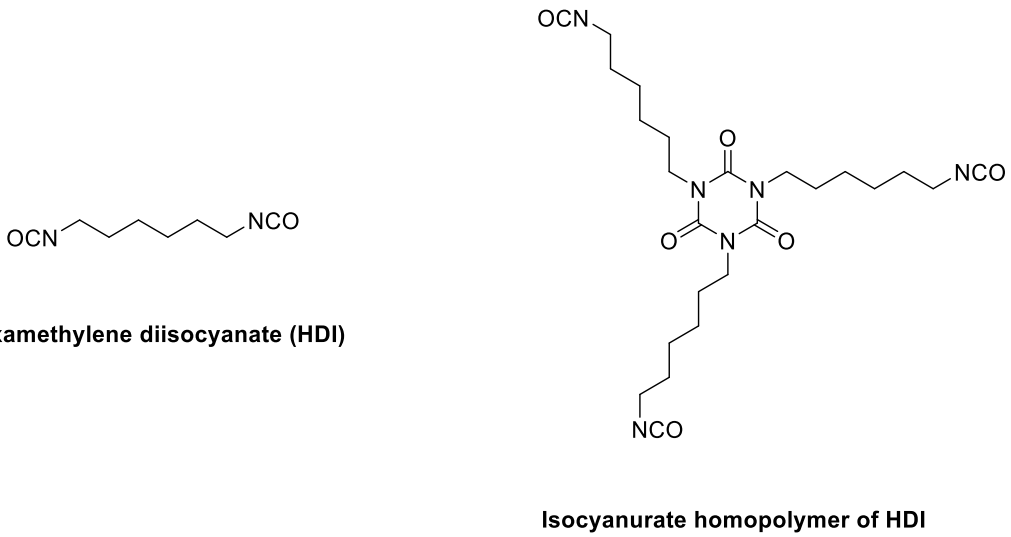


Figure 2 — Structure of 1,6-hexamethylene diisocyanate (HDI) monomer and isocyanurate homopolymer of HDI.

1.3 Regulatory Drivers

Exposure standards, or occupational exposure limits, exist for the maximum level of isocyanates permitted in the air of a worker's breathing zone. The National Institute for Occupational Safety and Health (NIOSH) has established full-shift (10-hour time-weighted-average (TWA)) and ceiling (10 minute) recommended exposure limits (RELs) for HDI (CAS# 822-06-0, see Appendix II) as 0.005 ppm (0.035 mg/m^3) and 0.020 ppm (0.140 mg/m^3), respectively, whereas the American Conference of Governmental and Industrial Hygienists (ACGIH) require a Threshold Limit Value (TLV) of 0.005 ppm for HDI.[11] Covestro, LLC (formerly Bayer Corporation), a global manufacturer of isocyanates, has established 8-hour and ceiling permissible exposure limit (PEL) for homopolymers of hexamethylene diisocyanate (CAS# 28182-81-2, see Appendix III) as 0.5 mg/m^3 and 1.0 mg/m^3, respectively.[12] In 2013, the Occupational Health and Safety Administration (OSHA) initiated a National Emphasis Program to identify and reduce, or eliminate, incidence of adverse health effects associated with occupational exposure to isocyanates.[13] However, to date, OSHA has yet to establish regulatory limits for HDI or homopolymers thereof.

To reduce exposure to isocyanates, personal protective equipment (PPE), such as Tyvek® suites, nitrile gloves, and full-face respirators with organic vapor cartridges, should be worn by individuals at all times when applying polyurethanes, and it is recommended that supplied-air respirators be worn to provide the best breathing protection. The U.S. Navy requires applicators of polyurethane topcoats to enrolled in an isocyanate surveillance program that conducts annual medical examinations and monitors for symptoms of sensitization (e.g., wheezing, coughing).[14] Baseline and periodic medical examinations are also required for applicators of polyurethane topcoats when deployed on Navy aircraft carriers (CVNs).[15] In addition, all Navy depot-level maintenance facilities (Fleet Readiness Centers (FRCs)), Naval Air Stations (NAS), and Air Force bases where polyurethane applications occur have an industrial hygiene (IH) office that monitors for over-exposure to isocyanates via air and/or blood sampling. It is worth mentioning that research conducted by the Yale University School of Medicine in 2012 showed that workers at Hill Air Force Base who painted large aircraft, such as C-130s, possessed elevated levels of HDI-specific serum immunoglobulin G (IgG) in their blood.[16]

Despite containing hazardous isocyanates, the polyurethane topcoats used on the exterior of aircraft and support equipment also contain high levels of VOCs and HAPs. VOCs react in the atmosphere and form

ground-level ozone, and HAP solvents, such as benzene and xylenes, are toxic air pollutants that can cause cancer, lead to serious health issues, or cause adverse environmental and ecological effects.[17,18] The National Emission Standards for Hazardous Air Pollutants (NESHAP) in aerospace manufacturing and rework facilities dictates that organic HAP and VOC contents for topcoats, as applied, not exceed 420 g/l (3.5 lb/gal),[19] although it is estimated that DoD maintenance facilities generate several hundred tons of VOC emissions and several tons of HAP emissions annually due to aircraft painting and de-painting operations.[20,21]

HDI, although not a solvent, is listed as a HAP under Section 112(b) of the Clean Air Act (CAA),[22] and the Environmental Protection Agency (EPA) added HDI to the list of hazardous chemicals under Section 313 of the Emergency Planning and Community Right-to-Know Act (EPCRA) and Section 6607 of the Pollution Prevention Act (PPA) in 1986 and 1990, respectively.[23,24] The Toxic Release Inventory (TRI) program, which is governed by these laws, require facilities that manufacture toxic chemicals to report annually how much of the chemical they release into the environment, in addition to focusing industry, government, and public attention on reducing toxic chemical pollution through cost-effective changes in production, operation, and raw materials use.[25]

Polyurethane topcoats restrict the amount of painting that can occur at Navy depots and Air Force bases due to their toxicity, and maintenance activities cannot be conducted by workers in adjacent areas when these topcoats are applied. This results in decreased productivity per worker, a reduced volume of painted assets, and increased costs to the DoD. However, in situations where isocyanate exposure limits cannot be exceeded, the use of isocyanates are prohibited, and/or spray applications are not possible, the touch-up of Navy and Marine Corps aircraft is conducted by brush-applying a MIL-PRF-81352 touch-up topcoat.[26] These topcoats, which are often a polyurethane dispersion (PUD) or alkyd, offer short-term color stability, limited hydrocarbon resistance, and inferior flexibility compared to MIL-PRF-85285 polyurethanes. In worst case examples, gray-colored spray paint from local hardware stores have been applied to cover the epoxy primer, and on limited occasions the primer has been left uncovered altogether. The use of inferior topcoats for touch-up / repair operations results in a continuous downward spiral of rapid topcoat degradation, increased inspections, and repairs with inadequate coatings, in addition to increased maintenance costs. It should be noted that due to the inadequate exterior durability of MIL-PRF-81352 topcoats the Navy has recently approved the application of MIL-PRF-85285 polyurethanes for repair of aircraft when deployed on carriers (CVNs). However, repainting for cosmetic appearance is strictly prohibited, the maximum cumulative amount of applied isocyanate-containing paint shall not exceed 16 ounces via spray-application or 40 ounces via roller/brush application in a 24-hour period, carrier hanger-bay doors must remain open to provide adequate ventilation, and the entire area must be roped-off with hazard signs stating "*Warning: Isocyanate Hazard Area. All Unprotected Personnel Keep Out*".[15]

2. DEMONSTRATION TECHNOLOGY

2.1 Technology Description

2.1.1 Organosilicon Polymers and Polysiloxane Coatings

Advances in organosilicon chemistry have led to the development of hybrid materials that contain both organic (i.e., carbon, hydrogen) and inorganic (i.e., silicon) elements. Specifically, poly(siloxanes), also written simply as polysiloxanes, are materials that contain Si–O–Si linkages with hydrocarbon groups attached to the silicon atoms (figure 3). A classic example of a polysiloxane polymer is poly(dimethylsiloxane), which is found in numerous commercial products.[27] Materials that contain polysiloxane polymers and oligomers have several advantages over those constructed solely of organic elements. For example, the silicon-oxygen (Si–O) bond has an enthalpy of 110 kcal/mol, which is stronger than the carbon-hydrogen (C–H, 99 kcal/mol) and carbon-carbon (C–C, 83 kcal/mol) bonds found in all organic polymers, thereby leading to materials with increased thermal stability and resistance to oxidative degradation from UV-radiation in sunlight. Polysiloxane polymers are also more hydrophobic than organic polymers, which can decrease the permeability of moisture when used in materials, such as coatings.[28]

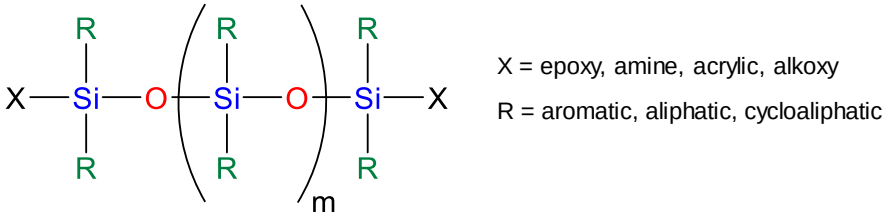
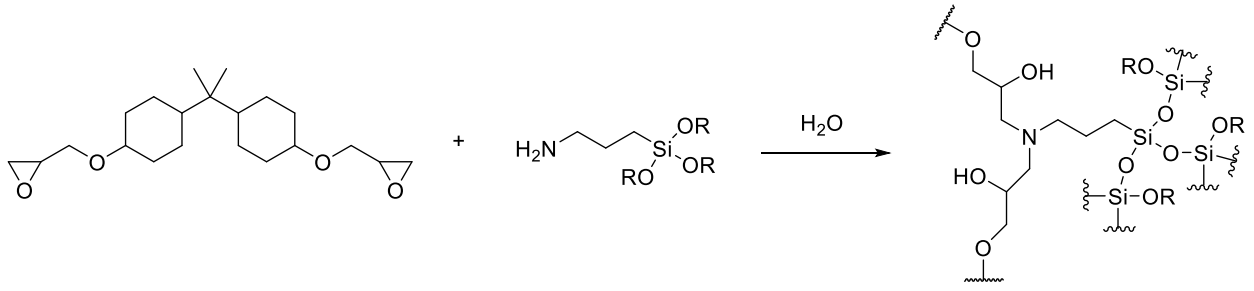


Figure 3 — Generic structure of a linear poly(siloxane) polymer with organic functional groups.

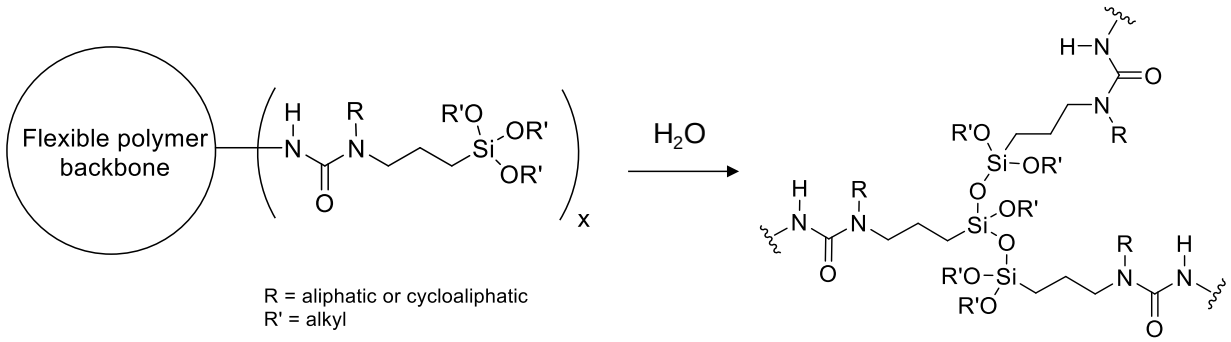
Coatings based on hybrid materials are commercially available from several manufacturers, primarily for use in the protective and marine markets. These coatings are 2K systems, where a portion of the coating is cross-linked via the ambient reaction between amine-functional and epoxy-functional molecules, or amine-functional and acrylic-functional molecules, and the other portion is based on the atmospheric hydrolysis of alkoxysilanes and subsequent condensation of silanol groups to form three-dimensional sol-gel / siloxane crosslinks (scheme 2). These coatings are commonly referred to as “polysiloxanes", even though their name is not descriptive of the actual chemical components.[29,30] Commercial 2K polysiloxane coatings are isocyanate-free and offer good exterior durability, adhesion, hardness, and chemical resistance. However, they possess high cross-link density due to extensive sol-gel formation and epoxy ring opening reactions, which hinders these networks from providing the necessary flexibility for use on aircraft and GSE.[31]



Scheme 2 — Reaction of cycloaliphatic diepoxy with an aminoalkyl alkoxysilane to form a crosslinked network. These components are used in numerous commercial two-component polysiloxane coatings.

2.1.2 NRL-Developed Organosilane Polymers for Single-Component Polysiloxane Topcoats

During an Office of Naval Research (ONR) Swampworks project (FY13-FY14), NRL developed and patented novel organosilicon polymers for use in exterior durable, high-performance polysiloxane aircraft coatings.[32-35] These polymers are organosilanes, which are constructed of an organic backbone with N-substituted urea linkages and alkoxysilane groups at the terminus. Upon reaction with atmospheric moisture, the alkoxysilanes hydrolyze to form silanols, which subsequently condense to form sol-gel / siloxane linkages and a cross-linked network (scheme 3). The N-substituted urea linkages provide reduced hydrogen bonding compared to non-substituted urea linkages, thereby imparting greater flexibility to the cross-linked network. The degree of intermolecular hydrogen bonding in the network can also be tuned by changing the aliphatic or cycloaliphatic group attached to the urea nitrogen, thereby providing the ability to control coating thermal and mechanical properties. Furthermore, coating cross-link density, and hence properties, can be tuned by changing the composition of alkoxysilane group at the polymer terminus. For example, polymers with trialkoxysilane groups (e.g., trimethoxysilane, triethoxysilane) generate coatings that are highly cross-linked with a relatively hard surface, whereas polymers with alkyldialkoxysilane groups (e.g., methyldimethoxysilane) result in reduced cross-links and coatings with a softer surface. These organosilane polymers were used to formulate single-component polysiloxane topcoats for aircraft and support equipment as discussed throughout the report.



Scheme 3 — Generic structure of NRL's organosilane polymer and the formation of a crosslinked network upon reaction with atmospheric moisture.

2.1.3 NRL-Developed Single-Component Polysiloxane Topcoats

Single-component (1K) polysiloxane topcoats for aircraft and GSE were formulated by NRL using the aforementioned organosilane polymers. These topcoats are solvent-borne, moisture-curable systems that are isocyanate-free, HAPs-free, and is lower in VOCs than MIL-PRF-85285 polyurethane topcoats. For example, the 1K camouflage gray topcoat for aircraft was formulated with titanium dioxide (TiO_2) and carbon black pigments, possessed <300 g/l VOCs, and had a Flash Point (Fp) >100 °F by utilizing pentyl propionate and other slow evaporating solvents. However, the topcoat remained sufficiently low in viscosity to be applied via high-volume, low-pressure (HVLP) spray equipment and did not require solvent reduction. A 1K gloss white topcoat was formulated solely with TiO_2 pigment, possessed <250 g/l VOCs, and also had a Fp >100 °F. As 1K systems, all materials were pre-mixed in one can and did not require the addition of components, such as a catalyst, before application, thereby providing a user-friendly system for applicators that eliminated metering and mixing of components.

2.1.4 NRL-Developed Two-Component Polysiloxane Topcoats

As part of the ONR Swampworks project, NRL also developed and patented novel 2K polysiloxane topcoats that are isocyanate-free, cure under ambient conditions, and provide greater flexibility than commercial 2K polysiloxane coatings based on small molecule epoxies and aminosilanes.[34] NRL's 2K polysiloxane topcoats are based on a unique combination of amine-functional oligomers, which are proprietary, and an epoxy-functional polysiloxane polymer (figure 4). In addition to being free of hazardous isocyanates, these solvent-borne coatings possesses ultra-low VOCs (i.e., <250 g/l) and are HAPs-free. Similar to the 1K polysiloxane topcoats, NRL's 2K camouflage gray topcoat was formulated with TiO_2 and carbon black pigments, whereas the gloss white topcoat was formulated with only TiO_2.

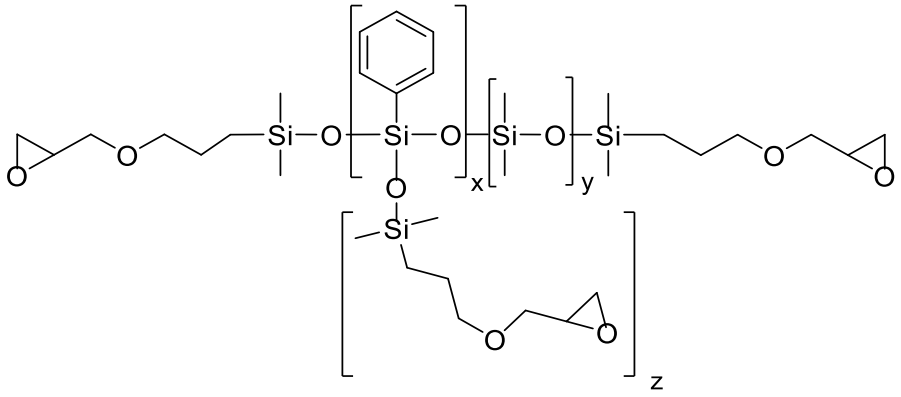


Figure 4 — Generic structure of the epoxy-functional polysiloxane polymer used in NRL's two-component polysiloxane coatings.

NRL's 2K polysiloxane topcoats are novel because they utilize pre-formed polysiloxane linkages rather than forming them *in-situ* during the hydrolysis and condensation phase. As a result, NRL's system provides significantly greater flexibility than commercial 2K polysiloxanes, while also maintaining excellent hardness, hydrocarbon resistance, and exterior durability.

2.2 Technology Development

2.2.1 Single-component camouflage gray polysiloxane topcoat development

During the ONR Swampworks project, NRL's single-component camouflage gray polysiloxane topcoat passed the majority of MIL-PRF-85285, Type IV requirements when sprayed and tested by NAWC-AD over a stack-up consisting of a MIL-PRF-85582, Type II (low infrared reflective pigments), Class C1 (chromate) waterborne epoxy primer, a MIL-DTL-81706, Type I (chromate) pretreatment, and a 3"x6"x0.020" aluminum alloy (AA) 2024-T3 temper substrate.[36,37] Samples tested for flexibility were applied directly over 3x6x0.020" chromic acid anodized AA 2024-0 temper substrates. The topcoat had passed the required viscosity, dry times, gloss, hydrocarbon resistance, methyl ethyl ketone (MEK) resistance, humidity resistance, wet tape adhesion, and low-temperature flexibility tests (figure 5). However, room temperature GE Impact results were inconsistent, as several samples would fail at 20% elongation, whereas others would pass at 40% elongation. Weather-o-meter (WOM) results were also inconsistent and were dependent on the black pigments used to produce the gray color. For example, topcoats that contained solely titanium dioxide (TiO_2) and carbon black would often exhibit a color change (ΔE) of <0.6 after 3000 hours of Xenon-Arc exposure (figure 6), whereas those that contained the latter and copper phthalocyanine blue pigment (i.e., in effort to color match to FED-STD-595 #36375) would often

demonstrate a color change of 0.98 or greater after 3000 hours exposure. It should be noted that all 1K camouflage gray topcoats tested under the ONR project were formulated and produced by NRL.

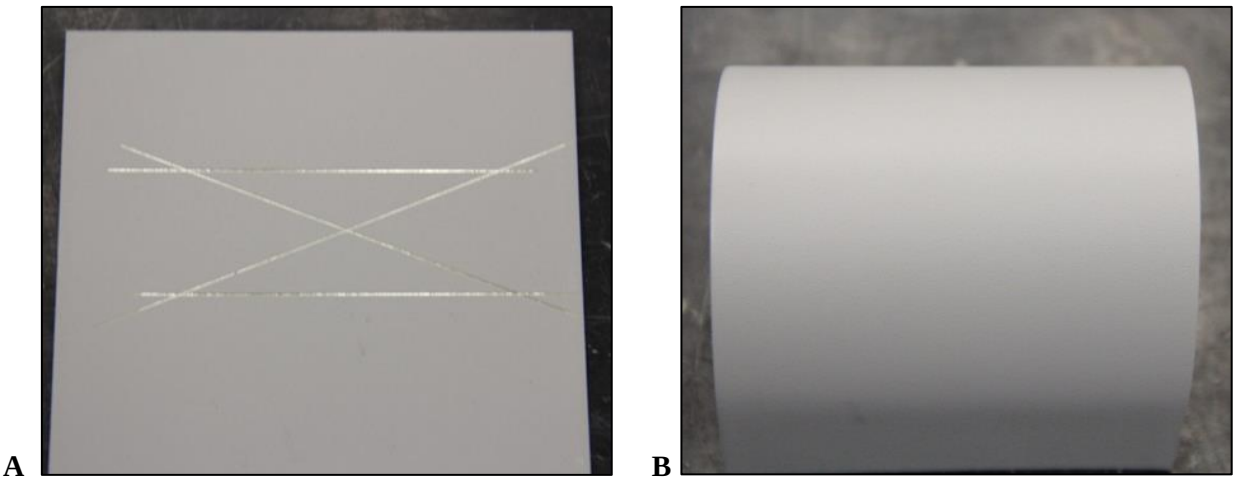


Figure 5 — NRL-formulated 1K camouflage gray (non-color matched) polysiloxane topcoat showing: a) 5A wet-tape adhesion rating and b) no cracking after a 2-inch cylindrical mandrel bend at -60 °F.

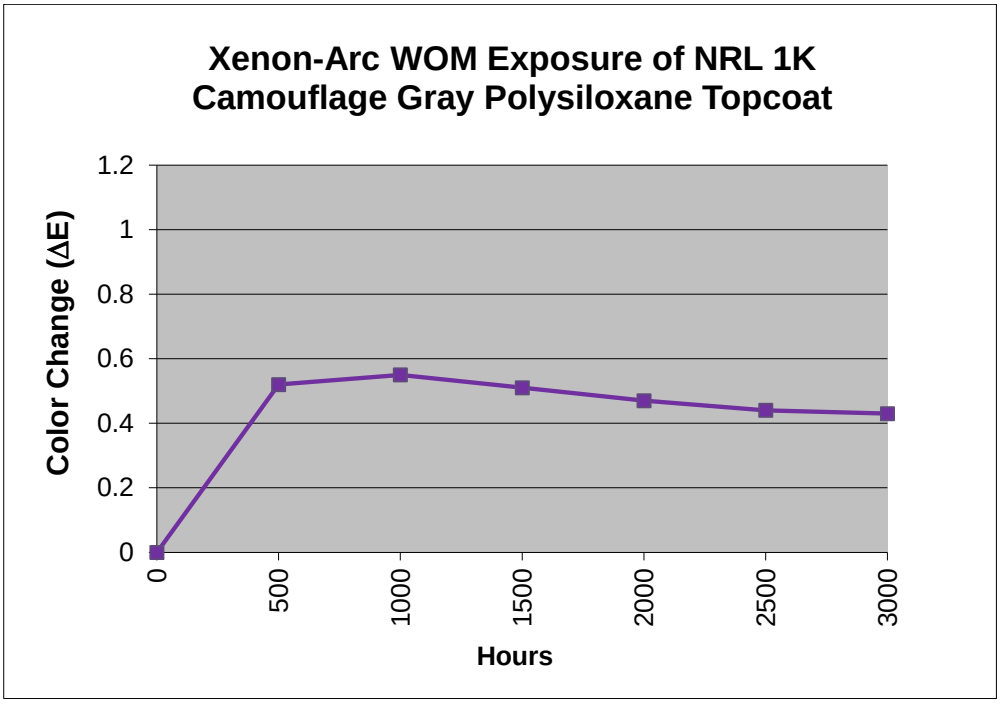


Figure 6 — 1K camouflage gray (non-color matched) topcoat showing a color change of <0.5 after 3000 hours Xenon-Arc WOM exposure.

2.2.2 Single-component gloss white polysiloxane topcoat development

Gloss white formulations of the single-component polysiloxane topcoat were also tested to MIL-PRF-85285E, Type II and IV performance requirements under the ONR Swampworks project. Samples for the majority of testing utilized a MIL-PRF-85582, Type I (standard pigments), Class C1 (chromate) water-

borne epoxy primer and a MIL-DTL-81706, Type I (chromate) pretreatment over 3”x6”x0.020” aluminum alloy (AA) 2024-T3 substrates, whereas the flexibility of the gloss topcoats were tested directly over 3”x6”x0.020” chromic acid anodized AA 2024-0 substrates. The 1K gloss white topcoat had passed the required hydrocarbon resistance, wet-tape adhesion, methyl ethyl ketone (MEK) resistance, humidity resistance, cold bend, heat resistance, and strippability tests, including demonstrating 20-40% elongation via GE Impact (figure 7). However, the gloss was often slightly below 90.0 GU after curing for 1-2 weeks and the initial viscosity of 70 seconds was greater than the required 30 seconds on a #4 Ford Cup. These failures were likely due to the inability to remove moisture from the TiO_2 when formulating the coating, which resulted in partial cross-linking within the can, in addition to the inability of the coating to flow properly and generate a high gloss finish once sprayed. The gloss white topcoat routinely demonstrated a color change of 0.4-0.5 after 3000 hours Xenon-Arc WOM, although none of the gloss white topcoats were color matched to FED-STD-595 #17925.

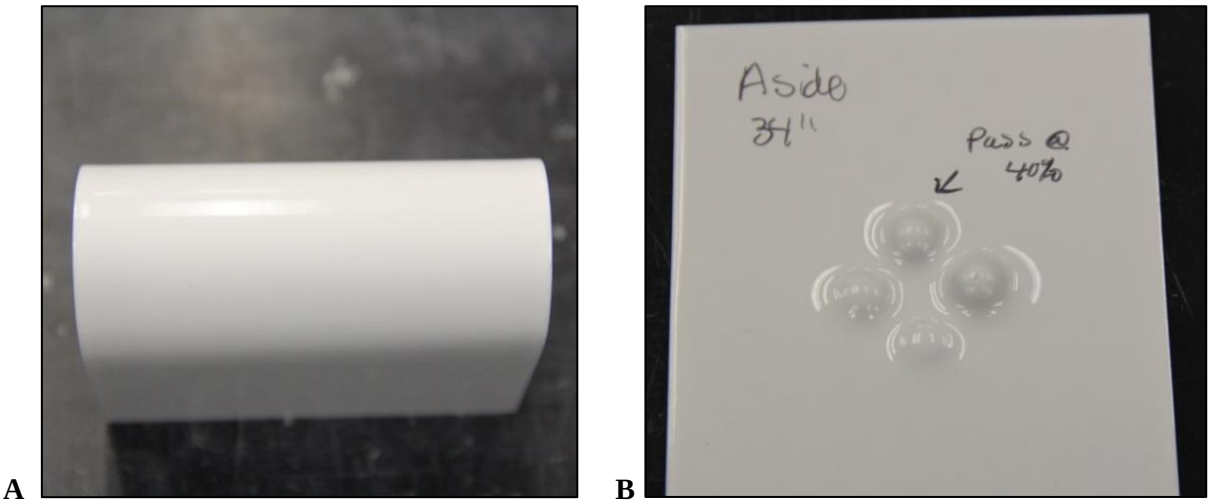


Figure 7 — NRL-formulated 1K gloss white polysiloxane topcoat showing: a) no cracking after a 2-inch cylindrical mandrel bend at -60 °F and b) 40% elongation after a room temperature GE Impact.

2.2.3 Two-component camouflage gray polysiloxane topcoat development

NRL used the epoxy-functional polymer shown in Figure 4 and proprietary amine-functional oligomers, in addition to TiO_2 and carbon black, to formulate a 2K camouflage gray topcoat. The topcoat possessed <250 g/l VOCs total solvent (no exempts) and was formulated as a 3:1 mixture by volume. This coating was spray-applied and tested by NAWC-AD over stack-ups consisting of a MIL-PRF-85582, Type I (standard pigments) or Type II (low infrared reflective pigments), Class C1 (chromate) waterborne epoxy primers, a MIL-DTL-81706, Type I (chromate) pretreatment, and a 3”x6”x0.020” aluminum alloy (AA) 2024-T3 substrate. Samples tested for flexibility were applied directly over 3”x6”x0.020” chromic acid anodized AA 2024-0 substrates. This coating passed several MIL-PRF-85285, Type I and IV tests, which include viscosity, gloss, MEK solvent resistance, low-temperature flexibility, heat resistance, wet-tape adhesion, and strippability. The 2K topcoat also demonstrated a color change of 0.77 and a change in gloss of 0.2 gloss units after 3000 hours of WOM exposure, which meets the Type IV weatherability requirement. However, the coating only demonstrated 10% elongation after GE Impact at room temperature, and attempts to increase elongation resulted in softening of the coating and failures with other tests (e.g., MEK resistance, hydrocarbon resistance). Due to NRL’s inability to formulate a 2K camouflage gray polysiloxane topcoat that met the majority of MIL-PRF-85285 performance requirements this coating was not demonstrated under the ESTCP project.

2.2.4 Two-component gloss white polysiloxane topcoat development

NRL formulated a 2K gloss white polysiloxane topcoat based on the epoxy-functional polymer shown in Figure 4 and proprietary amine-functional oligomers. The topcoat possessed <100 g/l VOCs (total solvent) and was formulated with only TiO_2 to provide the white color. The topcoat was spray-applied and tested at NAWC-AD to MIL-PRF-85285, Type II requirements over a stack-up consisting of a MIL-DTL-53022 lead and chromate-free corrosion-inhibiting epoxy primer, a MIL-DTL-81706B, Type I (chromate) pretreatment, and a 3"x6"x0.020" aluminum alloy (AA) 2024-T3 substrate. Samples tested for flexibility were applied directly over 3"x6"x0.020" chromic acid anodized AA 2024-0 substrates. Results showed that the coating passed the majority of requirements, such as viscosity, gloss, MEK solvent resistance, hydrocarbon resistance, wet-tape adhesion, GE Impact at room temperature, heat resistance, humidity resistance, weatherability, and cleanability. Figure 8 shows the NRL-formulated 2K gloss white topcoat and dry time after applied over a Leneta hiding chart. The only issue with the 2K gloss white polysiloxane topcoat is that it was soft and had a rubbery texture after 12 hours, which was viewed as a potential issue because the qualified MIL-PRF-85285, Type II gloss white polyurethanes used on GSE were harder at 12 hours and did not have a rubbery texture. Attempts to reduce the dry times at NRL using shorter chain di- and tri-functional amine cross-linkers resulted in either a decrease in gloss and/or failure of the coating to meet 5% elongation after GE Impact.

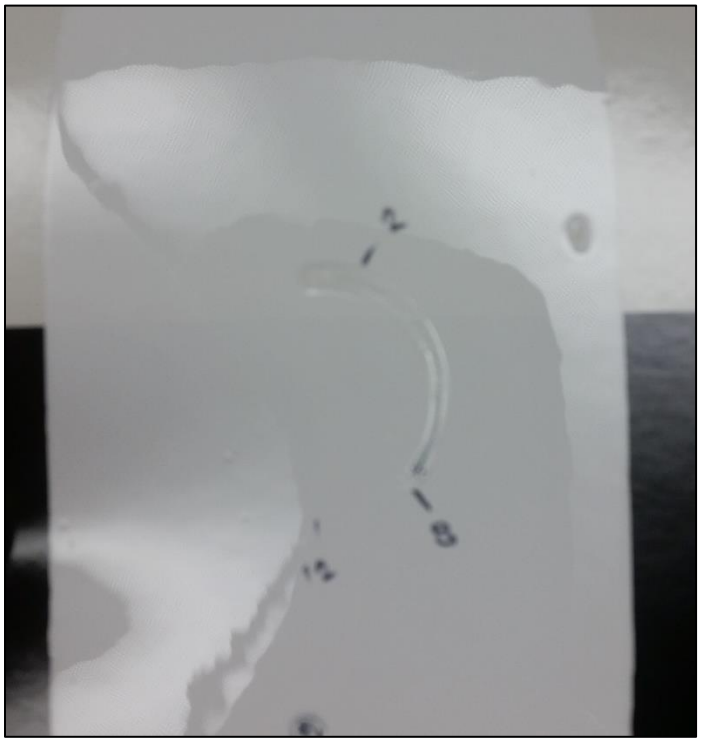


Figure 8 — NRL-formulated 2K gloss white polysiloxane topcoat.

2.2.5 Final selection for ESTCP project

As previously discussed, all work conducted under the ONR Swampworks project was based on NRL-developed and produced topcoats. All topcoats were unable to meet one or two performance requirements, and none of the topcoats were color matched to the requisite colors (i.e., #36375 gray or #17925 white). Furthermore, NRL did not have the ability to dry the pigments before adding to the moisture-curable organosilane polymer when formulating the 1K topcoats. Under this ESTCP project (WP-201506), NCP

Coatings, Inc., who licensed the 1K and 2K polysiloxane technology from NRL in 2014 for commercialization, was responsible for optimizing the various topcoat formulas and color-matching to the required Navy and Air Force colors, in addition to providing NAWC-AD and AFRL with quart or gallon quantities of topcoat for testing to MIL-PRF-85285 and MIL-PRF-32239 performance requirements, respectively. Table 2 shows the polysiloxane topcoats that were targeted for optimization, scale-up, laboratory testing, and potential field demonstration under this ESTCP project.

Table 2 — Target polysiloxane topcoats for ESTCP project.

Topcoat	Color	FED-STD-595 Color Number	Manufacturer	Use
1K polysiloxane	Camouflage gray	36375	NCP Coatings	OML of Navy/USMC aircraft and markings; touch-up/repair
1K polysiloxane	Camouflage gray	35237	NCP Coatings	OML of Navy/USMC aircraft and markings; touch-up/repair
1K polysiloxane	Camouflage gray	36173	NCP Coatings	OML of Air Force aircraft
1K polysiloxane	Semi-gloss gray	26173	NCP Coatings	Exterior of Air Force aerospace ground equipment
1K polysiloxane	Gloss white	17925	NCP Coatings	OML of Navy/USMC aircraft
2K polysiloxane	Gloss white	17925	NCP Coatings	Exterior of Navy ground support equipment

2.3 Advantages and Limitations of Topcoats (Polysiloxanes and Polyurethanes)

The single- and two-component polysiloxane topcoats offer numerous advantages and limitation compared to MIL-PRF-85285 qualified two-component polyurethane topcoats. Polysiloxane topcoat advantages include: 1) they are isocyanate-free, HAP-free, and lower in VOCs compared to polyurethanes, 2) they can be applied using the same spray equipment as polyurethanes, thus being a drop-in replacement, 3) they provide equivalent, and in some instances better, color and gloss retention than polyurethanes, 3) the 1K polysiloxane topcoat is easy for applicators to use, and 4) the cost of polysiloxanes is similar to qualified polyurethane topcoats. Limitations of the polysiloxanes topcoats include: 1) they are a new technology for aircraft and GSE with limited field demonstrations on in-service assets, 2) the single-component topcoat requires moisture to cure, thus 10-80% relative humidity (RH) must be present during application, and 3) quantities greater than 100 gallons have not yet been produced in a single batch by NCP Coatings, thus the ability to seamlessly produce batches of several hundred gallons is yet to be determined. Table 3 provides the advantages and limitation of the polysiloxane topcoats, whereas Table 4 provides advantages and limitations of the legacy polyurethane topcoats.

Table 3 — Advantages and limitations of polysiloxane topcoats.

Advantages of Polysiloxane Topcoats	**Limitation of Polysiloxane Topcoats**
Free of hazardous isocyanates	Polysiloxanes topcoats are a new technology for aircraft and ground support equipment; limited field demonstrations on active assets
Eliminate costs related to industrial hygiene monitoring, air and blood sampling, and laboratory analysis of isocyanates	Cure time of two-component polysiloxane topcoat cannot be accelerated with additional catalyst
HAP-free and lower in VOCs compared to polyurethane topcoats	Single-component polysiloxane topcoat requires moisture to cure and the recommended humidity level for application is 10-80%.
Utilizes the same spray equipment as polyurethane topcoats	Surface hardness of polysiloxane topcoats is slightly less than polyurethane topcoats
Single-component polysiloxane topcoat has greater sag resistance than polyurethane topcoats	Polysiloxane topcoats for aircraft and GSE have not been produced in batches greater than 50 gallons
Single-component topcoat provides artisans with a "user friendly" system that does not require the metering and mixing of components	
Single-component topcoat reduces the amount of hazardous waste generated because the container can be closed and unused material can be recovered for application the following day	
Single-component topcoat provides a more homogenous color across aircraft; colors blend well at transition points	
Polysiloxane topcoats meet MIL-PRF-85285, Type I, II and IV performance requirements; provide greater color and gloss retention in field compared to Type I and II polyurethane topcoats	
Cost of polysiloxane topcoats are similar to polyurethanes	

Table 4 — Advantages and limitations of polyurethane topcoats.

Advantages of Polyurethane Topcoats	**Limitations of Polyurethane Topcoats**
Mature and reliable technology; polyurethane topcoats for aircraft have been used for several decades	Contain toxic isocyanate-functional molecules
Artisans are familiar with application parameters (e.g., spray gun settings, stand-off distance, tip size) for polyurethane topcoats they routinely apply	Contain HAPs (i.e., isocyanates, xylenes)
Compatibility of manufacturers' topcoats with each other is known	Limits on the amount of isocyanate exposure per work shift and application
Cure time of polyurethanes can be accelerated using additional catalyst	Limited to touch-up / repair applications of aircraft when on carriers (CVNs)
Good physical and mechanical properties	Packaging in aerosol cans (for touch-up / repair) is difficult and expensive
	Costs associated with IH sampling and laboratory analysis of isocyanates
	Requires physically mixing two-components and at a specific volumetric ratio before spraying, which can lead to improper mixing and insufficient performance
	Unused mixed components are disposed of as hazardous waste
	Excess moisture in the activator/hardener component can result in bulging due to release of carbon dioxide

3. PERFORMANCE OBJECTIVES

The performance objectives for the polysiloxane topcoats were defined at the beginning of the project by Navy and Air Force stakeholders. The first performance objective was meeting laboratory testing to military performance requirements as required by the Joint Test Protocol (JTP), the second was meeting qualitative performance requirements during field demonstrations on active DoD assets, and the third objective was meeting quantitative performance requirements during field demonstrations on the active DoD assets.

3.1 JTP Performance Objectives

The joint test protocol was prepared to describe the laboratory tests and performance requirements that would be used to evaluate the various 1K and 2K polysiloxane topcoats as provided by NCP Coatings (see Table 2). These performance requirements were taken directly from MIL-PRF-85285, MIL-PRF-32239, and MIL-PRF-81352 documents, although the vast majority of the tests are performed according to American Society for Testing and Materials (ASTM) standards. Several iterations of each topcoat formula was spray-applied and evaluated by researchers at NAWC-AD or AFRL. Extended performance tests were taken from other military specifications or ASTM standards. Table 5 shows the standard JTP performance requirements, which include the objective, data requirement, success criteria, and results for the best performing 1K and 2K polysiloxane topcoats designed for Navy and Marine Corps aircraft or GSE. Table 6 shows the extended JTP performance requirements for these assets, including inhalation toxicity testing of the organosilane polymer used in the 1K camouflage gray polysiloxane topcoat. In addition, Table 7 shows the standard JTP performance requirements for the polysiloxane topcoats designed for Air Force aircraft, whereas Table 8 shows the extended requirement for Air Force aerospace ground equipment (AGE). It should be noted that the 1K semi-gloss gray topcoat for the Air Force was not tested to the majority of requirements because the formula was similar to the 1K camouflage gray version. It should be noted that NCP Coatings was unable to provide quart and gallon quantities of an optimized 1K gloss white polysiloxane topcoat for testing to Navy performance requirements, although panels of the topcoat were prepared for weatherability testing at FRC Southeast.

Table 5 — Standard JTP performance requirements for polysiloxane topcoats formulated for Navy and Marine Corps aircraft and GSE.

Performance Objective	Data Requirement	Success Criteria	Results
Viscosity and Pot Life	ASTM D1200; ASTM D1640	Type II & IV topcoats: ≤30 seconds initial, ≤60 seconds after 4 hours, no gelation after 5 hours; Touch-up topcoats: 16 to 25 seconds initial, no gelation after 5 hours	1K camouflage gray topcoats – PASS; 2K gloss white topcoat – PASS; 1K camouflage gray touch-up topcoat – PASS
Drying Times	ASTM D5895	Type II & IV topcoats: Set-to-touch in <6 hours, dry hard in <12 hours; Touch-up topcoats: Tack-free in <60 minutes	1K camouflage gray topcoats – PASS; 2K gloss white topcoat – PASS; 1K camouflage gray touch-up topcoat – PASS

Color	ASTM D2244; ASTM D1729	Type II & IV topcoats: Color difference (ΔE) of <1.0 when compared to the FED-STD-595 color chip; Touch-up topcoats: Visual observation	1K camouflage gray topcoats – PASS Type IV; 2K gloss white topcoat – PASS Type II; 1K camouflage gray touch-up topcoat – PASS
Gloss	ASTM D523	Type II & IV topcoats: ≥90 gloss units for gloss topcoats and ≤5 gloss units for camouflage topcoats at 60°; ≤10 gloss units for camouflage topcoats at 85°; Touch-up topcoats: <5 at 60°	1K camouflage gray topcoats – PASS Type IV; 2K gloss white topcoat – PASS Type II; 1K camouflage gray touch-up topcoat – PASS
Opacity	ASTM D2244; ASTM D2805	A contrast ratio of no less than 0.95 at a dry film thickness of 1.9-2.1 mils	1K camouflage gray topcoats – PASS; 2K gloss white topcoat – PASS; 1K camouflage gray touch-up topcoat – PASS
Adhesion (Wet Tape)	ASTM D3359, Method A; FED-STD-141, M6301	Type II & IV topcoats: No less than a 4A rating; Touch-up topcoats: No loss of adhesion	1K camouflage gray topcoats – PASS Type IV; 2K gloss white topcoat – PASS Type II; 1K camouflage gray touch-up topcoat – PASS
Weather Resistance	ASTM G155; ASTM D2244; ASTM D523	Type I and II topcoats: ≥80 gloss units at 60° and a color change (ΔE) of <1.0 after 500 hours for gloss topcoats; Type IV topcoats: a change in gloss of <3 gloss units at 60° and 85° and a ΔE of <1.0 after 3000 hours for camouflage topcoats; Touch-Up topcoats: a ΔE of <2.0 after 500 hours	1K camouflage gray topcoats – PASS Type IV; 2K gloss white topcoat – PASS Type II; 1K camouflage gray touch-up topcoat – PASS
Room Temperature Impact Flexibility	ASTM D6905	≥5% elongation for Type II topcoats and ≥40% elongation for Type IV topcoats	1K camouflage gray topcoats – PASS; 2K gloss white topcoat – PASS;
Low Temperature (-60 °F) Flexibility	ASTM D522, Method B	2” bend without cracking for gloss topcoats, 1” bend without cracking for camouflage topcoats	1K camouflage gray topcoats – PASS

Room Temperature Flexibility	ASTM D522, Method B	Gloss and camouflage topcoats shall pass a 1" bend without cracking; no loss of adhesion	1K camouflage gray topcoats – PASS; 2K gloss white topcoat – PASS; 1K camouflage gray touch-up topcoat – PASS
Fluid Resistance (lubricating oil, hydraulic fluid and JP-5 jet fuel)	ASTM D1193, Type IV; ASTM D3359, Method A; ASTM D3363; ASTM D2244	No blistering, softening, or other coating defects. Slight staining of the coating is acceptable.	1K camouflage gray topcoats – PASS; 2K gloss white topcoat – PASS; 1K camouflage gray touch-up topcoat – PASS
Humidity Resistance	ASTM D2247	No blistering, softening or exhibit any loss of adhesion or other defects	1K camouflage gray topcoats – PASS; 2K gloss white topcoat – PASS
Heat Resistance	ASTM D2244	A color difference (ΔE) of ≤ 1.0 when compared to an unexposed sample	1K camouflage gray topcoats – PASS; 2K gloss white topcoat – PASS; 1K camouflage gray touch-up topcoat – PASS
Solvent Resistance	ASTM D5402	25 double rubs without rubbing through to bare metal	1K camouflage gray topcoats – PASS; 2K gloss white topcoat – PASS
Water Resistance	ASTM D1308	The coatings shall exhibit no cracking, blistering, or whitening	1K camouflage gray touch-up topcoat – PASS
Cleanability	MIL-PRF-85285	Cleaning efficiency of not less than 75% for camouflage topcoats and not less than 90% for gloss topcoats	1K camouflage gray topcoats – PASS; 2K gloss white topcoat – PASS
Strippability (using toxic paint remover)	MIL-PRF-85285	A minimum of 90% of the coating shall be stripped using Method B	1K camouflage gray topcoats – PASS; 2K gloss white topcoat – PASS
Odor	ASTM D1296	No odor 48 hours after application	1K camouflage gray touch-up topcoat – PASS
Surface Appearance	MIL-PRF-81352	The coatings shall dry to a smooth, uniform film, free of runs, sags, bubbling, wrinkling, streaking, blushing, haze, blisters, coarse particles, or other surface irregularity when prepared and examined	1K camouflage gray touch-up topcoat – PASS

Tape Resistance	MIL-PRF-85285	No permanent marring caused by masking tape	1K camouflage gray topcoats – PASS; 1K camouflage gray touch-up topcoat – PASS

Table 6 — Extended JTP performance requirements for polysiloxane topcoats formulated for Navy and Marine Corps aircraft and GSE.

Performance Objective	Data Requirement	Success Criteria	Results
Acute inhalation toxicity of organosilane polymer	Environmental Protection Agency (EPA) Toxic Substance Control Act (TSCA) Good Laboratory Practice (GLP) Standards CFR Title 40, Part 792	No death to rodents during 4-hour nose-only inhalation and 14 days post-inhalation; LC50 value ≥554 mg/m^3 (value for oligomers of HDI)	No animal deaths; LC50 >2020 mg/m^3
Repair adhesion – for touch-up topcoats only	X-cut adhesion of polysiloxane over an abraded polyurethane topcoat; X-cut adhesion of polyurethane over an abraded polysiloxane topcoat	No less than a 4A rating after immersion in water for 24 hours at RT	1K camouflage gray touch-up topcoat – PASS
Skydrol LD-4 Resistance	BMS 10-72, section 8.2.11; ASTM D714; ASTM D3363	No blistering, loss of adhesion, softening or other irregularities; 2B or harder pencil hardness	Not performed
Direct-to-pretreatment and direct-to-metal adhesion	ASTM D3359, Method A	No less than a 4A rating	Not performed
Salt spray corrosion resistance	ASTM B117	Equivalent or greater corrosion resistance compared to a polyurethane topcoat. Equivalent or greater retention in color and gloss compared to polyurethane topcoat.	Not performed
Dry times and appearance at various temperatures and humidity	Spray application and curing at 20-80% R.H. and 50-80 °F	Topcoats possess required color, gloss and dry times over various conditions	Not performed

Table 7 — Standard JTP performance requirements for polysiloxane topcoats formulated for Air Force aircraft.

Performance Objective	Data Requirement	Success Criteria	Results
Color	ASTM D2244	Color difference (ΔE) of <1.0 when compared to the FED-STD-595 color chip	1K camouflage gray topcoat – PASS; 1K semi-gloss gray topcoat - PASS
Gloss	ASTM D523	≤5 gloss units at 60° and ≤9 gloss units at 85° for camouflage topcoats; 15 to 45 max. gloss units at 60° for semi-gloss topcoats	1K camouflage gray topcoat – PASS; 1K semi-gloss gray topcoat - PASS
Adhesion (Wet Tape)	ASTM D3359, Method A	No less than a 4A rating, no delamination or peeling	1K camouflage gray topcoat – PASS
Adhesion (Crosshatch)	ASTM D3359, Method B	No less than a 4B rating, no delamination or peeling	1K camouflage gray topcoat – PASS
Room Temperature Impact Flexibility	ASTM D6905; ASTM G155	≥10% elongation before and after 3000 hours Xenon-Arc weathering	1K camouflage gray topcoat – PASS
Low Temperature (-60 °F) Flexibility	ASTM D522, Method B	No cracking when bent over a 2” Mandrel	1K camouflage gray topcoat – PASS
Fluid Resistance (lubricating oil, hydraulic fluid, JP-8 jet fuel, deionized water)	ASTM D1193, Type IV; ASTM D3359, Method A; ASTM D3363; ASTM D2244	No blistering, delamination or loss of adhesion, and no more than a 2-pencil hardness change. Color change (ΔE) ≤3.0	1K camouflage gray topcoat – PASS
Weather Resistance	ASTM G155	<5 gloss units at 60° and a color change (ΔE) of ≤1.0 after 3000 hours	1K camouflage gray topcoat – PASS
Humidity Resistance	ASTM D2247; ASTM D3359, Method B; ASTM D3363	No blistering, loss of adhesion or change in pencil hardness	1K camouflage gray topcoat – PASS
Heat Resistance	ASTM D522, Method B; ASTM D3359, Method B	No cracking or flaking when bent over a 2” cylindrical mandrel, no less than a 4B adhesion rating, a color difference (ΔE) of ≤1.0	1K camouflage gray topcoat – PASS
Solvent Resistance	ASTM D5402, Method A	25 double rubs without rubbing through to bare metal	1K camouflage gray topcoat – PASS

Cleanability	MIL-PRF-32239A	Cleaning efficiency of not less than 75%	1K camouflage gray topcoat – FAIL
Skydrol LD-4 Resistance	BMS 10-72, section 8.2.11; ASTM D714; ASTM D3363	No blistering, loss of adhesion, softening or other irregularities; ≤2 change in pencil hardness; (ΔE) ≤3.0	1K camouflage gray topcoats – FAIL
Strippability (using toxic paint remover)	MIL-PRF-32239	A minimum of 90% of the coating shall be stripped within 24 hours	1K camouflage gray topcoat – PASS
Strippability (using environmentally friendly paint remover)	MIL-PRF-32239	A minimum of 90% of the coating shall be stripped within 24 hours	1K camouflage gray topcoat – PASS
Wet Edge	MIL-PRF-32239	No streaks, tiger stripes, or other visual irregularities	1K camouflage gray topcoat - PASS
Outdoor Exposure (Corrosion Resistance)	MIL-PRF-32239	Equal to or greater than chromate primer with a polyurethane topcoat after 12 months	1K camouflage gray topcoat – PASS
Strippability after aging using non-toxic paint removers	MIL-PRF-32239	A minimum of 90% of the coating shall be stripped within 24 hours	Not performed

Table 8 — Extended JTP performance requirements for polysiloxane topcoats formulated for Air Force aerospace support equipment.

Performance Objective	**Data Requirement**	**Success Criteria**	**Results**
Adhesion (Pull-Off Strength)	ASTM D4541	>1800 psi over various surface preparations; similar performance to a polyurethane control	1K semi-gloss gray topcoat – PASS

As is shown in Tables 5, the 1K camouflage gray polysiloxane passed all MIL-PRF-85285, Type IV topcoat performance requirements. However, it failed Skydrol LD-4 resistance as shown in Table 6. Skydrol LD-4 resistance is a Boeing requirement and is not required for Navy tactical aircraft with camouflage topcoats. The 1K topcoat was never designed to meet this requirement, nor was NCP Coatings able to optimize the formula to meet this requirement. Additionally, Table 5 shows that the 2K gloss white polysiloxane meets all MIL-PRF-85285, Type II topcoat performance requirements. Furthermore, Tables 5 and 6 show that the 1K polysiloxane touch-up coating meets all MIL-PRF-81352 touch-up requirements, which includes the extended test for "repair adhesion". The 1K gloss white polysiloxane met Type I topcoat weatherability, but was not subjected to other performance tests due to its appearance issues. The 1K camouflage gray polysiloxane topcoat passed the majority of the Air Force's MIL-PRF-32239 coating system performance requirements as well, but failed cleanability and Skydrol LD-4 resistance tests (Table 7). It is worth mentioning that all topcoats, even the 2K camouflage gray polyurethane control, failed the cleanability test when performed at AFRL.

3.2 Field Demonstration Performance Objectives

Per the approved Demonstration Plan, polysiloxane topcoats that met the majority of JTP requirements would be demonstrated on Navy, Marine Corps, and/or Air Force assets. As a result, qualitative and quantitative performance objectives, which are shown in Tables 9 and 10, respectively, were used to evaluate polysiloxane topcoat performance during field demonstrations on these assets. Performance was evaluated during the paint preparation stage, during spray application (i.e., via HVLP equipment) by artisans on the entire exterior of assets, and while the asset remained in-service at a DoD facility or after deployment on a CVN. The 1K camouflage gray polysiloxane topcoats were demonstrated on two AH-1Z Viper helicopters at Marine Corps Base Camp Pendleton, California from March 2019 through May 2021, in addition to being demonstrated on two UH-1Y Venom helicopters at Marine Corps Base New River, Jacksonville, North Carolina from February 2019 through May 2021. The 2K gloss white polysiloxane topcoat was demonstrated on a Mid-Range Tow Tractor (MRTT) at Naval Air Station Oceana from February 2017 through March 2018, a spotting dolly aboard the USS Nimitz (CVN-68) from March 2019 through April 2021, including two mobile facility units at Marine Depot Maintenance Command (MDMC), Albany, Georgia in September of 2019. The 1K semi-gloss gray polysiloxane topcoat was demonstrated on a B4 Maintenance Stand at MacDill AFB, Tampa, Florida from March 2019 through June 2020. Demonstrations of the 1K camouflage gray polysiloxane topcoat on the wings or horizontal stabilizer of an Air Force aircraft (e.g., C-17, C-130) were not conducted because corrosion engineers at bases were unable to devote time to participate in the program.

Table 9 — Qualitative field performance objectives.

Performance Objective	Data Requirements	Success Criteria	Results
Ease-of-Use and Training	Feedback from artisans on preparation time and mixing (2K systems) for polysiloxane topcoats	No training required; easy-to-use	1K polysiloxane topcoats are user-friendly and did not require metering and mixing of components; 2K gloss white polysiloxane topcoat was easy-to-mix at 3:1 ratio (by volume); 1K polysiloxane touch-up kits were easy-to-use
Equipment and Method of Application	Feedback from artisans on the sprayability and brushability of the polysiloxane topcoats using standard equipment	Little-to-no noticeable different in sprayability and brushability compared to qualified polyurethane topcoats	1K and 2K polysiloxane topcoats sprayed similarly to polyurethane topcoats; 1K semi-gloss polysiloxane topcoat was easier to brush than semi-gloss 2K polyurethane; 1K polysiloxane touch-up topcoat was easy to spray and brush
Appearance	Feedback from artisans on appearance after sprayed and cured	Little-to-no noticeable difference compared to a qualified polyurethane topcoat	1K and 2K polysiloxane topcoats, including 1K touch-up topcoat, had similar appearance to polyurethanes

In-Service Weatherability (Visual)	Feedback from aircraft and GSE maintainers in field; photographs after application and inspections; color and gloss change imperceptible or barely perceptible to human eye	Similar appearance to qualified polyurethane topcoats in field	No noticeable difference in visual color and gloss between polysiloxane and polyurethane topcoats on active field assets
In-Service Cracking and Discoloration due to Heat or Fluids (Visual)	Feedback from aircraft and GSE maintainers during field testing; visual inspections	Little-to-no visual change; equivalent performance compared to aircraft paint with qualified polyurethane topcoats	No cracking of topcoats in field; minor color change due to engine oil
In-Service Adhesion to Substrates (Visual)	Feedback from aircraft and GSE maintainers during field testing; visual inspections	Little-to-no coating loss over primers or abraded polyurethane topcoats	No loss of adhesion in field
In-Service Corrosion Resistance (Visual)	Feedback from aircraft and GSE maintainers during field testing; visual inspections	Little-to-no visual change; equivalent performance compared to aircraft paint with qualified polyurethane topcoats	No facial corrosion observed; minor corrosion on steel substrates due to mechanical damage

Table 10 — Quantitative field performance objectives.

Performance Objective	Data Requirements	Success Criteria	Results
Elimination of Airborne Isocyanates	Industrial Hygiene office monitoring of airborne isocyanates during spray application of polysiloxane topcoats	Zero airborne isocyanates detected	Zero HDI detected when airborne mist of 1K camouflage gray polysiloxane topcoat were analyzed by IH office at Camp Pendleton
Reduction in VOCs	Calculation of released VOCs during application of polysiloxane topcoat on aircraft and/or GSE	Reduction of VOCs compared to applying a qualified polyurethane topcoat	Reduced VOC emissions by 7.59 lb/gal when 1K camouflage gray polysiloxane topcoat used to paint an AH-1Z Viper
Reduction of Hazardous Paint Waste	Feedback from artisans on amount/volume of 1K polysiloxane topcoat discarded as waste during painting of assets	Little-to-no 1K polysiloxane topcoat discarded as hazardous waste	Near zero paint wasted generated when 1K camouflage gray polysiloxane topcoats applied on AH-1Z Vipers

In-Service Weatherability as Determined by Color and Gloss Measurements	Calculated change in topcoat color and gloss values between application and inspection	Color change (ΔE) ≤2.0; color and gloss change equivalent or less than qualified polyurethane topcoats after 1-2 years of service	Color and gloss change of polysiloxane topcoats were less than, or similar to, qualified polyurethane topcoats

4. SITE/PLATFORM DESCRIPTION

Per the approved Demonstration Plan, the Navy had agreed to participate in demonstration of the isocyanate-free polysiloxane topcoats on various in-service assets, assuming they met the requisite laboratory performance requirements. These assets consisted of rotary wing aircraft and various GSE. However, all demonstrations of the polysiloxane topcoats were conducted on the exterior skin of assets, as the bilge area of aircraft was not warranted for demonstration. The exterior skin, or OML for aircraft, was considered low risk for a demonstration because it was readily accessible and easily inspected, unlike most bilge areas on aircraft that are inspected only twice a year. Furthermore, any failures of the polysiloxane topcoat could be addressed by either removing the topcoat via mechanical abrasion (e.g., orbital sanders, hand-sanding), reapplying the same topcoat, replacing with a MIL-PRF-85285 qualified polyurethane topcoat, or repairing with a qualified MIL-PRF-81352 touch-up topcoat. Polysiloxane topcoat demonstrations on Navy and Air Force ground support equipment were also considered low risk, as the topcoats on GSE are not considered critical to their use/operation on the ground or when deployed on CVNs. Similar to the skin of aircraft, GSE topcoats can be easily inspected and replaced, or repaired, if failure occurs. The Air Force had originally agreed to demonstrate a polysiloxane topcoat on sections (e.g. wing, horizontal stabilizer) of an aircraft, although this did not occur as mentioned in the aforementioned paragraph. A description of the various Navy / Marine Corps and Air Force assets, the area of topcoat demonstration, present operations, in addition to site-related permits and regulations, is provided below. Information regarding the polysiloxane topcoat, primer, and pretreatment (if required) utilized for demonstration on each asset is also provided.

4.1 Test Platforms

4.1.1 UH-1Y Venom and MCAB New River

The Bell UH-1Y Venom is a rotary wing aircraft manufactured by Bell Textron, Inc. (formerly Bell Helicopter) (figure 9).[38] It is a twin-engine, medium-sized utility helicopter that was built for the Marine Corps under the H-1 upgrade program. This aircraft is found at Marine Corps Air Base (MCAB) New River in Jacksonville, North Carolina, and is supported by painters at NAVAIR Fleet Readiness Center East in Cherry Point, North Carolina. The skin of the UH-1Y is mostly aluminum alloy, and is currently coated with a chromate pretreatment, chromate epoxy primer, and a camouflage gray polyurethane topcoat. The engine nacelles and rotor housing are polymeric composites. Per the Demonstration Plan, stakeholders/end-users at FRC-East were interested in demonstrating the polysiloxane topcoat on the OML in effort to eliminate isocyanates and reduce VOCs during maintenance painting.

Figure 9 — Bell UH-1Y Venom.

The UH-1Y Venom has a two-toned paint scheme that consists of FED-STD-595 #36375 medium gray color on the fuselage, tail boom, and vertical stabilizer, and FED-STD-595 #35273 blue gray on the rotor housing, engine nacelles, top of tail boom, nose, and horizontal stabilizers. The paint scheme for the UH-1Y can be found in MIL-STD-2161C (see Appendix IV).[39] The 1K camouflage gray polysiloxane topcoat, in both colors, was applied on the entire exterior of two UH-1Y helicopters at MCAB New River during this project.

4.1.2 AH-1Z Venom and Camp Pendleton

The Bell AH-1Z Viper is a rotary wing aircraft manufactured by Bell Textron, Inc. (formerly Bell Helicopter) (figure 10).[40] It is a twin-engine attack helicopter, based on the AH-1W Super Cobra, that was built for the Marine Corps under the H-1 upgrade program. This aircraft is found at Marine Corps Base Camp Pendleton in California. The skin of the AH-1Z is mostly aluminum alloy, which is coated with a chromate pretreatment, chromate epoxy primer, and a camouflage gray polyurethane topcoat. The engine nacelles, leading edge of wings, and rotor housing are polymeric composites. Per the Demonstration Plan, stakeholders/end-users at Camp Pendleton were interested in demonstrating the polysiloxane topcoat on the OML of the AH-1Z in effort to eliminate isocyanates and reduce VOCs during maintenance painting.

Figure 10 — Bell AH-1Z Viper.

The AH-1Z Viper has a two-toned paint scheme that consists of FED-STD-595 #36375 medium gray color on the fuselage, tail boom, and vertical stabilizer, and FED-STD-595 #35273 blue gray on the rotor housing, engine nacelles, top of tail boom, nose, and horizontal stabilizers. The paint scheme for the AH-1Z can be found in MIL-STD-2161C (see Appendix V).[39] The 1K camouflage gray polysiloxane topcoat, in both colors, was applied on the entire exterior of three AH-1Z helicopters at Camp Pendleton during this project.

4.1.3 F/A-18 Super Hornet

The Boeing F/A-18E/F Super Hornet is a fixed wing aircraft manufactured by the Boeing Corporation (figure 11). It is a twin-engine, carrier-capable, multi-role fighter aircraft with variants based on the MacDonald Douglass F/A-18 Hornet.[41] This aircraft is found at several Naval Air Stations (NAS), such as NAS Oceana in Virginia Beach, Virginia and NAS Whidbey in Island County, Washington. The skin of the F/A-18E/F is aluminum alloy, which is currently coated with a chromate pretreatment, chromate epoxy primer, and a camouflage gray polyurethane topcoat.

Figure 11 — Boeing F/A-18E/F Super Hornet.

The F/A-18E/F Super Hornet has a two-toned paint scheme that consist of FED-STD-595 #36375 medium gray color on the fuselage, under the aircraft, and vertical stabilizers, and FED-STD-595 #36320 dark gray on the top of the aircraft and horizontal stabilizers. FED-STD-595 #35273 blue gray color is used as markings on the aircraft. The paint scheme for the F/A-18E/F can be found in MIL-STD-2161C (see Appendix VI).[39] For this project, the 1K camouflage gray polysiloxane touch-up topcoat was applied on approximately 1x1' areas of fuselage on several F/A-18s at various locations.

4.1.4 T-45 Goshawk and FRC Southeast

The McDonnell-Douglass T-45 Goshawk (figure 12) is a tandem seat, fixed-wing jet aircraft that is utilized by the Navy and Marine Corps to train pilots for carrier-based aviation and tactical strike missions. The skin of the T-45 is aluminum alloy, which is coated with a chromate pretreatment, a non-chromate epoxy primer, and a polyurethane topcoat. Stakeholders and end-users at FRC-Southeast (FRC-SE) were interested in demonstrating a gloss polysiloxane topcoat on the OML of the T-45 in effort to eliminate isocyanates and reduce VOCs during maintenance painting.

Figure 12 — T-45 Goshawk trainer aircraft at FRC-Southeast.

The T-45 has a two-toned paint scheme that consists of FED-STD-595 #17925 white on the fuselage, tail boom, horizontal stabilizers, and the majority of the wings, FED-STD-595 #12197 orange on the wing tips, nose, and vertical stabilizer, and FED-STD-595 #37038 for markings. The wheel wells are also painted with #17925 white. The paint scheme for the T-45 Goshawk can be found in MIL-STD-2161C (see Appendix VII).[39]. For this project, the 1K and 2K gloss white polysiloxane topcoats did not meet the laboratory requirements for MIL-PRF-85285, Type I or IV aircraft topcoats, thus demonstrations on the T-45 at FRC-SE were not conducted.

4.1.5 Mid-Range Tow Tractor and NAS Oceana

The A/S32A-45 Mid-Range Tow Tractor (MRTT) (figure 13) is a 4-cylinder, diesel-powered, 3-speed automatic transmission, liquid-cooled, rear-wheel-drive tractor designed for towing aircraft weighing up to 80,000 pounds. The exterior of this ground support equipment is steel, which is coated with a lead and chromate-free corrosion-inhibiting epoxy primer and a gloss white polyurethane topcoat. Stakeholders at

NAVAIR Lakehurst, New Jersey were interested in demonstrating a gloss white polysiloxane topcoat on the exterior of the MRTT in effort to eliminate isocyanates and reduce VOCs during maintenance painting.

Figure 13 — Mid-Range Tow Tractor used by the U.S. Navy.

The MRTT is painted with a FED-STD-595 #17925 white topcoat, followed by the addition of markings and decals. During this project, the 2K gloss white polysiloxane topcoat was applied on nearly the entire exterior of a MRTT, except for the doors, at NAS Oceana.

4.1.6 Spotting Dolly and USS Nimitz (CVN-68)

The A/S32A-32 Aircraft Towing Tractor (ATT) (figure 14), commonly referred to as a "spotting dolly," is designed to tow, turn, and position aircraft within the confines of an aircraft carrier hangar deck. It is powered by a 3-cylinder diesel engine, which drives two main hydraulic pumps. The exterior of this GSE is steel, which is coated with a lead and chromate-free corrosion-inhibiting epoxy primer and a gloss white polyurethane topcoat. Stakeholders at NAVAIR Lakehurst, New Jersey were interested in demonstrating a gloss white polysiloxane topcoat on the exterior of the asset in effort to eliminate isocyanates and reduce VOCs during paint operations.

Figure 14 — Aircraft Tow Tractor (a.k.a. spotting dolly) used by the U.S. Navy.

Spotting dollies are painted with a FED-STD-595 #17925 white topcoat, followed by the addition of markings and decals. During this project, the 2K gloss white polysiloxane topcoat was applied on the entire exterior of a spotting dolly at FRC Aviation Support Center, Solomon's Island, Maryland, then deployed for use on the flight deck of the USS Nimitz (CVN-68).

4.1.7 Mobile Facilities and MDMC Albany

Mobile facilities are manufactured by Gichner Systems Group and utilized by the Navy for housing parts in an environmentally controlled space (figure 15).[42] These lightweight, aluminum composite shelters, which are considered GSE, are painted with a lead and chromate-free corrosion-inhibiting epoxy primer and a gloss white polyurethane topcoat. Stakeholders at NAVAIR Lakehurst, New Jersey were interested in demonstrating a gloss white polysiloxane topcoat on the exterior in effort to eliminate isocyanates and reduce VOCs during maintenance painting.

Figure 15 — Mobile facility used by the Navy.

Mobile facilities are painted with a FED-STD-595 #17925 white topcoat, followed by the addition of markings and decals. The 2K gloss white polysiloxane topcoat was applied on the entire exterior of two mobile facilities at Marine Depot Maintenance Command (MDMC) Albany, Georgia during this project, then deployed overseas to Okinawa, Japan.

4.1.8 B4 Aircraft Maintenance Stand and MacDill AFB

B4 Aircraft Maintenance Stands are AGE utilized by the Air Force to conduct maintenance on aircraft while providing critical fall protection for workers (figure 16). The stand is made of steel and is coated with a non-chromate epoxy primer and a semi-gloss polyurethane topcoat. Stakeholders and end-users at MacDill AFB were interested in demonstrating a 1K semi-gloss gray polysiloxane topcoat on the exterior of the test stand in effort to eliminate isocyanates and reduce VOCs during maintenance painting. End-users also wanted to determine the corrosion performance of the polysiloxane topcoat compared to a B4 stand with a polyurethane topcoat.

Figure 16 — B4 Aircraft Maintenance Stand used by the Air Force.

B4 Test Stands are painted with a FED-STD-595 #26173 dark gray topcoat, followed by the addition of markings. For this project, a 1K semi-gloss gray polysiloxane topcoat was applied on the entire exterior of a test stand at MacDill AFB in Tampa, Florida.

4.2 Present Operations

4.2.1 Aircraft Operations

As previously discussed, the exterior skin of fixed and rotary wing aircraft are primarily composed of aluminum alloy, although rotary wing aircraft possess several sections of polymeric composite. These aircraft are prepared for painting at maintenance depots by first de-painting, which occurs by: 1) removing the old coatings on the aluminum alloy skin using plastic blast media or a chemical stripper, and 2) hand or rotary sanding of the coatings over composite materials to prevent damaging these sensitive substrates. After removal, the substrates are cleaned and masked. The aluminum alloy skins of the UH-1Y, AH-1Z

and F/A-18E/F aircraft are currently treated with a MIL-DTL-81706, Type I (chromate), Class 1A pretreatment, followed by a MIL-PRF-85582, Type II (low infrared pigments), Class C1 (chromate) epoxy primer and a MIL-PRF-85285, Type I or IV camouflage polyurethane topcoat. For the T-45, the aircraft is treated with a MIL-DTL-81706, Type I (chromate), Class 1A pretreatment, followed by a MIL-PRF-23377, Type I (standard pigments), Class N (non-chromate) epoxy primer and a MIL-PRF-85285, Type IV gloss polyurethane topcoat.[43] The primer and topcoats for both aircraft are applied using a HVLP spray gun and pressure-pot, whereas touch-up topcoats are applied via aerosol cans or brush. Application of the polysiloxane topcoats on UH-1Y, AH-1Z, and F/A-18E/F aircraft were performed using the same surface preparation, pretreatment, primer, and method of topcoat application as normal operations. As noted previously, topcoat demonstrations were not conducted on T-45 aircraft.

4.2.2 Support Equipment Operations

The exterior of Navy ground support equipment are steel or aluminum, and are de-painted to bare substrate via a chemical stripper or abrasive blast media (e.g., aluminum oxide). This is followed by applying a MIL-DTL-53022 lead and chromate-free corrosion-inhibiting epoxy primer and a MIL-PRF-85285, Type II gloss white polyurethane topcoat.[44] The primer and topcoat are applied using a HVLP spray gun and pressure-pot. Application of the polysiloxane topcoat on the MRTT, spotting dolly, and mobile facilities were performed using the same surface preparation, primer, and method of topcoat spray application as normal operations.

The exterior of the Air Force's B4 Maintenance Stand is steel and is de-painted using abrasive blast media. This is followed by applying an inorganic zinc dust epoxy primer and a MIL-PRF-85285, Type II semi-gloss gray polyurethane topcoat.[45] The primer is applied with a spray gun and agitated pressure pot, whereas the topcoat is applied via brushing or with a HVLP spray gun and pressure pot. Application of the polysiloxane topcoat on the B4 stand was performed using the same surface preparation, primer, and method of topcoat spray application as normal operations.

4.3 Site-Related Permits and Regulations

No site-related permits were required to apply the polysiloxane topcoats on the exterior of Navy, Marine Corps, and Air Force assets. Approvals from NAVAIR stakeholders at Patuxent River, Maryland, stakeholders at the various FRCs, personnel at the program office, and the type commander (TYCOM) were required for each tactical aircraft before the polysiloxane topcoats could be applied. Similarly, permission from NAVAIR stakeholders at Patuxent River, Maryland and Lakehurst, New Jersey were required before any GSE were painted. Similarly, approvals from stakeholders and corrosion engineers at MacDill AFB, Tampa, Florida were required before AGE could be painted with a polysiloxane topcoat.

Polysiloxane topcoat safety data sheet (SDS) and technical data sheet (TDS) documents were reviewed by stakeholders and paint applicators / artisans at each DoD site before polysiloxane topcoats were applied on assets. References to these documents are found in Section 6.0.

Applicable regulations include EPA regulation 40 CFR 63.745, "Standards: Primer, Topcoat and Specialty Coating Application Operations", which states that HAP and VOC emissions from topcoats shall be limited to a content of no more than 420 g/L (3.5 lb/gal), respectively.[19]

5. TEST DESIGN

The performance objectives for the polysiloxane topcoats, as discussed in Section 3.0, were addressed by conducting four distinctive groups of testing. These consisted of internal development / optimization testing by the coating manufacturer, NCP Coatings, standard and extended laboratory testing at DoD and third party laboratories per the JTP, spray applications on scrap parts in an industrial setting, including application and field testing on active DoD assets per the Demonstration Plan.

5.1 Manufacturer Development / Optimization

As discussed in Section 2.2.5, NRL provided relatively mature formulations of the various 1K and 2K polysiloxane topcoats to NCP Coatings at the beginning of this project. Under this project, NCP Coatings optimized the formulas, which included larger scale synthesis of the organosilicon polymers, color matching of the topcoat formulas to FED-STD-595 colors, and in-house testing to various performance requirements. Table 11 provides a summary of the various tests performed by NCP Coatings.

Table 11 — Summary of polysiloxane topcoat testing as performed by NCP Coatings.

Topcoat	Tests
1K camouflage gray polysiloxane	• Color matching to FED-STD-595 #36375, #35237 and #36173 • Viscosity • Gloss • Dry times • Opacity • Appearance • MEK resistance • Infrared reflectance • Wet-tape • Moisture content • Storage stability • VOC and HAP content
1K camouflage gray polysiloxane touch-up / repair topcoat	• Color matching to FED-STD-595 #36375 • Viscosity • Sprayability • Dry times • Opacity • Appearance • MEK resistance • Moisture content • VOC and HAP content
2K gloss white polysiloxane	• Color matching to FED-STD-595 #17925 • Dry times • Gloss • Opacity • MEK resistance • Appearance • VOC and HAP content

1K semi-gloss gray polysiloxane	• Color matching to FED-STD-595 #26173 • Viscosity • Gloss • Dry times • MEK resistance • Appearance • Moisture content • VOC and HAP content
1K gloss white polysiloxane	• Color matching to FED-STD-595 #17925 • Viscosity • Gloss • Opacity • Moisture content • VOC and HAP content

Upon completion of testing, quart and gallon quantities of the topcoats were provided to NAWC-AD and AFRL for application and testing to MIL-PRF-85285, MIL-PRF-81352, or MIL-PRF-32239 performance requirements.

5.2 Laboratory Testing

The following sections provide information about the substrates, coating stack-ups, and method of fabrication, including detailed descriptions of the laboratory tests performed per the JTP.

As described in the JTP, the 1K and 2K polysiloxane topcoats were tested to Navy and Air Force aircraft topcoat requirements currently designed for polyurethane topcoat chemistries. For the Navy, the topcoats were tested to MIL-PRF-85285, Type I (aircraft, 420 g/l max. VOC), Type II (support equipment, 340 g/l max. VOCs), and Type IV (aircraft with extended weatherability, 420 g/l max. VOCs) performance requirements, in addition to MIL-PRF-81352 touch-up performance requirements. Several extended (i.e., non-standard) performance tests were also required per Navy stakeholders. The polysiloxane topcoats for Air Force aircraft and AGE were tested to the performance requirements described in MIL-PRF-32239, in addition to several extended tests as required by Air Force stakeholders.

5.2.1 Substrates

For Navy and Air Force laboratory testing, the substrates consisted of bare 3”x6”x0.020” or 12”x12”x0.032” aluminum alloy (AA) 2024-T3 (temper) panels, respectively, conforming to SAE AMS-QQ-A-250/4 (*Aluminum Alloy 2024, Plate and Sheet*), in addition to 3”x6”x0.020” AA 2024-0 (0 temper) panels conforming to SAE AMS-QQ-A-250/4. The latter were used to determine flexibility of the polysiloxane topcoats without the influence from an underlying primer, as the flexibility required by anti-corrosive epoxy primers is less than that of topcoats. Bare 6”x12”x1/8” cold rolled steel panels with a SP-10 surface profile were also used by the Air Force.

5.2.2 Coating Stack-Ups and Sample Fabrication

Single-component camouflage gray polysiloxane topcoats designed for the exterior of aircraft were tested to Navy MIL-PRF-85285, Type I and IV performance requirements, including Air Force MIL-PRF-32239 performance requirements. Single-component camouflage gray polysiloxane topcoats for touch-up / repair applications on aircraft were tested to Navy MIL-PRF-81352 performance requirements. Two-component gloss white polysiloxane topcoats for Navy GSE were tested to MIL-PRF-85285, Type II performance

requirements. Single-component semi-gloss gray polysiloxane topcoats for Air Force AGE were tested to Air Force extend performance tests only. Single-component gloss white polysiloxane topcoats were only tested for weatherability according to Navy MIL-PRF-85285, Type I and IV requirements.

5.2.2.1 Stack-Ups for Navy Testing

The pretreatment for Navy stack-ups was Henkel's Bonderite M-CR 1200S Aero (formerly Alodine 1200S), which is a hexavalent chromium (Cr^{+6}) treatment that is qualified to MIL-DTL-81706, Type I (compositions containing hexavalent chromium), Class 1A requirements.[46] Pretreatments are often referred to as conversion coatings because they chemically alter the surface of the aluminum alloy substrates and enable adhesion of organic coatings. The primers for testing under Navy requirements consisted of the following: 1) a MIL-PRF-85582, Type I (standard pigments), Class C1 (barium chromate based corrosion inhibitors) waterborne epoxy primer, such as PPG Industries / Deft 44-GN-7,[47] 2) a MIL-PRF-85582, Type II (low infrared reflective pigments), Class C1 (barium chromate based corrosion inhibitors) waterborne epoxy primer, such as PPG Industries / Deft 44-GN-008A,[48] or 3) a MIL-DTL-53022, Type IV (high solids, enhanced corrosion performance, lead and chromate free, HAP-free formulation to meet maximum VOC content of 340 g/l) solvent borne epoxy primer, such as Hentzen Coatings 22167WEP.[49]

A MIL-PRF-85285, Type IV qualified 2K camouflage gray polyurethane topcoat was utilized as a control stack-up when testing the 1K camouflage gray polysiloxane topcoat stack-ups, whereas a MIL-PRF-85285, Type II qualified 2K gloss white polyurethane topcoat was utilized as a control stack-up when testing 2K gloss white polysiloxane topcoat stack-ups. A MIL-PRF-81352 qualified topcoat was not utilized as a control when testing stack-ups of the 1K camouflage gray polysiloxane touch-up topcoat. Stack-ups of the 1K gloss white polysiloxane topcoat for weatherability testing were compared to stack-ups with a MIL-PRF-85285, Type I or IV qualified 2K gloss white polyurethane topcoat.

Table 12 provides a list of the polysiloxane and polyurethane coating stack-ups that were tested to Navy requirements.

Table 12 — Coating stack-ups for testing to Navy performance requirements.

Topcoat	**Primer**	**Pretreatment**
1K camouflage gray polysiloxane	MIL-PRF-85582, Type II, Class C1	MIL-DTL-81706, Type I, Class 1A
MIL-PRF-85285, Type IV camouflage gray polyurethane	MIL-PRF-85582, Type II, Class C1	MIL-DTL-81706, Type I, Class 1A
1K camouflage gray polysiloxane touch-up / repair topcoat	MIL-PRF-85582, Type II, Class C1	MIL-DTL-81706, Type I, Class 1A
2K gloss white polysiloxane	MIL-DTL-53022, Type IV	MIL-DTL-81706, Type I, Class 1A
MIL-PRF-85285, Type II gloss white polyurethane	MIL-DTL-53022, Type IV	MIL-DTL-81706, Type I, Class 1A
1K gloss white polysiloxane	MIL-PRF-85582, Type I, Class C1	MIL-DTL-81706, Type I, Class 1A

MIL-PRF-85285, Type I gloss white polyurethane	MIL-PRF-85582, Type I, Class C1	MIL-DTL-81706, Type I, Class 1A
MIL-PRF-85285, Type IV gloss white polyurethane	MIL-PRF-85582, Type I, Class C1	MIL-DTL-81706, Type I, Class 1A

5.2.2.2 Stack-Ups for Air Force Testing

PreKote, which is a non-toxic, hexavalent chromium free conversion coating that is produced by Pantheon Enterprises, was the pretreatment for all Air Force coating stack-ups over aluminum alloys.[50] Bare cold rolled steel panels did not receive a pretreatment. The primers for the Air Force stack-ups consisted of the following: 1) a MIL-PRF-23377, Type I (standard pigments), Class C2 (strontium chromate based corrosion inhibitors) solvent borne epoxy primer, such as PPG Industries / Deft 02-Y-040 epoxy primer [43,51], 2) Aerodur 2100 Mg-RP from Akzo Nobel, which is a non-chrome, magnesium-rich, solvent borne epoxy primer,[52] and 3) AkzoNobel 10P3-2, which is a zinc dust containing solvent borne epoxy primer.[45]

A MIL-PRF-85285, Type IV qualified 2K camouflage gray polyurethane topcoat was utilized as a control stack-up when testing the 1K camouflage gray polysiloxane topcoat stack-ups, whereas a MIL-PRF-85285, Type IV qualified 2K semi-gloss gray polyurethane topcoat was utilized as a control stack-up when testing the 1K semi-gloss gray polysiloxane topcoat stack-ups.

Table 13 provides a list of the polysiloxane and polyurethane coating stack-ups that were tested to Air Force requirements.

Table 13 — Coating stack-ups for testing to Air Force performance requirements.

Topcoat	**Primer**	**Pretreatment**
1K camouflage gray polysiloxane	MIL-PRF-23377, Type I, Class C2	PreKote
MIL-PRF-85285, Type IV camouflage gray polyurethane	MIL-PRF-23377, Type I, Class C2	PreKote
1K camouflage gray polysiloxane	Aerodur 2100 Mg-RP	PreKote
MIL-PRF-85285, Type IV camouflage gray polyurethane	Aerodur 2100 Mg-RP	PreKote
1K semi-gloss gray polysiloxane	Aerodur 2100 Mg-RP	PreKote
MIL-PRF-85285, Type IV semi-gloss gray polyurethane	Aerodur 2100 Mg-RP	PreKote
1K semi-gloss gray polysiloxane	10P3-2 Zinc-Rich	None
MIL-PRF-85285, Type IV semi-gloss gray polyurethane	10P3-2 Zinc-Rich	None

5.2.2.3 Test Sample Fabrication

All primers and pretreatments were applied according to manufacturer recommended film thicknesses and MIL-PRF-85285 or MIL-PRF-32239 requirements. All topcoats were applied via HVLP spray equipment at the recommended primer overcoat period. For Navy topcoats, the target dry film thickness was 1.7-2.3 mils when applied at 60-90 °F and 20-80% RH. For Air Force topcoats, the target dry film thickness was 2.2 ± 0.2 mils when applied at 60-90 °F and 20-80% RH. The touch-up topcoat for Navy aircraft was applied with a Preval® refillable spray gun to simulate touch-up activities on aircraft in the field, and the target dry film thickness for the coating was ≥1.0 mil.[53] All topcoats were allowed to cure for a minimum of 14 days to ensure adequate cross-linking had occurred. After 14 days, the appearance of the coatings were visually examined to ensure the surface was smooth, uniform, and free from any visible defects (e.g., bubbles, cracks, pinholes, hazing, or significant orange peel).

5.2.3 Test Descriptions

The following sections describe, in detail, the standard and extended laboratory tests performed during this project. Tests that were not performed, as stated in Tables 6 and 7, are not described.

5.2.3.1 Viscosity and Pot Life

Rationale

This test was identified as a performance requirement for polysiloxane topcoats tested to Navy requirements. This test evaluates the viscosity of a topcoat once mixed (for 2K systems) or initially opened (for 1K systems) and exposed to atmospheric moisture. The test also evaluates the pot life of the coating, which is the time for the viscosity to double upon mixing in a closed/covered container. This test is useful for determining the application viscosity of topcoats.

Detailed Description of Test

This test method covers the determination of the viscosity of Newtonian or near-Newtonian paints, varnishes, lacquers, and related liquid materials using a Ford-type efflux viscosity cup. This test is performed according to ASTM D1200 (*Standard Test Method for Viscosity by Ford Viscosity Cup*), and results should meet those specified in MIL-PRF-85285 and MIL-PRF-81352.

Topcoats were evaluated for viscosity and pot life using a calibrated #4 Ford Viscosity Cup. Viscosity determinations should be performed in a room free of drafts and rapid changes in temperature. For the highest degree of precision, the room temperature should be between 72 and 82°F (22 and 28°C). Determinations should be made at a temperature above the dew point of the atmosphere surrounding the apparatus.

The #4 Ford Viscosity Cup is placed in a tripod stand or bracketed clamp and the top of the cup is leveled. Next, the orifice at the bottom of the cup is covered with a finger or rubber stopper, and the mixed or opened topcoat is poured into the cup until a meniscus is formed and nearly overflowing. The top of the cup is then scraped with a spatula to verify that the cup is full and does not contain excess material. Release the finger or stopper and simultaneously begin recording the time using a stopwatch. Stop recording the time when the flowing stream of topcoat first breaks. This is the initial viscosity of the topcoat. A viscosity of <30 seconds is considered adequate for MIL-PRF-85285, Type II and IV topcoats, whereas a viscosity of 16-25 seconds is considered adequate for MIL-PRF-81352 touch-up topcoats.

Topcoat material that has not been tested for initial viscosity is then mixed (no vortex) in a closed/covered container for 4 hours using a mechanical stirrer. After 4 hours, the viscosity is again tested and recorded using the aforementioned procedure. At this point, a viscosity of >60 seconds is considered inadequate for MIL-PRF-85285 topcoats. After 5 hours of mixing, gelation of any topcoat is considered a failure.

Test Description

Parameters	Opened 1K topcoats and mixed 2K topcoats; viscosity of initial topcoat and after mixing
Number and Type of Specimens per Candidate Alternative	1K camouflage gray polysiloxane topcoat, 1K camouflage gray polysiloxane touch-up topcoat, 2K gloss white polysiloxane topcoat
Trials per specimen	1
Experimental Control Specimens	MIL-PRF-85285 and MIL-PRF-81352 qualified topcoats
Acceptance Criteria	Type II & IV topcoats: ≤30 seconds initial, ≤60 seconds after 4 hours, no gelation after 5 hours; Touch-up topcoats: 16 to 25 seconds initial, no gelation after 5 hours
Government Stakeholder	NAVAIR

Equipment / Instrumentation

- Calibrated #4 Ford Viscosity Cup – Gardco or other manufacturer
- Tripod or bracketed stand
- Stopwatch with discrimination of 0.2 seconds or better
- Thermometer

Data Analysis

- Determine according to MIL-PRF-85285 and MIL-PRF-81352 requirements.
- Report the initial and 4 hour viscosities, and note if any gelation occurred at 5 hours.

5.2.3.2 Drying Times

Rationale

This test was identified as a performance requirement for polysiloxane topcoats tested to Navy and Air Force requirements. The test evaluates the length of time for the topcoat to dry/cure once sprayed, brushed, or rolled. Insufficient dry/cure times are the primary mode of failure.

Application Method

All polysiloxane topcoats listed in Tables 12 and the 1K semi-gloss polysiloxane topcoat in Table 13 were applied via high volume, low pressure (HVLP) spray equipment.

Detailed Description of Test

This test method determines several stages of drying and the rate of dry-film formation of organic coatings using a circular mechanical drying-time recording devices. The test is conducted in accordance with ASTM D5895 (*Standard Test Methods for Evaluating Drying or Curing During Film Formation of Organic Coatings Using Mechanical Recorders*) and rated according to MIL-PRF-85285 and MIL-PRF-81352.

The test is conducted by applying the coating over a metal substrate or Leneta Form B hiding chart. Immediately after applying, place a mechanical dry time recorder, such as a Gardco Ultracycle Circular Dry Time Recorder 5000 Series or equivalent, over the coating such that the Teflon ball contacts the coating and can rotate in a clockwise or counter-clockwise motion (depending on the instrument) making a 360° arc. The dry time recorder is allowed to rotate through the coating for a period of 1 to 24 hours. After the test is finished, the dry time recorder is removed and the coating is visually inspected using Figure 17 to determine the various stages of drying/curing.

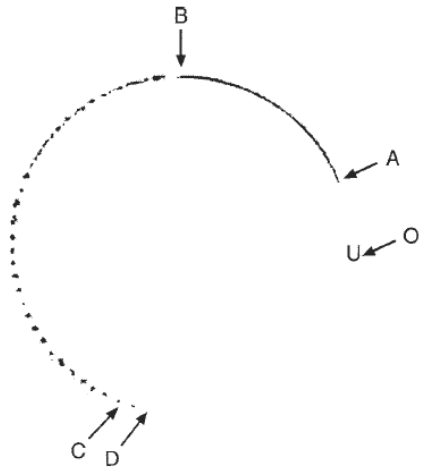


Figure 17 — Stage of drying using a circular dry time recorder.

The stages of drying are rated as follows:

- Stage A – Set-to-touch
- Stage B – Tack-free time
- Stage C – Dry-hard time
- Stage D – Dry-through time

The set-to-touch time is reached when the film has solidified sufficiently, by solvent evaporation or chemical reaction, or both, that it no longer flows nor sticks to a finger that lightly touches it. In this test method, the set-to-touch time is reached when a pear-shaped depression appears in the film and the film stops flowing over the path of the recorder's stylus to leave a track in the film that reveals substrate.

The tack-free time is reached when the film surface has dried or cured (see set-to-touch time) so that the film does not adhere to very light objects placed on it. In this test method, the tack-free time is reached where the continuous track in the film ceases and the stylus starts to tear the film or leave a ragged/sharp-edged grove as it first begins to climb over the film.

The dry-hard time is reached when the drying and curing, or both, reactions have proceeded sufficiently that the film is not displaced nor is any noticeable mark left by pinching the panels between the thumb on the film and forefinger with a relatively strong force. In this test method, the dry-hard time is reached where the stylus has risen out of the film and rides on the surface, leaving only a mark without disrupting the body of the film.

The dry-through time is reached when the film has solidified so completely that a large, twisting force can be applied without distorting the film. In this test method, the dry-through time is reached when the stylus no longer leaves a visible mark on the film. Per MIL-PRF-85285, the Navy topcoat shall be set-to-touch

within six hours and dry-hard within twelve hours. Per MIL-PRF-81352, the Navy aircraft touch-up topcoat shall be tack-free in less than 60 minutes.

For Air Force topcoats, the test method used to determine the coating dry time was the dry-to-tape test. This test is conducted by applying a five inch strip of masking tape (3M #250), or equivalent, to the sprayed topcoat and pressing down with four double passes of a roller weighing no less than 4.5 lbs. (2.04 kg). The tape shall remain in contact with the test panel for no less than one hour. The tape shall then be removed by seizing the free end and with a steady, moderate motion, pull back on itself as close to 180 degrees as possible. Per MIL-PRF-32239, a topcoat shall be dry-to-tape with no adhesion loss or permanent marring within eight hours or less.

Test Description

Parameters	All polysiloxane topcoats; record dry times using a mechanical recorder or tape
Number and Type of Specimens per Candidate Alternative	1K camouflage gray polysiloxane topcoat, 1K camouflage gray polysiloxane touch-up topcoat, 2K gloss white polysiloxane topcoat, 1K semi-gloss gray polysiloxane topcoat
Trials per specimen	1
Experimental Control Specimens	MIL-PRF-85285 qualified polyurethane topcoats; MIL-PRF-81352 qualified touch-up topcoats
Acceptance Criteria	*Navy*: set-to-touch in <6 hours and dry-hard in <12 hours for Type II and Type IV topcoats; tack-free in <60 minutes for touch-up topcoats *Air Force*: Dry-to-tape ≤8 hours with no adhesion loss or permanent marring
Government Stakeholder	NAVAIR, Air Force

Equipment / Instrumentation

- Gardco Ultracycle Circular Dry Time Recorder 5000 Series or equivalent
- AA 2024 panel or Leneta Form B hiding card
- Tape – 1.0 inch (25.4 mm) wide masking tape, such as 3M Company #250 or equivalent; less than 1 year old
- 4.5-5 pound rubber covered roller that is ~3.5 inch in diameter and 1.75 inches long and with a durometer hardness of Shore D 70-80

Data Analysis

- Perform dry time test of Navy topcoats according to ASTM D5895
- Perform dry time for Air Force topcoats according to MIL-PRF-32239A
- Report dry times of Navy topcoats for comparison to MIL-PRF-85285E and MIL-PRF-81352C
- Report any loss of adhesion or permanent marring within 8 hour period for Air Force topcoats

5.2.3.3 Color

Rationale

This test was identified as a performance requirement for polysiloxane topcoats tested to Navy and Air Force requirements. The test evaluates the color of topcoats after they have been applied and cured for 14 days at room temperature. Color is important for visual aesthetics and evading sight by an enemy.

Application Method

The polysiloxane topcoats were applied via HVLP spray equipment over stack-ups as shown in Tables 12 and 13 and within the primer's specified overcoat window. The topcoats were then allowed to cure for 14 days before testing occurred.

Detailed Description of Test

This test method covers the calculation, from instrumentally measured color coordinates based on daylight illumination, of color tolerances and small color differences between opaque specimens, such as painted panels, plastic plaques, or textile swatches. This test is performed in accordance with ASTM D2244 (*Standard Practice for Calculation of Color Tolerances and Color Differences from Instrumentally Measured Color Coordinates*), and results should conform to those specified in MIL-PRF-85285 and MIL-PRF-32239. For this JTP, Navy camouflage gray and gloss white topcoats should be color-matched to FED-STD-595 #36375 and #17925, respectively, whereas Air Force camouflage gray topcoats should be color matched to FED-STD-595 #36173 and Air Force semi-gloss gray topcoats color matched to FED-STD-595 #26173.

A CIELAB (1976 CIE L*a*b* Space) color meter determines an approximately uniform color space of a surface, such as a coating, based on nonlinear expansion of the tri-stimulus values and utilizes the differences to produce three opponent axes that approximate the percepts of lightness to darkness (L*), redness to greenness (a*), and yellowness to blueness (b*). As shown in Figure 18, the L* value is the central vertical axis with values set from 0 (black) to 100 (white), whereas the a* and b* color axes are designated as positive or negative values. These color axes are based on the fact that a color can't be red and green, or blue and yellow, because these colors oppose each other. For both axes, zero is neutral gray. The L*a*b* color space includes all perceivable colors.

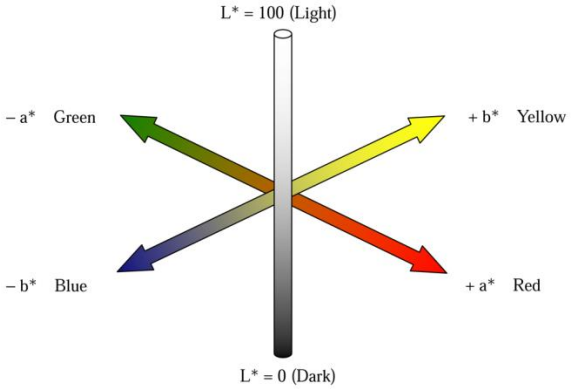


Figure 18 — CIELAB color space.

The total difference between two colors is the Delta E (ΔE*) and is calculated as follows:

$$\Delta E^* = \sqrt{(L^*_2 - L^*_1)^2 + (a^*_2 - a^*_1)^2 + (b^*_2 - b^*_1)^2}$$

Thus, for comparing a topcoat color to a FED-STD-595 color chip the topcoat would be the L^*_2, a^*_2, and b^*_2 values in the calculation.

The color meter should have a D65 illuminant, a 10° observer angle and a spectral reflectance. Colors appear differently under different light sources, and the D65 illuminant represents natural sunlight. A 10° angle is standing for viewing colors at angles greater than 10°, such as when viewing topcoats. The sample is then illuminated at a 45° angle to the sample, and the light that is reflected off the sample is captured by a detector and used to calculate the L*a*b* color values. Spectral reflectance does not account for the loss of scattered light due to topcoat surface structure.

Each polysiloxane topcoat that is applied as a stack-up shall be subjected to color testing. Per ASTM D2244, record the color of a topcoat by placing the meter in 3 different locations of a panel. Use a total of 3 panels for each topcoat, then average these values. Record the color values of the FED-STD-595 color chip. Determine the color difference (ΔE) using the calculation above.

Per MIL-PRF-85285 and MIL-PRF-32239, the color of the topcoat shall have a difference of less than 1.0 when compared to the color chip. Per MIL-PRF-81352, touch-up topcoats shall have a difference of less than 2.0 when compared to the color chip.

Test Description

Parameters	Topcoats cured for 14 days at RT after applied as stack-ups; 3 color measurements per panel
Number and Type of Specimens per Candidate Alternative	1K camouflage gray polysiloxane topcoat, 1K camouflage gray polysiloxane touch-up topcoat, 2K gloss white polysiloxane topcoat, 1K semi-gloss gray polysiloxane topcoat
Trials per specimen	3
Experimental Control Specimens	FED-STD-595 color chips for #36375, #17925, #36173 and #26173
Acceptance Criteria	ΔE of <1.0 when compared to the FED-STD-595 color chip
Government Stakeholder	NAVAIR, Air Force

Equipment / Instrumentation

- CIELAB color meter with a 10° observer angle, D65 illuminant and spectral reflectance.

Data Analysis

- Record color values of topcoats and calculate difference from color chips.
- Determine if color of topcoats are within specification.

5.2.3.4 Gloss

Rationale

This test was identified as a performance requirement for polysiloxane topcoats tested to Navy and Air Force requirements. The test evaluates the gloss of the topcoats after they have been applied and cured for 14 days at room temperature. Gloss is important for visual aesthetics and evading sight by an enemy.

Application Method
The polysiloxane topcoats were applied via HVLP spray equipment over stack-ups as shown in Tables 12 and 13 and within the primer's specified overcoat window. The topcoats were then allowed to cure for 14 days before testing occurred.

Detailed Description of Test
This test method covers the measurement of the specular gloss of non-metallic specimens for gloss meter geometries of 60, 20, and 85 degrees. This test is performed in accordance with ASTM D523 (*Standard Test Method for Specular Gloss*), and results should conform to those specified in MIL-PRF-85285 and MIL-PRF-32239.

Gloss is associated with the capacity of a surface to reflect more light in some directions than in others. The directions associated with mirror, or specular, reflection of a substrate normally have the highest reflectance values. Measurements by this test method correlate with visual observations of surface shininess made at roughly the same viewing angles. Measured gloss ratings by this test method are obtained by comparing the specular reflectance from the specimen to that from a black glass standard. The measured gloss is reported as gloss units (GU).

The geometries selected for measurement are determined by the glossiness of the substrate. For example, a 60° angle of incidence is used to compare the majority of specimens, whereas a 20° angle is used to compare specimens with gloss greater than 70 GU. An angle of 85° is used to compare specimens with low sheen and near zero gloss.

Each polysiloxane topcoat that is applied over a stack-up shall be subjected to gloss testing. Per ASTM D523, the gloss meter is calibrated using the black glass, then the 20°, 60° and/or 85° gloss values of the topcoat are recorded by placing the meter in 3 different locations of each topcoat panel. A total of 3 panels for each topcoat are utilized and the values for each angle of incidence are averaged.

Per MIL-PRF-85285, gloss and camouflage topcoats shall measure ≥90 GU and ≤5 GU at 60°, respectively, whereas camouflage topcoats shall also measure ≤10 GU at 85°. Per MIL-PRF-32239, camouflage topcoats shall measure ≤5 GU at 60° and ≤9 GU at 85°, whereas semi-gloss topcoats shall measure 15 to 45 GU max. at 60°.

Test Description

Parameters	Topcoats cured for 14 days at RT after applied as stack-ups; gloss measured at 60° and 85°
Number and Type of Specimens per Candidate Alternative	1K camouflage gray polysiloxane topcoat, 1K camouflage gray polysiloxane touch-up topcoat, 2K gloss white polysiloxane topcoat, 1K semi-gloss gray polysiloxane topcoat
Trials per specimen	3
Experimental Control Specimens	MIL-PRF-85285 qualified camouflage, semi-gloss and gloss polyurethane topcoats
Acceptance Criteria	≥90 GU for gloss topcoats and ≤5 GU for camouflage topcoats at 60°; ≤10 GU for Navy camouflage and ≤9 GU for Air Force camouflage topcoats at 85°; 15-45 GU at 60° for Air Force semi-gloss topcoats
Government Stakeholder	NAVAIR, Air Force

Equipment / Instrumentation

- Gloss meter with 20°, 60° and 85° angles of incidence.

Data Analysis

- Record gloss values of topcoats.
- Determine if gloss of topcoats are within specification.

5.2.3.5 Opacity

Rationale

This test was identified as a performance requirement for polysiloxane topcoats tested to Navy requirements. The test evaluates how well a topcoat hides over a dark background when applied at the recommended dry film thickness (DFT). Insufficient hiding of an underlying primer is considered a failure and typically results from topcoats with low levels of pigmentation.

Application Method

The polysiloxane topcoats in Tables 12 were applied via HVLP spray equipment over a black and white hiding chart. The topcoats were then allowed to cure for 14 days at room temperature before testing occurred.

Detailed Description of Test

This test method covers the opacity (hiding power) of a topcoat over a black and white hiding chart. Per MIL-PRF-85285, the topcoat shall be applied at DFT of 1.9 to 2.1 mils [48 to 53 micrometers (μm)] over a black and white hiding chart (Leneta Form 3B or equivalent). The contrast ratio shall be determined by measuring the "L" reflectance value of the topcoat over the black and white sides of the chart, respectively. Determine the "L" value of the coating covering the white and black parts of the chart, L_W and L_B, respectively, using a color meter in accordance with ASTM D2244 *Calculation of Color Tolerances and Color Differences from Instrumentally Measured Color Coordinates*). The contrast ratio is calculated as follows: $C = L_B \div L_W$. Each topcoat shall be applied over 3 hiding charts.

Per MIL-PRF-85285, the contrast ratio shall be equal or greater than 0.95.

Test Description

Parameters	Topcoats cured for 14 days at RT after applied over a black and white hiding chart; record "L" values and calculate hiding efficiency
Number and Type of Specimens per Candidate Alternative	1K camouflage gray polysiloxane topcoat, 1K camouflage gray polysiloxane touch-up topcoat, 2K gloss white polysiloxane topcoat
Trials per specimen	3
Experimental Control Specimens	MIL-PRF-85285 qualified camouflage gray and gloss polyurethane topcoats
Acceptance Criteria	≥0.95 contrast ratio for camouflage and gloss topcoats
Government Stakeholder	NAVAIR

Equipment / Instrumentation

- Black and white hiding chart, such as a Leneta Form B (7-5/8 x 11-3/8" (194 x 289mm) or equivalent
- CIELAB color meter with a 10° observer angle, D65 illuminant and spectral reflectance.

Data Analysis

- Record "L" values for each topcoat over the hiding chart.
- Determine if contrast ratios of topcoats are within specification.

5.2.3.6 Adhesion (Wet Tape)

Rationale

This test was identified as a performance requirement for polysiloxane topcoats tested to Navy and Air Force requirements. The test evaluates intercoat adhesion between the topcoat and underlying stack-up primer, in addition to intercoat adhesion between all layers of the stack-up. Loss of topcoat adhesion to the primer is the primary mode of failure.

Application Method

The polysiloxane topcoats were applied via HVLP spray equipment over stack-ups as shown in Tables 12 and 13 and within the primer's specified overcoat window. The topcoats were then allowed to cure for 14 days at room temperature before testing occurred.

Detailed Description of Test

This test method covers a procedure for establishing adequacy of adhesion between a topcoat and primer after immersed in water, an "X" is cut into the film, and the "X" is peeled using pressure sensitive adhesive tape. This test is performed in accordance with MIL-PRF-85285 and MIL-PRF-32239, and results are rated according ASTM D3359 (*Standard Test Methods for Measuring Adhesion by Tape Test*) Method A (*X-Cut Tape Adhesion*). The rating scale for X-cut adhesion is as follows:

- 5A – No peeling or removal
- 4A – Trace peeling or removal along incisions or at their intersection
- 3A – Jagged removal along incisions up to 1.6 mm (1⁄16 in.) on either side
- 2A – Jagged removal along most of incisions up to 3.2 mm (1⁄8 in.) on either side
- 1A – Removal from most of the area of the X under the tape
- 0A – Removal beyond the area of the X

Each polysiloxane topcoat that is applied as a stack-up shall be subjected to the wet tape adhesion test, and three panels per topcoat shall be tested. Per MIL-PRF-85285 and MIL-PRF-32239, the test panels shall be immersed in distilled water for no less than 24 hours at room temperature. Remove the test panels from the water and wipe dry with a soft cloth. Within 3 minutes after removal from the water make two parallel scribes with a stylus or razor through the coating to the substrate. The scribes shall be ¾ of an inch apart and 2-inches long. The panels shall then be scribed to the substrate from opposing ends of the parallel scribes to form an "X". Immediately apply a 1-inch wide strip of masking tape with the adhesive side down across the scribes. Press the tape against the surface of the coating and roll the rubber cover roller across the tape eight times. Within 90 seconds, remove the tape with one quick motion at 180 degrees from the plane of the panel. Visually examine the X-cut area for removal of the coating from the primer. A rating of less than 4A is considered a failure. Delamination or peeling is also considered a failure. For the Air Force, adhesion values pertain to the entire coating system, not just intercoat adhesion between the topcoat and primer.

Test Description

Parameters	Topcoats cured for 14 days at RT after applied as stack-ups; 24 hour immersion in distilled water at RT then X-cut test
Number and Type of Specimens per Candidate Alternative	1K camouflage gray polysiloxane topcoat, 1K camouflage gray polysiloxane touch-up topcoat, 2K gloss white polysiloxane topcoat
Trials per specimen	3
Experimental Control Specimens	MIL-PRF-85285 qualified polyurethane topcoats and MIL-PRF-32239 coating systems with polyurethane topcoats
Acceptance Criteria	No less than a 4A rating; no delamination or peeling
Government Stakeholder	NAVAIR, Air Force

Equipment / Instrumentation

- Cutting tool – stylus or razor
- Cutting guide – steel or other hard metal straightedge
- Tape – 1.0 inch (25.4 mm) wide masking tape, such as 3M Company #250 or equivalent; less than 1 year old
- 4.5-5 pound rubber covered roller that is ~3.5 inch in diameter and 1.75 inches long and with a durometer hardness of Shore D 70-80

Data Analysis

- Rate according to ASTM D 3359, Method A.
- Report whether or not delamination or peeling is present.

5.2.3.7 Adhesion (Crosshatch)

Rationale

This test was identified as a performance requirement for the 1K camouflage gray polysiloxane topcoat tested to Air Force requirements. The test evaluates intercoat adhesion between the topcoat and underlying stack-up primer, in addition to intercoat adhesion between all layers of the stack-up. Loss of topcoat adhesion to the primer is the primary mode of failure.

Application Method

The 1K camouflage gray polysiloxane topcoat was applied via HVLP spray equipment over Air Force stack-ups (Table 13) and within the primer's specified overcoat window. The coating system was then allowed to cure for 14 days at room temperature before testing occurred.

Detailed Description of Test

This test method covers a procedure for establishing adequacy of adhesion between all layers of the coating system when a grid is cut into the coating and pulled at room temperature using pressure sensitive adhesive tape. This test is performed in accordance with MIL-PRF-32239, and results are rated according ASTM D3359 (*Standard Test Methods for Measuring Adhesion by Tape Test*) Method A (*Cross-Hatch Adhesion*). The rating scale for cross-hatch adhesion is as follows:

- 5B – 0% of area removed
- 4B – less than 5% of area removed
- 3B – 5-15% of area removed
- 2B – 15-35% of area removed
- 1B – 35-65% of area removed
- 0B – greater than 65% of area removed

To perform the test, utilize a Gardco cutting tool or equivalent with 6 – 2 mm spaced blades. Per ASTM D3359, place the cutter assembly on the test specimen so that the guide and cutter rests on the substrate. Grasp the handle and rotate it upward with respect to the line of contact of the guide with the test surface. During this motion, the tips of the cutter first contact the test surface when the top of the handle is about seven degrees with respect to the test surface. Continue this motion until the top surface of the handle is elevated to about 15°. This is the correct attitude of the cutter assembly for the test. With enough pressure on the handle to insure that all of the cutter tip penetrates to the test specimen supporting base, pull the assembly along the test surface through 0.75 to 1.00 inch. After making the required cuts brush the film lightly with a soft brush or tissue to remove any detached flakes or ribbons of coatings. Repeat this procedure with a second cut intersecting the first pattern at 90° (±5°). Brush the area as before and inspect the incisions for reflection of light from the substrate. If the metal has not been reached make another grid in a different location.

Removed a 3 inch long strip of pressure sensitive adhesive tape, such as 3M Company #250 or equivalent (less than 1 year old), and place the center of the tape over the grid. Smooth the tape into place using a finger. To ensure good contact with the film rub the tape firmly with an eraser on the end of a pencil. The color under the tape is a useful indication of when good contact has been made. Within 90 seconds of application, remove the tape by seizing the free end and pulling back upon itself at an angle of 180°. Inspect the grid for removal of coating and rate according to the scale above.

Each polysiloxane topcoat that is applied as an Air Force stack-up shall be subjected to the cross-hatch adhesion test, and three panels per topcoat shall be tested. The coating system shall have no less than a 4B rating according to ASTM 3359, and no component of the coating system shall peel or delaminate from the substrate or any other component of the system.

Test Description

Parameters	Topcoats cured for 14 days at RT after applied as stack-ups; cross-hatch at RT
Number and Type of Specimens per Candidate Alternative	1K camouflage gray polysiloxane topcoat
Trials per specimen	3
Experimental Control Specimens	MIL-PRF-32239 coating system with a polyurethane topcoat
Acceptance Criteria	No less than a 4B rating; no delamination or peeling
Government Stakeholder	Air Force

Equipment / Instrumentation

- Gardco cutting tool (part no. PA-2058)
- Tape – 1.0 inch (25.4 mm) wide masking tape, such as 3M Company #250 or equivalent; less than 1 year old
- Rubber eraser, on the end of a pencil

Data Analysis

- Rate according to ASTM D3359, Method A.
- Report whether or not delamination or peeling is present.

5.2.3.8 Weather Resistance

Rationale

This test was identified as a performance requirement for polysiloxane topcoats. The test evaluates the ability of a topcoat to resist discoloration and gloss change upon exposure to cycles of artificial sunlight and moisture over a specified period of time. Color change and/or loss of gloss relative to standards are the primary modes of failure.

Application Method

The polysiloxane topcoats were applied via HVLP spray equipment over stack-ups as shown in Tables 12 and 13 and within the primer's specified overcoat window. The topcoats were then allowed to cure for 14 days at room temperature before testing occurred.

Detailed Description of Test

This test method covers the procedure for using a xenon-arc light and water apparatus intended to reproduce the weathering effects that occur when materials, such as coatings, are exposed to actual sunlight and moisture as rain or dew during actual use. This test is performed in accordance MIL-PRF-85285 and MIL-PRF-32239 with reference to ASTM G155 (*Standard Practice for Operating Xenon Arc Light Apparatus for Exposure of Non-Metallic Materials*).

The design of the test chamber may vary, but it should be constructed from corrosion resistant material and, in addition to the radiant source, should provide for a means of controlling the temperature and relative humidity. The test chamber should also provide for a means of spraying water on the test specimens. Recommended Xenon-Arc Weather-o-Meter (WOM) instruments include the Q-Sun/3000, Q-Sun/1000, and ATLAS models Ci3000+ and Ci4000.

Per MIL-PRF-85285, MIL-PRF-81352, and MIL-PRF-32239, the Xenon-Arc WOM should be set at the following conditions when tested in accordance with ASTM G155:

- Cabinet temperature: 42 ±3 °C (108 ± 5 °F)
- Black body temperature in cabinet: 63 ± 3 °C (145 ± 5 °F)
- Relative humidity in cabinet: 50 ± 5 percent
- Intensity (spectral irradiance): 0.35 to 0.5 watt/meter^2 (W/m^2) at a wavelength of 340 nm

For topcoats tested to MIL-PRF-85285, Type II (support equipment) and MIL-PRF-81352 (touch-up) requirements the WOM instrument should cycle between 102 minutes of light only and 18 minutes of light and water spray for not less than 500 hours. For Navy MIL-PRF-85285, Type IV topcoats and Air Force coating systems the Xenon-Arc should cycle between 102 minutes of light only and 18 minutes of light and water spray for not less than 3000 hours.

Each polysiloxane topcoat that is applied as a stack-up shall be subjected to the weather resistance test, and a total of three panels per topcoat shall be tested. After removal of the topcoats from the WOM, the 60° and 85° specular gloss of the topcoats shall be tested according to ASTM D532 (Section 3.6 of this JTP),

whereas the color shall be tested using a CIELAB color meter according to ASTM D2244 (Section 3.5 of this JTP).

Per MIL-PRF-85285, the 60° specular gloss of a Navy topcoat tested to Type II requirements shall be a minimum of 80 GU and possess a color change (ΔE) of less than 1.0 when compared to an unexposed sample. The 60° and 85° specular gloss of a camouflage topcoat tested to Type IV requirements shall demonstrate a change of less than 3 GU when compared to an unexposed sample, in addition to a ΔE of less than 1.0 when compared to an unexposed sample. The 60° specular gloss of a glossy topcoat tested to Type IV requirements shall demonstrate a change of less than 20 GU when compared to an unexposed sample, in addition to a ΔE of less than 1.0 when compared to an unexposed sample. Per MIL-PRF-81352, the topcoat shall have a ΔE of not greater than 2.0 when compared to an unexposed sample. Per MIL-PRF-32239, the 60° specular gloss of a camouflage topcoat tested to Air Force requirements shall demonstrate a maximum gloss of 5 GU when compared to an unexposed sample and a ΔE of less than 1.0 when compared to an unexposed sample.

Test Description

Parameters	Topcoats cured for 14 days at RT after applied as stack-ups; WOM testing for 500 or 3000 hours
Number and Type of Specimens per Candidate Alternative	1K camouflage gray polysiloxane topcoat, 1K camouflage gray polysiloxane touch-up topcoat, 2K gloss white polysiloxane topcoat, 1K gloss white polysiloxane topcoat.
Trials per specimen	3
Experimental Control Specimens	MIL-PRF-85285, Type II and IV qualified gloss and camouflage polyurethane topcoats; MIL-PRF-81352 touch-up topcoats; MIL-PRF-32239 qualified coating systems with polyurethane topcoats
Acceptance Criteria	*Navy:* Color change (ΔE) of <2.0 after 500 hours for touch-up topcoats; ≥80 GU at 60° and a ΔE of <1.0 after 500 hours for Type II topcoats; a change in gloss of <20 GU at 60° and a ΔE of <1.0 after 3000 hours for Type IV gloss topcoats; a change in gloss of <3 GU at 60° and 85° and a ΔE of <1.0 after 3000 hours for Type IV camouflage topcoats *Air Force:* <5 GU at 60° and a ΔE of <1.0 after 3000 hours
Government Stakeholder	NAVAIR, Air Force

Equipment / Instrumentation

- Xenon-Arc Weather-o-Meter (WOM) chamber with temperature control, humidity control, and water spray – Q-Sun/3000, Q-Sun/1000, those from Atlas Material Testing Technology or equivalent
- Gloss meter according to ASTM D523
- CIELAB color meter according to ASTM D2244

Data Analysis

- Evaluate according to MIL-PRF-85285, MIL-PRF-81352, and MIL-PRF-32239.
- Report color and gloss values and whether or not topcoats pass requirements.

5.2.3.9 Room Temperature Impact Flexibility

Rationale

This test was identified as a performance requirement for polysiloxane topcoats. The test evaluates the percent elongation of a topcoat or coating system when impacted with a falling weight. Cracking of the topcoat is the primary mode of failure.

Application Method

The polysiloxane topcoats were applied via HVLP spray equipment. For the Navy, topcoats were applied over chromic acid anodized AA 2024-0 panels. However, the Air Force utilize pretreated and primed stack-ups over AA 2024-0 panels (Table 13). The topcoats were applied within the primer's specified overcoat window. All topcoats were allowed to cure for 14 days at room temperature before being tested.

Detailed Description of Test

This test method covers a procedure for evaluating the ability of a topcoat or coating system to resist shattering, cracking, or chipping when distended beyond their original form upon impact at room temperature. This test is conducted in accordance with ASTM D6905 (*Standard Test Method for Impact Flexibility of Organic Coatings*), MIL-PRF-85285 and MIL-PRF-32239.

This test uses a Gardco GE Universal Impact Tester, Model 172. The test is conducted by dropping a standard weight/indenter from a measured distance so as to strike and deform the coating and the substrate. The standard weight/indenter consists of a 3.6 lb (1.63 kg) round rod that has formed on each end four convex spherical segments that are of different radii and extensions. The end marked with "A" corresponds to a 10, 20, 40 and 60% area increase, whereas the end marked with a "B" corresponds to a 0.5, 1, 2 and 5% area increase. The rod slides in a 48" vertical tube that serves to guide the falling weight. The base (at bottom of guide tube) of the tester contains an aluminum fixture plate and a rubber anvil pad with a Shore A hardness of 60. The percent elongation is the highest area of distension where there are no breaks or cracks in the film once impacted. Percent elongation is rated according to ASTM D6905 as shown in Table 8.

Table 14 — Percent elongation ratings according to ASTM D6905.

End of Indenter used for Impact	% Elongation of Topcoat or Coating System
A	60
A	40
A	20
A	10
B	5
B	2
B	1
B	0.5

To perform the test, place the coated panel, film side downward, on the rubber anvil pad at the bottom of the guide tube. With the "B" side of the indenter rod facing down, drop the indenter from above the panel.

Once impacted, ensure that an impression of the entire rim of the indenter is made on the back of the panel. Reverse the impactor to the "A" end and drop from above the panel adjacent to the first area of impact. Examine the impacted areas of the coating using a microscope with 10X power magnification to assess for cracks. Using Table 14, rate the percent elongation corresponding to the largest spherical impression at which no cracking occurs. Assess coating systems for cracks using an Elcometer, Model D204-01 holiday detector or equivalent.

Each polysiloxane topcoat applied as a stack-up containing an AA 2024-0 panel shall be subjected to the GE Impact Flexibility test, and three panels per topcoat shall be tested. Per MIL-PRF-85285, the Navy topcoat shall exhibit a minimum of 5% elongation for Type II topcoats and a minimum of 40% elongation for Type IV topcoats. Per MIL-PRF-32239, the coating system shall exhibit a minimum impact elongation of 10 percent for camouflage coating systems. This requirement remains the same for coating systems after weathering for 3000 hours in a Xenon-Arc WOM chamber (Section 3.10 of this JTP).

Test Description

Parameters	Topcoats cured for 14 days at RT after applied as stack-ups; impact testing at RT
Number and Type of Specimens per Candidate Alternative	1K camouflage gray polysiloxane topcoat, 1K camouflage gray polysiloxane touch-up topcoat, 2K gloss white polysiloxane topcoat
Trials per specimen	3
Experimental Control Specimens	MIL-PRF-85285 qualified polyurethane topcoats and MIL-PRF-32239 qualified systems with polyurethane topcoats
Acceptance Criteria	*Navy:* ≥5% elongation for Type II topcoats and ≥40% elongation for Type IV topcoats *Air Force*: ≥10% elongation before and after 3000 hours Xenon-Arc weathering for coating systems
Government Stakeholder	NAVAIR, Air Force

Equipment / Instrumentation

- Gardco GE Universal Impact Instrument, Model 172
- 3.6 lb (1.63 kg) weight/indenter with four convex spherical segments on each end and ends marked as "A" and "B"
- Rubber anvil pad with a Shore A hardness of 60
- Aluminum fixture plate
- Elcometer, Model D204-01 holiday detector or equivalent

Data Analysis

- Rate percentage elongation according to ASTM D6905.
- Report percentage of elongation at which no cracks occur per MIL-PRF-85285 and MIL-PRF-32239

5.2.3.10 Low Temperature Flexibility

Rationale

This test was identified as a performance requirement for the 1K camouflage gray polysiloxane topcoats. The test evaluates the resistance of a topcoat to cracking when cooled and simultaneously bent over a cylindrical mandrel. Cracking of the topcoat is the primary mode of failure.

Application Method

The 1K camouflage gray polysiloxane topcoats in Tables 12 and 13 were applied via HVLP spray equipment. For the Navy, the topcoat was applied over chromic acid anodized AA 2024-0 panels. However, the Air Force utilized pretreated and primed stack-ups over AA 2024-0 panels (Table 13). The later were applied within the primer's specified overcoat window. All topcoats were allowed to cure for 14 days at room temperature before being tested.

Detailed Description of Test

This test method covers the determination of the resistance to cracking (flexibility) of attached organic coatings on substrates of sheet metal or rubber-type materials. This test is conducted as described in ASTM D522 (*Standard Test Methods for Mandrel Bend Test of Attached Organic Coatings*), Method B (*Cylindrical Mandrel Test*) at a low temperature in accordance with MIL-PRF-85285 and MIL-PRF-32239.

Each polysiloxane topcoat applied as a stack-up containing an AA 2024-0 panel shall be subjected to the Low Temperature Flexibility test, and two panels per topcoat shall be tested. The test is conducted by placing the topcoat or coating system in a cold box at a temperature of -60 ± 5°F (-51 ± 3°C) and allowing to cool overnight (i.e., 12-14 hours). After removing, place the test panel over a steel mandrel of selected radii with the uncoated side in contact with the cylinder and with at least 2 inches (50 mm) of overhang on either side. Using a steady pressure of the fingers, bend the panel approximately 180° around the mandrel at a uniform velocity in a time of 1 second. Remove and examine the panel immediately for cracking visible to the unaided eye.

In accordance with MIL-PRF-85285, Type IV requirements, camouflage topcoats shall pass a 2.0 inch bend without cracking, whereas gloss topcoats shall pass a 1.0 inch bend without cracking. Camouflage coating systems shall also pass a 2.0 inch bend without cracking according to MIL-PRF-32239.

Test Description

Parameters	Topcoats cured for 14 days at RT after applied as stack-ups; mandrel bend at -60 °F
Number and Type of Specimens per Candidate Alternative	1K camouflage gray polysiloxane topcoat
Trials per specimen	2
Experimental Control Specimens	MIL-PRF-85285 qualified polyurethane topcoats; MIL-PRF-32239 qualified systems with polyurethane topcoats
Acceptance Criteria	*Navy:* 1" bend without cracking for camouflage topcoats *Air Force:* 1" bend without cracking for camouflage coating systems
Government Stakeholder	NAVAIR, Air Force

Equipment / Instrumentation

- 1.0 and 2.0 inch steel cylindrical mandrels according to ASTM D522, Method B
- Freezer capable of maintaining a temperature of -60 ± 5°F

Data Analysis

- Report any cracking of topcoat or coating system after bending

5.2.3.11 Room Temperature Flexibility

Rationale

This test was identified as a performance requirement for the polysiloxane topcoats tested to Navy requirements. The test evaluates the resistance of a topcoat to cracking when bent at room temperature over a cylindrical mandrel. Cracking of the topcoat is the primary mode of failure.

Application Method

The polysiloxane topcoats in Table 12 were applied via HVLP spray equipment over chromic acid anodized AA 2024-0 panels. The topcoats were then allowed to cure for 14 days at room temperature before being tested.

Detailed Description of Test

This test method covers the determination of the resistance to cracking (flexibility) of attached organic coatings on substrates of sheet metal or rubber-type materials. This test is conducted as described in ASTM D522 (*Standard Test Methods for Mandrel Bend Test of Attached Organic Coatings*), Method B (*Cylindrical Mandrel Test*) at room temperature.

Each polysiloxane topcoat applied as a Navy stack-up containing a AA 2024-0 panel shall be subjected to the Room Temperature Flexibility test, and two panels per topcoat shall be tested. At room temperature, place the test panel over a steel mandrel of selected radii with the uncoated side in contact with the cylinder and with at least 2 inches (50 mm) of overhang on either side. Using a steady pressure of the fingers, bend the panel approximately 180° around the mandrel at a uniform velocity in a time of 1 second. Remove and examine the panel immediately for cracking visible to the unaided eye. Camouflage and gloss topcoats shall pass a 1.0 inch bend without cracking.

Test Description

Parameters	Topcoats cured for 14 days at RT after applied as stack-ups; mandrel bend at RT
Number and Type of Specimens per Candidate Alternative	1K camouflage gray polysiloxane topcoat, 1K camouflage gray polysiloxane touch-up topcoat, 2K gloss white polysiloxane topcoat
Trials per specimen	2
Experimental Control Specimens	MIL-PRF-85285 qualified polyurethane topcoats
Acceptance Criteria	1” bend without cracking for gloss and camouflage topcoats
Government Stakeholder	NAVAIR

Equipment / Instrumentation

- 1.0 inch steel cylindrical mandrels

Data Analysis

- Report any cracking of topcoat after bending

5.2.3.12 Fluid Resistance

Rationale
This test was identified as a performance requirement for the polysiloxane topcoats tested to Navy and Air Force requirements. The test evaluates the resistance of topcoats to deformation when immersed in a fluid at a specified temperature and time period. Softening, blistering, color change or other defects of the topcoat are the primary modes of failure.

Application Method
The polysiloxane topcoats were applied via HVLP spray equipment as Navy and Air Force stack-ups (Tables 12 and 13) and within the primer's specified overcoat window. The topcoats or coating systems were then allowed to cure for 14 days at room temperature before testing occurred.

Detailed Description of Test
This test covers a procedure for immersing coatings in fluids and examining their resistance to deformation after immersion. The fluids include: lubricating oil conforming to MIL-PRF-23699 (*Lubricating Oil, Aircraft Turbine Engine, Synthetic Base, NATO code numbers: O-152, O-154, O-156, and O-167*), hydraulic fluid conforming to MIL-PRF-83282 (*Hydraulic Fluid, Fire Resistant, Synthetic Hydrocarbon Base, Metric, NATO Code Number H-537*), JP-5 fuel conforming to MIL-DTL-5624 (*Turbine Fuel, Aviation, Grades JP-4 and JP-5*), JP-8 fuel conforming to MIL-DTL-83133 (*Turbine Fuel, Aviation, Kerosene Type, JP-8 (NATO F-34), NATO F-35, and JP-8+100 (NATO F-37)*), and water conforming to ASTM D1193 (*Standard Specification for Reagent Water*), Type IV (*Distilled or Deionized*). This test is performed in accordance with MIL-PRF-85285 and MIL-PRF-32239, and the coatings shall be immersed according to Table 15.

Table 15 — Immersion fluids and conditions for Navy and Air Force topcoat requirements.

Service	Fluid	Fluid Temperature	Time of Immersion (minimum)
Navy and Air Force	Lubricating oil	121 ± 3 °C (250 ± 5 °F)	24 hours
Navy and Air Force	Hydraulic fluid	66 ± 3 °C (150 ± 5 °F)	24 hours
Navy	JP-5 fuel	Room temperature	7 days
Air Force	JP-8 fuel	Room temperature	30 days
Air Force	Deionized water	120 ± 5 °F (49 ± 3 °C)	30 days

Polysiloxane topcoats for testing to Navy requirements shall be immersed in lubricating oil, hydraulic fluid and JP-5 fuel, whereas polysiloxane topcoats for testing to Air Force requirements shall be immersed in lubricating oil, hydraulic fluid, JP-8 fuel and water. Three panels of each top shall be immersed in each fluid. Per MIL-PRF-32239, the pencil hardness of each coating system shall be evaluated according to ASTM D3363 (*Standard Test Method for Film Hardness by Pencil Test*) before testing, and the color of each coating systems shall be recorded according to ASTM D2244 (Section 3.5 of this JTP).

To conduct the pencil hardness test, a coated panel is placed on a firm horizontal surface. The pencil is held firmly against the film at a 45° angle (point away from the operator) and pushed away from the operator in a 6.5-mm (1⁄4-in.) stroke. The process is started with the hardest pencil and continued down the scale of hardness to either of two end points: 1) the pencil that will not cut into or gouge the film (pencil hardness), or 2) the pencil that will not scratch the film (scratch hardness). The initial pencil hardness for each coating system is then recorded. Pencil lead hardness is calibrated to the scale shown in Figure 19.

6*B*-5*B*-4*B*-3*B*-2*B*-*B*-*HB*-*F*-*H*-2*H*-3*H*-4*H*-5*H*-6*H*
Softer Harder

Figure 19 — Pencil hardness rating scale.

The immersion test is conducted by immersing the topcoat in a glass jar or metal container filled with each fluid so that half of the topcoat is immersed. The jar or container is then closed and each container is stored at a specific temperature for the period of time as stated in Table 15.

Per MIL-PRF-85285, the panels shall be inspected one hour after removal from the fluids. The coatings shall not exhibit any blistering, softening, or other coating defects. Slight staining of the coating is acceptable. Per MIL-PRF-81352, the panels shall exhibit no blistering, softening, or other coating defects four hours after removal from the fluids. A slight staining of the coatings is acceptable.

Per MIL-PRF-32239, after each immersion, remove the panels and immediately evaluate for blistering and film delamination. After evaluation, gently clean the panels with the coating system cleaner and rinse thoroughly with water. Blot the panels dry and allow to air dry for an additional one hour. Measure the final color using a CIELAB color meter in accordance with ASTM D2244. After the color measurement has been made, test the cross-hatch adhesion in accordance with ASTM D3359, Method B (Section 3.9 of this JTP), in addition to the pencil hardness using the rating scale above (Figure 2) in accordance with ASTM D3363. Compare the average of the initial values with the average of the final values. The coating system shall show no blistering or coating delamination or adhesion loss when tested in accordance with ASTM D3359, Method A and shall not exhibit more than a 2-pencil hardness change from the original hardness when tested in accordance with ASTM D3363. Additionally, the coating system shall not demonstrate a color change of greater than 3.0 from the non-immersed sample when tested with a CIELAB color meter according to ASTM D2244.

Test Description

Parameters	Topcoats cured for 14 days at RT after applied as stack-ups; immersion in fluids at various times and temperatures
Number and Type of Specimens per Candidate Alternative	1K camouflage gray polysiloxane topcoat, 1K camouflage gray polysiloxane touch-up topcoat, 2K gloss white polysiloxane topcoat
Trials per specimen	3
Experimental Control Specimens	MIL-PRF-85285, Type II and IV qualified gloss and camouflage polyurethane topcoats; MIL-PRF-32239 qualified systems with polyurethane topcoats
Acceptance Criteria	*Navy:* no blistering, softening, or other coating defects. Slight staining of the coating is acceptable; *Air Force:* coating system shall show no blistering, coating delamination, or adhesion loss, no more than a 2-pencil hardness change, $\Delta E \leq 3.0$
Government Stakeholder	NAVAIR, Air Force

Equipment / Instrumentation

- Pencil hardness kit with leads ranging from 6B to 6H
- CIELAB color meter according to ASTM D2244
- Gardco cutting tool (part no. PA-2058) for making a cross-hatch
- Tape – 1.0 inch (25.4 mm) wide masking tape, such as 3M Company #250 or equivalent; less than 1 year old
- Rubber eraser, on the end of a pencil

Data Analysis

- Report any blistering, softening or defects for Navy topcoats
- Rate pencil hardness of Air Force topcoat systems according to ASTM D3363
- Rate cross-hatch adhesion of Air Force topcoat systems according to ASTM D3359, Method B
- Report any blistering, softening or delamination for Air Force topcoat systems, in addition to any change in color

5.2.3.13 Humidity Resistance

Rationale

This test was identified as a performance requirement for polysiloxane topcoats tested to Navy and Air Force requirements. The test evaluates the resistance of topcoats to deformation when exposed to high humidity at an elevated temperature. Softening, blistering, loss of adhesion or other defects of the topcoat are the primary modes of failure.

Application Method

The polysiloxane topcoats were applied via HVLP spray equipment as Navy and Air Force stack-ups (Tables 12 and 13) and within the primer's specified overcoat window. The topcoats were then allowed to cure for 14 days at room temperature before testing occurred.

Detailed Description of Test

This test covers the basic principles and operating procedures for testing water resistance of coatings by exposing coated specimens in an atmosphere maintained at 100 % relative humidity so that condensation forms on the test specimens. This test is conducted in accordance with ASTM D2247 (*Standard Practice for Testing Water Resistance of Coatings in 100% Relative Humidity*) and at temperatures according to MIL-PRF-85285 and MIL-PRF-32239.

Each polysiloxane topcoat applied as a stack-up shall be subjected to the Humidity Resistance test, and three panels per topcoat shall be tested. The test is conducted by placing a coating in an enclosed chamber containing a heated, saturated mixture of air and water vapor. The temperature of the chamber is maintained at 120 ± 3 °F (48.9 ± 1.6 °C). At 100% RH, the temperature difference between the specimen and the surrounding vapor causes the formation of condensation on the specimens. The coatings are exposed for no less than 30 days. Water permeates the coating at rates that are dependent upon the characteristics of the coating.

Per MIL-PRF-85285, the topcoats shall show no blistering, softening, exhibiting any loss of adhesion, nor other film defects after testing. Per MIL-PRF-32239, the coating systems shall not blister, nor shall it exhibit any loss of adhesion when tested for cross-hatch adhesion in accordance with ASTM D3359, Method B (Section 3.9 of this JTP), nor exhibit a change in pencil hardness from the original hardness when tested in accordance with ASTM D3363, nor exhibit other film defects.

Test Description

Parameters	Topcoats cured for 14 days at RT after applied as stack-ups; cabinet with 100% R.H. and elevated temperature
Number and Type of Specimens per Candidate Alternative	1K camouflage gray polysiloxane topcoat, 2K gloss white polysiloxane topcoat
Trials per specimen	3
Experimental Control Specimens	MIL-PRF-85285, Type II and IV qualified gloss and camouflage polyurethane topcoats; MIL-PRF-32239 qualified systems with polyurethane topcoats
Acceptance Criteria	*Navy:* no blistering, softening, loss of adhesion or other coating defects; *Air Force:* coating system shall show no blistering or adhesion loss, no more change in pencil hardness
Government Stakeholder	NAVAIR, Air Force

Equipment / Instrumentation

- Pencil hardness kit with leads ranging from 6B to 6H
- Gardco cutting tool (part no. PA-2058) for making a cross-hatch grid
- Tape – 1.0 inch (25.4 mm) wide masking tape, such as 3M Company #250 or equivalent; less than 1 year old
- Rubber eraser, on the end of a pencil

Data Analysis

- Report any blistering, softening or loss of adhesion for Navy topcoats
- Rate pencil hardness of Air Force topcoat systems according to ASTM D3363
- Rate cross-hatch adhesion of Air Force topcoat systems according to ASTM D3359, Method A
- Report any blistering, loss of adhesion or change in pencil hardness for Air Force coating systems

5.2.3.14 Heat Resistance

Rationale

This test was identified as a performance requirement for polysiloxane topcoats tested to Navy and Air Force requirements. The test evaluates the resistance of a topcoat to degradation and post-curing affects when heated at an elevated temperature. Cracking, flaking, decreased flexibility and color change are the primary modes of failure.

Application Method

The polysiloxane topcoats were applied HVLP spray equipment as Navy and Air Force stack-ups (Tables 12 and 13) and within the primer's specified overcoat window. The topcoats were then allowed to cure for 14 days at room temperature before testing occurs.

Detailed Description of Test

This test is conducted in accordance with MIL-PRF-85285, MIL-PRF-81352, and MIL-PRF-32239.

Each polysiloxane topcoat applied over a stack-up shall be subjected to the Heat Resistance test, including Air Force stack-ups over AA 2024-0 panels. Two panels per topcoat shall be utilized for testing. The test is conducted using one coating as a control and one as the test specimen. The test specimen coating is then heated to 121 ± 3 °C (250 ± 5 °F) for 60 minutes in a convection oven.

Per MIL-PRF-85285 and MIL-PRF-81352, after exposure, the coating is allowed to cool to room temperature and is then evaluated for color change using a CIELAB color meter according to ASTM D2244 (Section 3.5 of this JTP). The coating shall have a ΔE of less than or equal to 1.0 when compared to the unexposed sample.

Per MIL-PRF-32239, after expose, the coating system is allowed to cool to room temperature for 1 hour. The coatings over AA 2024-0 substrates are then tested for mandrel flexibility according to ASTM D522, Method B (Section 3.13 of this JTP) with a 2-inch cylindrical mandrel. Coating systems over AA 2024-T3 substrates are tested for cross-hatch adhesion according to ASTM D3359, Method B (Section 3.9 of this JTP) and the ΔE compared to the unexposed coating using a CIELAB color meter according to ASTM D2244. The exposed coating system shall demonstrate no cracking, flaking, or adhesion loss when tested for mandrel flexibility and cross-hatch adhesion. The exposed coating shall also have a ΔE of less than or equal to 1.0 when compared to the unexposed sample.

Test Description

Parameters	Topcoats cured for 14 days at RT after applied over stack-ups; heated in a convection oven for 60 min.
Number and Type of Specimens per Candidate Alternative	1K camouflage gray polysiloxane topcoat, 1K camouflage gray polysiloxane touch-up topcoat; 2K gloss white polysiloxane topcoat
Trials per specimen	2
Experimental Control Specimens	MIL-PRF-85285, Type II and IV qualified gloss and camouflage polyurethane topcoats; MIL-PRF-81352 touch-up topcoats; MIL-PRF-32239 qualified systems with polyurethane topcoats
Acceptance Criteria	*Navy:* a ΔE of ≤1.0 when compared to an unexposed sample ; *Air Force:* no cracking or flaking when bent over a 2" cylindrical mandrel, no less than a 4B adhesion rating, a ΔE of ≤1.0
Government Stakeholder	NAVAIR, Air Force

Equipment / Instrumentation

- 2-inch steel cylindrical mandrel according to ASTM D522, Method B
- CIELAB color meter according to ASTM D2244
- Gardco cutting tool (part no. PA-2058) for making a cross-hatch according to ASTM 3359, Method B
- Tape – 1.0 inch (25.4 mm) wide masking tape, such as 3M Company #250 or equivalent; less than 1 year old
- Rubber eraser, on the end of a pencil

Data Analysis

- Report color change for Navy topcoats and Air Force coating systems
- Rate cross-hatch adhesion of Air Force topcoat systems according to ASTM D3359, Method A and report results
- Report any cracking or flaking of topcoat or coating system after bending

5.2.3.15 Solvent Resistance

Rationale

This test was identified as a performance requirement for polysiloxane topcoats tested to Navy and Air Force requirements. The test evaluates the resistance of a topcoat to solvation when contacted with methyl ethyl ketone (MEK) solvent and a rubbing force. Rubbing through the coating is the primary mode of failure.

Application Method

The polysiloxane topcoats were applied via HVLP spray equipment as Navy and Air Force stack-ups (Tables 12 and 13) and within the primer's specified overcoat window. The topcoats were then allowed to cure for 14 days at room temperature before testing occurred.

Detailed Description of Test

This test method describes a solvent rub technique for assessing the solvent resistance of an organic coating that chemically changes during the curing process and become more resistant to solvents as it cures. This test is conducted in accordance with ASTM D5402 (*Standard Practice for Assessing the Solvent Resistance of Organic Coatings Using Solvent Rubs*) and rated in accordance with MIL-PRF-85285 and MIL-PRF-32239.

Each polysiloxane topcoat applied as a stack-up shall be subjected to the Solvent Resistance test, and three panels per topcoat shall be utilized for testing. The test is conducted by select areas on the coated surface at least 150 mm (6 inches) long on which to run the tests. Fold a cotton, terrycloth rag into a pad of double thickness and saturate it to a dripping wet condition with methyl ethyl ketone (MEK) solvent. Place the properly protected index finger into the center of the pad while holding excess cloth with the thumb and remaining fingers of the same hand. With the index finger at a 45° angle to the test surface, rub the rectangular test area with moderate pressure first away from the operator and then back towards the operator. One forward and back motion is one double rub, and complete at the rate of approximately 1 per second. Continue rubbing the test area for a total of 25 double rubs. Take care to stay within the rectangular test area.

Per MIL-PRF-85285 and MIL-PRF-32239, the coating or coating system shall withstand 25 MEK double rubs without rubbing through to the metal substrate beneath. Rubbing through to bare metal indicates failure of the coating due to improper cure or low crosslink density.

Test Description

Parameters	Topcoats cured for 14 days at RT after applied as stack-ups; double rubs with MEK soaked cloth
Number and Type of Specimens per Candidate Alternative	1K camouflage gray polysiloxane topcoat, 2K gloss white polysiloxane topcoat
Trials per specimen	3

Experimental Control Specimens	MIL-PRF-85285, Type II and IV qualified gloss and camouflage polyurethane topcoats; MIL-PRF-32239 qualified systems with polyurethane topcoats
Acceptance Criteria	25 double rubs without rubbing through to bare metal
Government Stakeholder	NAVAIR, Air Force

Equipment / Instrumentation

- Cotton, terrycloth rag
- Methyl ethyl ketone (MEK) solvent from Sigma-Aldrich or equivalent

Data Analysis

- Perform double rubs according to ASTM D5402
- Report pass or fail after 25 double rubs with MEK

5.2.3.16 Water Resistance

Rationale

This test was identified as a performance requirement for the 1K camouflage gray polysiloxane touch-up topcoats tested to Navy requirements. The test evaluates the resistance of a topcoat to immersion in distilled water at room temperature. Blisters and cracking are the primary modes of failure.

Application Method

The polysiloxane touch-up topcoats were applied via HVLP spray equipment as Navy stack-ups (Table 12) and within the primer's specified overcoat window. The topcoats were then allowed to cure for 7 days at room temperature before testing occurred.

Detailed Description of Test

This test method covers the effects of household chemicals, including water, on organic coatings, resulting in any objectionable alteration in the surface, such as discoloration, blistering, softening, swelling, or loss of adhesion. This test is conducted in accordance with ASTM D1308 (*Standard Test Method for Effect of Household Chemicals on Clear and Pigmented Organic Finishes*) and is rated in accordance with MIL-PRF-81352C.

Each 1K camouflage gray polysiloxane touch-up topcoat applied as a stack-up shall be subjected to the Water Resistance test, and three panels per topcoat shall be utilized for testing. The test is conducted by immersing panels to a depth of 50% in distilled water, contained in a beaker, for 24 hours at room temperature. After 24 hours, withdraw the panels, allowed them to recover for 5 minutes, then examine.

Per MIL-PRF-81352, the coatings shall exhibit no cracking, blistering, or whitening. A slight whitening or dulling, which is removed by lightly wiping with a soft cloth, shall not be cause for rejection.

Test Description

Parameters	Topcoats cured for 7 days at RT after applied as stack-ups; immersion in distilled water
Number and Type of Specimens per Candidate Alternative	1K camouflage gray polysiloxane touch-up topcoat
Trials per specimen	3

Experimental Control Specimens	MIL-PRF-81352 touch-up topcoats
Acceptance Criteria	No cracking, blistering, or whitening
Government Stakeholder	NAVAIR

Equipment / Instrumentation
- Distilled water

Data Analysis
- Perform immersion test according to ASTM D1308
- Report pass or fail after examining

5.2.3.17 Cleanability

Rationale
This test was identified as a performance requirement for the polysiloxane topcoats tested to Navy and Air Force requirements. The test evaluates the ability to easily clean the topcoats when exposed to an artificial soil solution. Low cleaning efficient is the typical mode of failure.

Application Method
The polysiloxane topcoats were applied via HVLP spray equipment as Navy and Air Force stack-ups (Tables 12 and 13) and within the primer's specified overcoat window, then be allowed to cure for 14 days at room temperature before testing occurs. For the Navy, the substrates was 3"x6"x0.020" sized AA 2024-T3 panels, whereas for the Air Force the AA 224-T3 panels were 3"x6"x0.063".

Detailed Description of Test
This test method describes a procedure for testing the cleanability of topcoats. The test includes the preparation of artificial soil and cleaning compound, soiling the test panels, cleaning the panels and calculating the cleaning efficiency. The test is conducted according to MIL-PRF-85285 and MIL-PRF-32239.

Each polysiloxane topcoat applied over a stack-up shall be subjected to the Cleanability test, and three panels per topcoat shall be utilized for testing.

Artificial soil is made by placing 50.0 ±0.5g of carbon black and 500.0 ±1.0g of hydraulic fluid conforming to MIL-PRF-83282, in a container, such as a one quart jar. The soil is homogenized using a high shear, such as a Cowles disperser or equivalent mixer, for 15 ±1 minutes. Prior to application of the soil, stir or shake the mixture by hand.

Per MIL-PRF-32239, cleaning compounds MIL-PRF-87937 (*Cleaning Compound, Aerospace Equipment*), Type IV (*Heavy Duty, Water Dilutable Cleaning Compound*) or MIL-PRF-85570 (*Cleaning Compounds, Aircraft, Exterior*), Type II (*General Purpose, Non-Solvent*) are made in accordance with the manufacturer's instructions. Per MIL-PRF-85285, a 1 weight percent (1.0 wt.%) solution of Alconox detergent can be used as the cleaning compound.

Using a clean, hog bristle brush, lightly scrub the topcoat of each panel with the aforementioned cleaning solution. Rinse each panel thoroughly three times with reagent water. Dry for no less than 18 hours at 49 ± 2 °C (120 ± 4 °F). Determine the L* value of the coating using a CIELAB color meter according to

ASTM D2244 (Section 3.5 of this JTP). This will be the "A" value that is used to calculate cleaning efficiency.

Using a soft-bristle brush, apply the prepared soil to the topcoat. Remove excess soil by covering the topcoat with folded absorbent tissue and exerting pressure by rolling the tissue with a 5 pound rubber roller. Repeat this blotting procedure twice. Brush the soiled surface parallel to the long dimension of the test panel, using 10 brush strokes in each direction. Bake the test panel at 105 ± 2 °C (221 ± 4 °F) for 60 ± 1 minutes. Determine the L* value of the coating using a CIELAB color meter in accordance with ASTM D2244. This will be the "B" value that is used to calculate cleaning efficiency.

Clean the soiled test panel within four hours of soil application using a Gardner Heavy Duty Wear Tester, Model D10V, or equivalent, with a sponge attached to the wear head. Using hook-and-loop (Velcro) type strips, attach the nylon web side of a dry sponge, dimensions 3.5 × 2.75 inches (88.9 × 69.85 mm) to the cleaning head of the wear tester, such that the dimension parallel to the cleaning stroke is 3.5 inches (88.9 mm). The combined weight of the sponge and cleaning head shall be 2.98 to 3.09 lbs. (1350 to 1400 grams). Place the test panel holder in the wear tester. Place a soiled test panel in the holder such that the test panel is at +45 degrees to the cleaning stroke. Saturate the sponge and cover the test panel with the cleaning compound. After 30 seconds, clean the test panel using five cycles of the wear tester, then immediately turn the test panel 90 degrees in the template and clean for an additional five cycles. Remove the test panel from the holder and rinse the test panel with a flowing stream of water at room temperature. Allow the test panel to dry. Determine the L* value of the test panel using a CIELAB color meter according to ASTM D2244. This will be the "C" value that is used to calculate cleaning efficiency.

The cleaning efficiency of a coating is calculated using the following formula:

% Cleaning Efficiency = [(C-B)/(A-B)] × 100

Per MIL-PRF-85285, camouflage topcoats shall maintain a cleaning efficiency of at least 75%, whereas gloss topcoats shall maintain a cleaning efficiency of at least 90%. Per MIL-PRF-32239, camouflage topcoat systems shall maintain a cleaning efficiency of at least 75%.

Test Description

Parameters	Topcoats cured for 14 days at RT after applied as stack-ups; cleaning efficiency using artificial soil and cleaner
Number and Type of Specimens per Candidate Alternative	1K camouflage gray polysiloxane topcoat, 2K gloss white polysiloxane topcoat
Trials per specimen	3
Experimental Control Specimens	MIL-PRF-85285, Type II and IV qualified gloss and camouflage polyurethane topcoats; MIL-PRF-32239 qualified systems with polyurethane topcoats
Acceptance Criteria	*Navy*: cleaning efficiency of ≥75% for camouflage topcoats and ≥90% for gloss topcoats; *Air Force*: cleaning efficiency of ≥75% for camouflage topcoat systems
Government Stakeholder	NAVAIR, Air Force

Equipment / Instrumentation

- CIELAB color meter according to ASTM D2244
- MIL-PRF-87937, Type IV or MIL-PRF-85570, Type II cleaning compounds
- Alconox detergent
- Carbon black
- Hog bristle brush
- Soft bristle brush
- Gardner Heavy Duty Wear Tester, Model D10V, or equivalent
- Convection oven

Data Analysis

- Perform cleanability test according to MIL-PRF-85285 and MIL-PRF-32239
- Report cleaning efficiency for topcoats and topcoat systems

5.2.3.18 *Strippability*

Rationale

This test was identified as a performance requirement for the polysiloxane topcoats tested to Navy and Air Force requirements. The test evaluates the ability of the topcoat or coating system to be removed when treated with a toxic and/or environmentally friendly chemical stripping solution. Insufficient removal of the topcoat is the primary mode of failure.

Application Method

The polysiloxane topcoats were applied via HVLP spray equipment as Navy and Air Force stack-ups (Tables 12 and 13) and within the primer's specified overcoat window. The topcoats were then be allowed to cure for 14 days at room temperature before testing occurred.

Detailed Description of Test

This test method describes a procedure for testing the efficiency of topcoat or coating system removal from the underlying substrate when treated with a certified chemical paint stripper. The test is conducted according to MIL-PRF-85285 or MIL-PRF-32239.

Each polysiloxane topcoat applied over a stack-up shall be subjected to the Strippability test, and three panels per topcoat shall be utilized for testing.

Per MIL-PRF-85285, Method B: Two test panels are weathered using a Xenon-Arc WOM according to ASTM G155 (see section 5.2.3.8) for no less than 500 hours, then placed on a rack at a 60° angle with the horizontal. Seal the edges of the prepared test panels with beeswax by dipping in melted wax to a depth not to exceed 6 mm (0.25 in.) from all edges. Enough methylene chloride paint remover conforming to MIL-R-81294, Type I (*Epoxy and Polyurethane Topcoat Systems*) or Type II (*Polyurethane Topcoat Systems*) shall then be poured along the upper edge of each test panel to completely cover the coating surface.[54] After 60 minutes of exposure, the loosened topcoat shall be brushed off, and the test panels shall be rinsed while brushing under a stream of cool water. The result shall be the average of the two panels tested.

Per MIL-PRF-32239, test panels shall cure under standard conditions (77 °F and 50% RH) for seven days followed by artificial aging at an elevated temperature of 210 °F (99 °C) for 96 continuous hours. All test panel edges shall then be masked with 3M aluminum tape and placed on a rack at a 60 degree angle from horizontal. Enough methylene chloride, or environmentally friendly chemical stripper selected from Air

Force Technical Order 1-1-8,[55] shall be poured along the upper edge of each test panel to completely cover the coating surface. After six hours of exposure, the loosened coating system shall be brushed off, and the test panel shall be rinsed while brushing under a stream of cool water. Successive applications of the same chemical stripper or different stripper may be applied in the same manner. No more than four applications of strippers, totaling 24 hours, shall be applied. The amount of coating stripped in this test is determined by the percentage of substrate surface area exposed.

Per MIL-PRF-85285, a minimum of 90 percent of the coating shall be stripped according to Method B. Per MIL-PRF-32239, a minimum of 90 percent of the coating system shall be stripped from the test panel within 24 hours and not more than four applications of chemical stripper or strippers shall be utilized.

Test Description

Parameters	Topcoats cured for 7-14 days at RT after applied as stack-ups; artificial aging; application of chemical paint strippers to remove topcoats or coating systems
Number and Type of Specimens per Candidate Alternative	1K camouflage gray polysiloxane topcoat, 2K gloss white polysiloxane topcoat
Trials per specimen	3
Experimental Control Specimens	MIL-PRF-85285, Type II and IV qualified gloss and camouflage polyurethane topcoats; MIL-PRF-32239 qualified systems with polyurethane topcoats
Acceptance Criteria	*Navy*: ≥90% removal of topcoat; *Air Force*: ≥90% removal of coating system within 24 hours
Government Stakeholder	NAVAIR, Air Force

Equipment / Instrumentation

- Xenon-Arc Weather-o-Meter (WOM) chamber with temperature control, humidity control, and water spray according to ASTM G155
- Methylene chloride stripper according to MIL-R-81294, Type I or II
- Commercial non-toxic chemical strippers used by the Air Force
  - Cee-Bee R256 (toxic, phenol / methylene chloride coating remover)
  - Aerosolutions AS 5050 (environmentally friendly, peroxide activated benzyl alcohol coating remover)
- 3M aluminum tape
- Beeswax

Data Analysis

- Perform strippability tests according to MIL-PRF-85285 and MIL-PRF-32239
- Report percentage of topcoat or coating system removed

5.2.3.19 Odor

Rationale

This test was identified as a performance requirement for the 1K camouflage gray polysiloxane touch-up topcoats tested to Navy requirements. The test evaluates the presence of residual odors several hours after a topcoat was applied and air-dried. An odor after 48 hours is considered a failure.

Application Method
The polysiloxane touch-up topcoats were applied via HVLP spray equipment as Navy stack-ups (Table 12) and within the primer's specified overcoat window. The topcoats were then allowed to cure for 2 days (48 hours) at room temperature before testing occurred.

Detailed Description of Test
This test method covers a comparative procedure for observing the characteristic and residual odors of volatile organic solvents and diluents to determine their odor acceptability in a solvent system. This test is conducted in accordance with ASTM D1296 (*Standard Test Method for Odor of Volatile Solvents and Diluents*) and is rated in accordance with MIL-PRF-81352.

Each 1K camouflage gray polysiloxane touch-up topcoat applied as a stack-up shall be subjected to the Odor test. The test is conducted by smelling the air-dried panels 48 hours after application and determining if a solvent odor remains. Per MIL-PRF-81352, the air-dried coatings shall retain no residual odor 48 hours after application.

Test Description

Parameters	Topcoats cured for 7 days at RT after applied as stack-ups; smelling panels
Number and Type of Specimens per Candidate Alternative	1K camouflage gray polysiloxane touch-up topcoat
Trials per specimen	1
Experimental Control Specimens	MIL-PRF-81352 touch-up topcoats
Acceptance Criteria	No odor 48 hours after application
Government Stakeholder	NAVAIR

Equipment / Instrumentation
- None

Data Analysis
- Smell panels
- Report pass or fail after examining

5.2.3.20 Surface Appearance

Rationale
This test was identified as a performance requirement for the 1K camouflage gray polysiloxane touch-up topcoats tested to Navy requirements. The test evaluates the surface appearance of the topcoat after it has cured. An irregular, non-smooth, or non-uniform surface is considered a failure.

Application Method
The polysiloxane touch-up topcoats were applied via HVLP spray equipment and aerosol cans/containers (e.g., Preval spray gun) as Navy stack-ups (Table 12) and within the primer's specified overcoat window. The topcoats were then allowed to cure for 14 days at room temperature before visual examination occurred.

Detailed Description of Test
This test method covers the visual examination of touch-up topcoat surfaces after applied and cured for 14 days. Each 1K camouflage gray polysiloxane touch-up topcoat applied as a stack-up shall be subjected to the Surface Appearance test. Per MIL-PRF-81352, the coatings shall dry to a smooth, uniform film, free of runs, sags, bubbling, wrinkling, streaking, blushing, haze, blisters, coarse particles, or other surface irregularity.

Test Description

Parameters	Topcoats cured for 14 days at RT after applied as stack-ups via HVLP or Preval® spray gun; visual evaluation of surface
Number and Type of Specimens per Candidate Alternative	1K camouflage gray polysiloxane touch-up topcoat
Trials per specimen	3
Experimental Control Specimens	MIL-PRF-81352 touch-up topcoats
Acceptance Criteria	Smooth, uniform, free of surface irregularities
Government Stakeholder	NAVAIR

Equipment / Instrumentation
- None

Data Analysis
- Visual examination of surface
- Report pass or fail after examining

5.2.3.21 Tape Resistance

Rationale
This test was identified as a performance requirement for the 1K camouflage gray polysiloxane topcoats tested to Navy requirements. The test evaluates the ability to apply and remove tape from the topcoat without damaging the coating surface.

Application Method
The polysiloxane touch-up topcoats were applied via HVLP spray equipment as Navy stack-ups (Table 12) and within the primer's specified overcoat window. The topcoats were then allowed to cure for a minimum of 12 hours at room temperature before testing occurred.

Detailed Description of Test
Test panels shall be air-dried at room temperature for no less than twelve hours. A strip of masking tape (3M Company #250 or equivalent as approved by the qualifying activity), no less than 1.0 in. (25.4 mm) wide, shall be applied to each panel, adhesive side down, and pressed down with one pass of a roller weighing no less than 4.5 pounds (2.04 kilograms (kg)). The tape shall remain in contact with the test panel for no less than one hour and then shall be carefully removed. All 1K camouflage gray polysiloxane topcoats applied as a stack-up shall be subjected to the Tape Resistance test. Per MIL-PRF-85285, the coating shall not exhibit permanent marring caused by masking tape applied to the coated test panels.

Test Description

Parameters	Topcoats cured for ≥12 hours at RT after applied as stack-ups; surface evaluation
Number and Type of Specimens per Candidate Alternative	1K camouflage gray polysiloxane topcoat; 1K camouflage gray polysiloxane touch-up topcoat
Trials per specimen	3
Experimental Control Specimens	MIL-PRF-85285 polyurethane topcoat
Acceptance Criteria	No permanent marring upon removal of tape
Government Stakeholder	NAVAIR

Equipment / Instrumentation

- 3M Company #250 tape or equivalent (1.0 in wide)
- 4.5 pound or greater pound roller

Data Analysis

- Visual examination of surface
- Report pass or fail after examining

5.2.3.22 Acute Inhalation Toxicity of Organosilane Polymer

Rationale

This test was identified as an extended test requirement for the 1K camouflage gray polysiloxane aircraft and aircraft touch-up topcoats per Navy stakeholders and the ESTCP program manager. The test evaluates the acute inhalation toxicity of the organosilane polymer used in these topcoats (see Section 2.1.2). The inhalation toxicity of the organosilane polymer was compared to the inhalation toxicity of 1,6-hexamethylene diisocyanate (HDI) and homopolymers of HDI that are used in MIL-PRF-85285 polyurethane topcoats. The goal was to determine if the organosilane polymer is less toxic than the isocyanates used in Navy topcoats.

Application Method

A solution of the organosilane polymer in pentyl propionate solvent, as synthesized by NCP Coatings, was aerosolized in a text chamber.

Detailed Description of Test

The inhalation study was performed by Illinois Institute of Technology Research Institute (IITRI) in Chicago, Illinois according to EPA Toxic Substance Control Act (TSCA) Good Laboratory Practice (GLP) Standards CFR Title 40, Part 792. The study duration was 15 days. Day 1 consisted of a single exposure of the organosilane polymer solution, at a target concentration of 2 mg/L (2000 mg/m^3), to Sprague-Dawley derived rats (5 male, 5 female) via aerosolized spray in a 64-port, flow-past type, nose-only inhalation exposure chamber for a period of 4 hours (figure 20). The animals were then removed from the test chamber, examined, then observed for a period of 14 days, followed by terminal necropsy on Day 15. Toxicological experimental endpoints consisted of moribundity/mortality and clinical observations, physical examinations, body weight measurements, and body weight change calculations, including gross necropsy observations.

The limit concentration value at 50% deaths (LC50) of the organosilane polymer is determined based on animal mortality during the 4-hour exposure and until the 15 day period is reached. Demonstration of an LC50 value greater than those for HDI and hompolymers of HDI is considered a success.

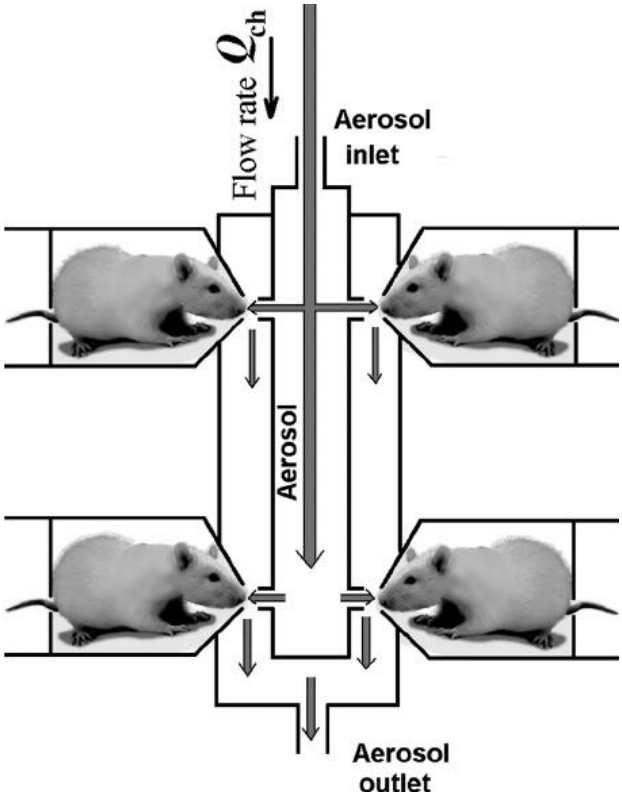


Figure 20 — Illustration of nose-only inhalation test chamber.[56]

Test Description

Parameters	4 hour nose-only inhalation of organosilane polymer solution; 14 day observation period
Number and Type of Specimens per Candidate Alternative	Organosilane polymer used in 1K camouflage gray polysiloxane topcoat and 1K camouflage gray polysiloxane touch-up topcoat
Trials per specimen	1
Experimental Control Specimens	Inhalation LC50 values for HDI (124 mg/m^3) and homopolymers of HDI (554 mg/m^3)
Acceptance Criteria	LC50 >554 mg/m^3
Government Stakeholder	NAVAIR, ESTCP PM

Equipment / Instrumentation

- Target solution concentration of 2 mg/L (2000 mg/m^3)
- Flow-past type, nose-only inhalation exposure chamber
- Sprague-Dawley derived rats (5 male, 5 female)

Data Analysis

- Examination of rodents during test period
- Determine LC50 value

5.2.3.23 Repair Adhesion for Touch-Up Topcoats

Rationale

This test was identified as an extended performance requirement for the 1K camouflage gray polysiloxane touch-up topcoats tested to Navy requirements. The test evaluates the adhesion of the touch-up topcoat over a MIL-PRF-85285 qualified camouflage gray polyurethane topcoat that has been lightly abraded and solvent wiped. The test also evaluates the adhesion of the same qualified polyurethane topcoat over the polysiloxane topcoat when lightly abraded and solvent wiped. The test is performed to simulate a field or depot-level repair on an aircraft. Insufficient adhesion to the underlying polyurethane is the primary mode of failure.

Application Method

All Navy polysiloxane topcoats intended for touch-up applications (Table 12) were applied via HVLP spray equipment or Preval® spray gun over an abraded and solvent wiped MIL-PRF-85285 qualified camouflage gray polyurethane topcoat that had cured for at least 14 days. Once applied over the abraded polyurethane, the polysiloxane topcoat was allowed to cure for 14 days at room temperature before testing occurred. A qualified polyurethane topcoat was also applied in the same manner over the polysiloxane topcoat stack-up that was abraded and solvent wiped once cured for at least 14 days.

Detailed Description of Test

This test method covers a procedure for establishing adequacy of adhesion between a topcoat and an underlying abraded topcoat after immersed in water, an "X" is cut into the film, and the "X" is peeled using pressure sensitive adhesive tape. This test is performed in accordance with MIL-PRF-85285 and results are rated according ASTM D3359 (*Standard Test Methods for Measuring Adhesion by Tape Test*) Method A (*X-Cut Tape Adhesion*). The X-cut adhesion rating scale is shown in Section 5.2.3.6.

The test is performed by abrading a qualified polyurethane topcoat, or polysiloxane topcoat, with a maroon-colored 3M Scotch-Brite General Purpose Hand Pad 7447 in a vertical direction, then horizontal direction, then a circular direction. The panel is then wiped with acetone to clean the surface and remove any loose material. The polysiloxane touch-up topcoat, or polyurethane topcoat, is then applied over the abraded topcoat and allowed to cure.

After 14 days, test panels shall be immersed separately in distilled water at room temperature for 24 hours. Remove the test panels from the water after the specified time period and wipe dry with a soft cloth. Within 3 minutes after removal from the water make two parallel scribes with a stylus or razor through the coating to the substrate. The scribes shall be ¾ of an inch apart and 2-inches long. The panels shall then be scribed to the substrate from opposing ends of the parallel scribes to form an "X". Immediately apply a 1-inch wide strip of masking tape with the adhesive side down across the scribes. Press the tape against the surface of the coating and roll the rubber cover roller across the tape eight times. Within 90 seconds, remove the tape with one quick motion at 180 degrees from the plane of the panel. Visually examine the X-cut area for removal of the coating from the underlying and abraded coating. An X-cut rating of less than 4A is considered a failure. Delamination or peeling is also considered a failure.

Test Description

Parameters	All polysiloxane touch-up topcoats tested to Navy requirements; X-cut adhesion of polysiloxane over abraded polyurethane; X-cut adhesion of a polyurethane over abraded polysiloxane

Number and Type of Specimens per Candidate Alternative	1K camouflage gray polysiloxane touch-up topcoat
Trials per specimen	2 at each temperature
Experimental Control Specimens	MIL-PRF-85285, Type I or IV qualified polyurethane topcoat over itself at each temperature
Acceptance Criteria	*Navy*: no less than a 4A adhesion rating after immersion for 24 hours at RT
Government Stakeholder	NAVAIR

Equipment / Instrumentation

- Maroon 3M Scotch-Brite General Purpose Hand Pad 7447
- MIL-PRF-85285, Type IV qualified polyurethane topcoat panel, cured for at least 14 days
- Cutting tool – stylus or razor
- Cutting guide – steel or other hard metal straightedge
- Tape – 1.0 inch (25.4 mm) wide masking tape, such as 3M Company #250 or equivalent; less than 1 year old
- 4.5-5 pound rubber covered roller that is ~3.5 inch in diameter and 1.75 inches long and with a durometer hardness of Shore D 70-80

Data Analysis

- Rate wet-tape adhesion according to ASTM D 3359, Method A
- Report if adhesion is a pass or fail

5.2.3.24 Skydrol LD-4 Resistance

Rationale

This test was identified as an extended performance requirement for the 1K camouflage gray polysiloxane topcoats tested to Air Force requirements. The Skydrol Resistance test is used to determine the resistance of topcoats to immersion in Skydrol LD-4 fluid. Blistering, loss of adhesion, significant softening, and color change are the primary modes of failure.

Application Method

All 1K camouflage gray polysiloxane topcoats were applied via HVLP spray equipment as Air Force stack-ups (Tables 13) and within the primer's specified overcoat window. The topcoats were then allowed to cure for 14 days at room temperature before testing occurred.

Detailed Description of Test

This test method describes a procedure for testing the resistance of topcoats to immersion in Skydrol LD-4 fluid. Skydrol LD-4 is a fire-resistant hydraulic fluid that is used by Boeing and has since been adopted by the Air Force for MIL-PRF-32239, Type I and Type II coating systems.

Prior to exposure, the pencil hardness of each coating system shall be evaluated according to ASTM D3363 (*Standard Test Method for Film Hardness by Pencil Test*) (Fig. 19, Section 5.2.3.12), and the color of each coating systems shall be recorded according to ASTM D2244 (Section 5.2.3.3).

The immersion test is conducted by immersing the topcoat in a glass jar or metal container filled with Skydrol LD-4 fluid so that half of the topcoat is immersed. The jar or container is then closed and each container is stored at 77 ± 5 °F for the period of 30 days. After immersion, remove the panels and

immediately evaluate for blistering and film delamination. After evaluation, gently clean the panels with the coating system cleaner and rinse thoroughly with water. Blot the panels dry and allow to air dry for an additional one hour. Measure the final color using a CIELAB color meter in accordance with ASTM D2244. After the color measurement has been made, test the cross-hatch adhesion in accordance with ASTM D3359, Method B (Section 5.2.3.7), in addition to the pencil hardness in accordance with ASTM D3363. Compare the average of the initial values with the average of the final values.

Per MIL-PRF-32239, the coating system shall show no blistering or coating delamination or adhesion loss when tested in accordance with ASTM D3359, Method A and shall not exhibit more than a 2-pencil hardness change from the original hardness when tested in accordance with ASTM D3363. Additionally, the coating system shall not demonstrate a color change (ΔE) of greater than 3.0 from the non-immersed sample when tested with a CIELAB color meter according to ASTM D2244.

Test Description

Parameters	Topcoats cured for 14 days at RT after applied as stack-ups; immersion in Skydrol LD-4 for 30 days
Number and Type of Specimens per Candidate Alternative	1K camouflage gray polysiloxane topcoat
Trials per specimen	3
Experimental Control Specimens	MIL-PRF-32239 qualified systems with polyurethane topcoats
Acceptance Criteria	Coating system shall show no blistering, coating delamination, or adhesion loss, no more than a 2-pencil hardness change, $\Delta E \leq 3.0$
Government Stakeholder	Air Force

Equipment / Instrumentation

- Pencil hardness kit with leads ranging from 6B to 6H
- CIELAB color meter according to ASTM D2244
- Gardco cutting tool (part no. PA-2058) for making a cross-hatch
- Tape – 1.0 inch (25.4 mm) wide masking tape, such as 3M Company #250 or equivalent; less than 1 year old
- Rubber eraser, on the end of a pencil

Data Analysis

- Rate pencil hardness of coating system according to ASTM D3363
- Rate cross-hatch adhesion of coating system according to ASTM D3359, Method B
- Report any blistering, softening or delamination for coating system, in addition to any change in color for the topcoat

5.2.3.25 Wet Edge

Rationale

This test was identified as an extended performance requirement for the 1K camouflage gray polysiloxane topcoats tested to Air Force requirements. The Wet Edge test is used to determine the appearance of the polysiloxane topcoats after an overlapping layer is applied after 15 minutes. Unsightly appearance and inconsistent gloss are the primary modes of failure.

Application Method
All 1K camouflage gray polysiloxane topcoats in Table 13 were applied over bare 12”x12” AA 2024-T3, 12x12” epoxy primed panels, or 4’x8’ epoxy primed plywood via high volume, low pressure spray equipment in a spray booth with air flow of 75 to 125 linear feet per minute (0.381 to 0.635 meters per second). Spray a coating layer of the topcoat to half of the panel or plywood. After 15 minutes in the spray booth, spray a coating layer of the mixed topcoat over the second half of the panel and overlapping the first application by one inch. After the second application, the panel may be removed from spray booth for final cure. Evaluation of test panel shall be after a minimum of 24 hours cure.

Per MIL-PRF-32239, there shall be no streaks, tiger stripes, or other visual irregularities on the test panels when tested in accordance

Test Description

Parameters	Topcoats cured for 24 hours at RT after applied according to test; visual evaluation
Number and Type of Specimens per Candidate Alternative	1K camouflage gray polysiloxane topcoat
Trials per specimen	1
Experimental Control Specimens	MIL-PRF-85285 qualified polyurethane topcoat
Acceptance Criteria	No streaks, tiger strips, or other visual irregularities (e.g. inconsistent gloss)
Government Stakeholder	Air Force

Equipment / Instrumentation
- 12”x12” AA 2024-T3 panels, 4’x8’ plywood
- Epoxy primer for aircraft

Data Analysis
- Evaluate appearance of topcoat
- Report as pass or fail

5.2.3.26 Outdoor Exposure

Rationale
This test was identified as a performance requirement for the 1K camouflage gray polysiloxane topcoat stack-ups tested to Air Force requirements. The Outdoor Exposure test is used to determine the outdoor corrosion resistance of a coating system compared to a system containing a chromate-containing epoxy primer and qualified polyurethane topcoat. Inadequate corrosion protection of the underlying metal alloy is the primary mode of failure.

Application Method
For this test, the metal substrate of the coating system shall be a 3”x6”x0.125” AA 2024-T3 panel conforming to AMS-QQ-A-250/4. Three holes shall be drilled and countersunk as shown in Figure 21 to accommodate the dry installation of either a titanium (Ti) fastener or cadmium plated steel (Cd-Stl) fastener. The titanium fasteners shall be 10-24 × 5/8, Grade 2 with a 10-24 Grade 2 titanium nut. The cadmium plated steel fasteners shall be a NASM24693 screw with a 10-24 cadmium plated nut.

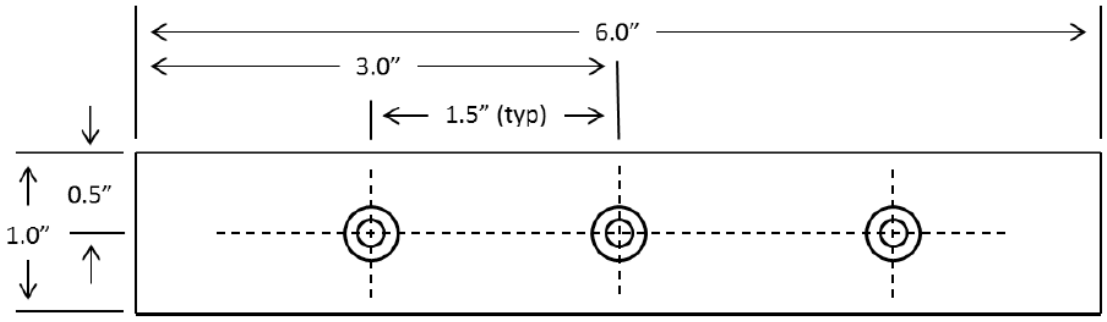


Figure 21 — Diagram of outdoor exposure test panel per MIL-PRF-32239A.

The system panels for outdoor exposure testing are prepared according to the following procedure:

a. Wipe 12 panels with MEK solvent
b. Apply PreKote per Air Force T.O. 1-1-8
c. Apply the epoxy primer to achieve a dry film thickness of 0.75 ±0.2 mil
d. Apply camouflage gray topcoat to achieve a dry film thickness of 2.2 ±0.2 mils
e. Allow coating systems to cure for 14 days at standard conditions

All 1K camouflage gray polysiloxane topcoats for testing to Air Force performance requirements (Table 13) were applied via HVLP spray equipment and within the primer's specified overcoat window. The coating systems was then allowed to cure for 14 days at room temperature. Total dry film thickness of the coating system shall be less than 3.2 mils.

Detailed Description of Test

This test method describes a procedure for testing the corrosion protection of the metal alloy provided by a coating system when scribed and exposed to the outdoor elements in Daytona Beach, FL. This test is conducted and rated in accordance with MIL-PRF-32239.

A test coating system and a control system panels shall be utilized for this test. Half of the test panels and half of the control panels shall be scribed with one, 0.75 ± 0.03 inch line parallel to the 1.0 inch dimension of the test panel and through the center of each fastener utilizing a New Hermes engraving machine and rotating carbide cutter as shown in Figure 22.

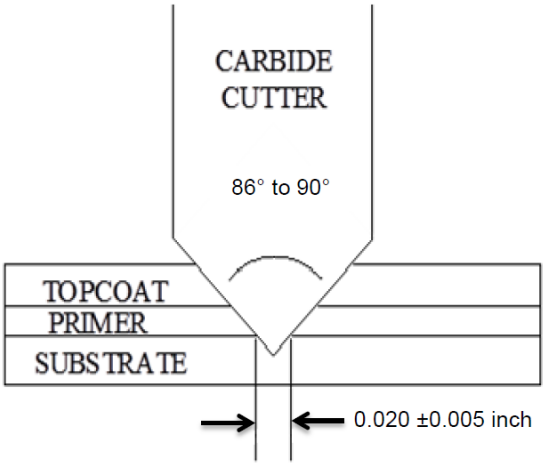


Figure 22 — Dimensions for scribing test panels for outdoor exposure testing per MIL-PRF-32239.

The panels shall be securely fixed to an outdoor rack with non-conductive supports such that no panel is touching another panel and no panel is dripping on another panel. The exposure racks shall be located at the Battelle Daytona Beach site in Florida, tilted at 45 degrees from horizontal and exposed 180 degrees from magnetic north. The panels shall remain at the outdoor exposure site for up to 1 year.

The coatings systems are evaluated for the extent of corrosion in the scribe, blistering, and undercutting. Per MIL-PRF-32239, the test coating system shall perform equal to or better than a control coating system containing a MIL-PRF-85285, Type IV qualified polyurethane topcoat and a chromate-containing epoxy primer.

Test Description

Parameters	All polysiloxane topcoats tested to Air Force requirements; outdoor exposure testing for up to 1 year
Number and Type of Specimens per Candidate Alternative	1K camouflage gray polysiloxane topcoat
Trials per specimen	6 panels for use with Ti fasteners; 6 panels for use with Cd-Stl. fasteners
Experimental Control Specimens	Coating system with a MIL-PRF-85285, Type IV camouflage gray polyurethane topcoat and chromate-containing epoxy primer
Acceptance Criteria	Equivalent to or greater performance than control system
Government Stakeholder	Air Force

Equipment and Instrumentation

- New Hermes engraving machine
- Carbide cutter
- 3”x6”x0.125” AA 2024-T3 panels
- PreKote from Pantheon Chemical
- Chromate and non-chromate containing epoxy primers
- FED-STD-595 #36173 polyurethane topcoat qualified to MIL-PRF-85285, Type IV requirements

Data Analysis

- Rate for corrosion in scribe, blisters and undercutting
- Report as pass or fail

5.2.3.27 Adhesion (Pull-Off Strength)

Rationale

This test was identified as a performance requirement for the 1K semi-gloss gray polysiloxane topcoat tested to Air Force requirements. The test evaluates the pull-off adhesion strength between the topcoat and underlying stack-up, in addition to intercoat adhesion between all layers of the stack-up. Loss of topcoat adhesion to the underlying coating is the primary mode of failure.

Application Method

The 1K semi-gloss gray polysiloxane topcoat was applied via HVLP spray equipment as Air Force stack-ups (Table 13) and within the primer's specified overcoat window. The 1K semi-gloss gray topcoat was also applied over an abraded polyurethane topcoat, with and without an adhesion promoter, to simulate a repair at a depot. After the final topcoat layer was applied the coating systems were allowed to cure for 14 days at room temperature before testing occurred.

Detailed Description of Test

This test method, ASTM D4541 (*Standard Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Tester*), covers a procedure for evaluating the pull-off strength (via glued dolly/stud) of a coating on a rigid substrate, such as metal, concrete or wood. The test determines either the greatest perpendicular force (in tension) that a surface area can bear before a plug of material is detached, or whether the surface remains intact at a prescribed force. Failure will occur along the weakest plane within the system. This test method maximizes tensile stress as compared to the shear stress applied by other methods, such as scratch or knife adhesion, and results may not be comparable.

Per ASTM D4541, the general pull-off test is performed by securing a loading fixture (dolly/stud) normal (perpendicular) to the surface of the coating with an adhesive. After the adhesive is cured, a testing apparatus is attached to the loading fixture and aligned to apply tension normal to the test surface. The force applied to the loading fixture is then gradually increased and monitored until either a plug of material is detached, or a specified value is reached. When a plug of material is detached, the exposed surface represents the plane of limiting strength within the system. The pull-off strength is computed based on the maximum indicated load, the instrument calibration data, and the original surface area stressed. Pull-off strength results obtained using different devices may be different because the results depend on instrumental parameters. Use the calibrated chart from the manufacturer to determine the force, in pounds per square inch (psi), required for coating loss.

Per Air Force stakeholders, the adhesion value of the 1K semi-gloss gray polysiloxane topcoat to the underlying surface, regardless of preparation, should be greater than 1800 psi pull-off test strength (POTS) adhesion or equivalent to the polyurethane topcoat control system.

Test Description

Parameters	Topcoats cured for 14 days at RT after applied over stack-ups; dolly/stud pulls
Number and Type of Specimens per Candidate Alternative	1K semi-gloss gray polysiloxane topcoat

Trials per specimen	3
Experimental Control Specimens	Coating system with MIL-PRF-85285 polyurethane topcoat
Acceptance Criteria	>1800 psi POTS over various surface preparations; similar performance as a polyurethane control
Government Stakeholder	Air Force

Equipment / Instrumentation

- Adhesion tester
- Fine sandpaper
- Glue
- Studs

Data Analysis

- Rate according to ASTM D4541
- Report psi value

5.3 Spray Application and Evaluation

Spray application and evaluation of the 1K camouflage gray polysiloxane topcoat was performed in an industrial setting at NAS North Island, Coronado, California in 2017. The spray application was performed to familiarize applicators with the 1K polysiloxane topcoat technology, gauge ease-of-use due to it being an all-in-one-can system that does not require metering and mixing of components, evaluate HVLP spray gun settings (e.g., fluid tip size, pressure at gun), spray the 1K polysiloxane topcoat on scrap F-18 aircraft parts (e.g., engine inlet, aileron) and determine sag resistance on rounded areas compared to a MIL-PRF-85285 polyurethane topcoat, in addition to evaluating appearance of the 1K polysiloxane topcoat once cured (Table 9). The 1K camouflage gray polysiloxane topcoat was provided in quart quantities by NCP Coatings.

5.4 Field Testing

As mentioned previously, the 1K camouflage gray polysiloxane topcoat, 1K camouflage gray polysiloxane touch-up topcoat, 1K semi-gloss gray polysiloxane topcoat, and 2K gloss white polysiloxane topcoat were applied on various assets during this project.

5.4.1 Topcoat applications

Assets selected for demonstration of the 1K camouflage gray and 2K gloss white polysiloxane topcoats were painted during a scheduled maintenance interval. Artisans applied the topcoats using HVLP spray guns with pressure pots in one or multiple coats to sufficiently cover the underlying primer on the aircraft or GSE, and also to meet the required dry film thickness per the topcoat technical data sheet. Field aircraft repaired with 1K polysiloxane touch-up topcoat were either sprayed with a Preval® gun or brushed. Painted assets were then be allowed to cure for several days or weeks before returning to service, although assembly and routine maintenance occurred during this period.

5.4.2 Detection of airborne isocyanates

Individuals from the industrial hygiene office at each application site were requested to oversee and obtain air samples during aerosolizing of the polysiloxane topcoats. This was achieve by connecting an isocyanate sampling tube, hose, and pump to the artisan during spray application of the topcoats. Unfortunately, the IH Office from Camp Pendleton was the only office that obtained air samples during this project, which occurred during painting of the first AH-1Z aircraft when using the 1K camouflage gray polysiloxane topcoat. The samples were analyzed in a laboratory for HDI and oligomers of HDI, and the amount detected was compared to those found when applying MIL-PRF-85285 polyurethane topcoats on similar aircraft. No detection of isocyanates in the polysiloxane topcoats was required to meet this objective (Table 10).

5.4.3 VOCs emitted from topcoats

The amount of VOCs emitted to the air during spray applications was calculated by recording the amount of topcoat sprayed on each assets, or area of asset, and multiplying by the pound per gallon VOC content from the manufacturer's technical data sheet. A reduction in VOCs when using the polysiloxane topcoats was required to meet this objective (Table 10).

5.4.4 Hazardous paint waste generation

Paint waste is generated from mixed and unused 2K polyurethane topcoats. The waste is considered hazardous and must be properly disposed of according to EPA regulations. The 1K polysiloxane topcoat does not require mixing of components, thus only the material required to paint an asset should be removed from the container. Furthermore, as long as the 1K polysiloxane is not exposed to moisture for a significant time period the paint can be returned to the original contain and closed for future use. Little-to-no generation of hazardous paint waste when using the 1K camouflage gray polysiloxane topcoat was required to meet this objective (Table 10).

5.4.5 Appearance after application and initial metrics

After application, the appearance of the polysiloxane topcoats was assessed for smoothness, sheen, sags, tiger-striping, orange-peel, color homogeneity across the asset, and adhesion between color transitions. Photographs were recorded to establish a baseline for tracking, and artisans were asked to provide their opinions. Little-to-no visual difference in appearance compared to a MIL-PRF-85285 qualified polyurethane topcoats was required to meet this objective (Table 10).

For the majority of the polysiloxane topcoats the initial color, gloss, and DFT values were collected after application and curing for at least 1 day. For the 1K camouflage gray topcoats, initial values were recorded the day following the application on aircraft. The initial values for GSE painted with the 2K gloss white polysiloxane topcoat were recorded several weeks after the assets were painted and fully assembled, whereas no initial values were recorded for the 1K semi-gloss gray polysiloxane topcoat after application on the B4 Maintenance Stand. DFT values were recorded in mils (1 mil = 25.4 microns) with a DeFelsko PosiTector coating thickness gauge for non-ferrous metals. The gloss was recorded in gloss units (GU) at 60 and 85 degree angles with a Byk-Gardner micro-TRI gloss meter or an Elcometer 407 statistical gloss meter (see Section 5.2.3.4). Color values in CIELAB (L*, a*, b*) color space coordinates were recorded with a Hunter Lab Mini-scan D65/10° spectrophotometer or an X-RITE SP60 spectrophotometer (see Section 5.2.3.3). Values were collected from several locations on the platforms (e.g., fuselage, tail boom, doors), then averaged.

Once the initial data for the 1K camouflage gray polysiloxane topcoats on aircraft were collected the platforms were released back to their squadron for training. Similarly, once initial data for the 2K gloss

white polysiloxane topcoats were collected the GSE were released back to their technical authority for deployment aboard a CVN or use at a NAS. During deployments, GSE were inspected every 7 to 15 months by the technical points of contact (TPOC) for each service or by corrosion maintenance officers responsible for the asset. Non-deployed aircraft and GSE were inspected by corrosion engineers and/or maintainers every 6 to 9 months.

5.4.6 In-service assessment (qualitative)

During asset inspections, all topcoats were visually assessed for changes in color and gloss, cracking of the topcoat, mechanical damage, blistering, discoloration due to heat and fluids, any loss of adhesion to the underlying substrate, and any facial corrosion. Similar or better performance compared to a MIL-PRF-85285 qualified polyurethane topcoat on the same or similar asset, and under the same operating conditions, was required to meet this objective (Table 9). It should be noted that a semi-quantitative rating system that was approved in the project Demonstration Plan was not utilized to visually assess the topcoats because a baseline rating was not established by active duty / maintenance personnel during the initial 6 month inspections, different personnel assessed the topcoats during each inspection, thus preventing a consistent rating, and there was a period during the COVID-19 pandemic where inspections did not occur.

5.4.7 In-service weatherability (quantitative)

All polysiloxane topcoats on DoD assets were supposed to be washed, or wiped with water and rags, prior to inspection to provide a contaminant-free surface to record color and gloss values. The color and gloss values of the polysiloxane topcoats were recorded during all subsequent inspections if recorded after the initial application. The gloss was recorded in gloss units at 60 and 85 degree angles with a Byk-Gardner micro-TRI gloss meter or an Elcometer 407 statistical gloss meter. Color values in CIELAB (L*, a*, b*) color space coordinates were recorded with a Hunter Lab Mini-scan D65/10° spectrophotometer or an X-RITE SP60 spectrophotometer. Values were collected from several locations on the platforms (e.g., fuselage, tail boom, doors), then averaged. The ΔE for the topcoats was calculated according to the formula in Section 5.2.3.3, whereas the gloss change was the difference between the initial and final values. A ΔE of ≤ 2.0 for the polysiloxane topcoats after 1-2 years of field service was required to meet this objective. Alternatively, a change in color and gloss that were similar to, or less than, a MIL-PRF-85285 qualified polyurethane topcoat on the same or similar asset, and under the same operating conditions, was required to meet this objective (Table 10).

6. LABORATORY AND INDUSTRIAL PERFORMANCE ASSESSMENT

6.1 Laboratory Performance Assessment of Polysiloxane Topcoats

This section discusses the standard and extended laboratory performance results for the single- and two-component polysiloxane topcoats that were optimized and produced by the coating manufacturer, NCP Coatings.

6.1.1 Polysiloxane topcoat optimization and testing by manufacturer

As stated previously, formulations of the NRL-developed 1K and 2K polysiloxane topcoats were transferred to NCP Coatings under a non-disclosure agreement (NDA). NCP optimized the synthesis of the organosilane polymers on a multi-gallon scale, in addition to optimizing viscosity, opacity, dry times, and gloss for the various topcoats. NCP also matching the color of the topcoats to FED-STD-595 color chips and ensured consistency from batch-to-batch upon multi-gallon scale-up. A description of the various NCP-produced polysiloxane topcoats is provided below.

6.1.1.1 Single-component polysiloxane topcoats from NCP Coatings

The single-component camouflage gray polysiloxane topcoat for aircraft is free of hazardous isocyanate-functional molecules, contains <290 g/l VOCs, is free of HAP solvents, and has a Flash Point (Fp) >100 °F (see Technical Data Sheet in Appendix VIII). This topcoat was color matched to FED-STD-595 #36375 and #35237 for testing by the Navy, including #36173 for testing by the Air Force. The 1K semi-gloss gray topcoat for Air Force AGE is also isocyanate free and HAP-free, but contains 98 g/l VOCs (see Technical Data Sheet in Appendix IX). This topcoat was color matched to FED-STD-595 #26173. A gallon container of the NCP-produced 1K camouflage gray aircraft topcoat is shown in Figure 23A, whereas a 4”x12” color-matched panel of the 1K semi-gloss topcoat is shown in Figure 23B. It is worth mentioning that the organosilane polymers in these topcoats were registered on the EPA’s TSCA Chemical Substance Inventory by NCP for commercial use. All other raw materials (e.g., pigments, matting agents, solvents) used in these 1K topcoat formulas were commercially available in large quantities and TSCA registered (see Safety Data Sheets in Appendix X and XI). During this project, greater than 50 gallons of the 1K camouflage gray topcoat was produced for laboratory testing, industrial spray-outs, and applications on aircraft.

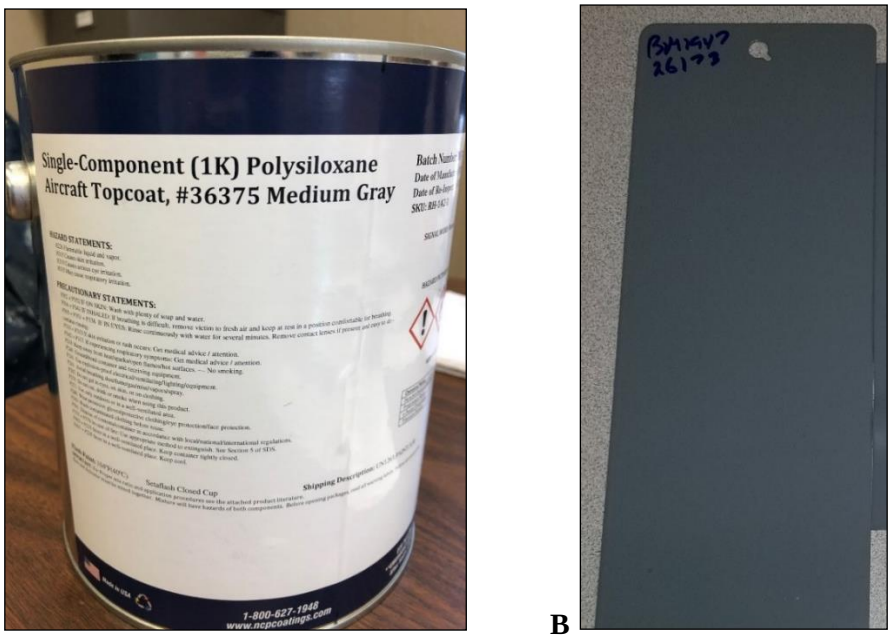


Figure 23 — a) Gallon container of camouflage gray (#36375) single-component polysiloxane topcoat for aircraft and b) 4"x12" panel of semi-gloss gray (#26173) 1K polysiloxane topcoat for AGE.

The 1K polysiloxane topcoat for aircraft was also color-matched to FED-STD-595 #36375 and packaged as NCP Smart Touch® touch-up kits for the repair of polyurethane topcoats on deployed aircraft or at depots (figure 24a). The kit is composed of an 8 oz. can of 1K polysiloxane topcoat, a can of methyl acetate reducer, a Preval® spray gun, and two brushes (figure 24b). Over 60 touch-up kits were produced by NCP during this project for testing and evaluation at NAWC-AD and naval air stations worldwide.

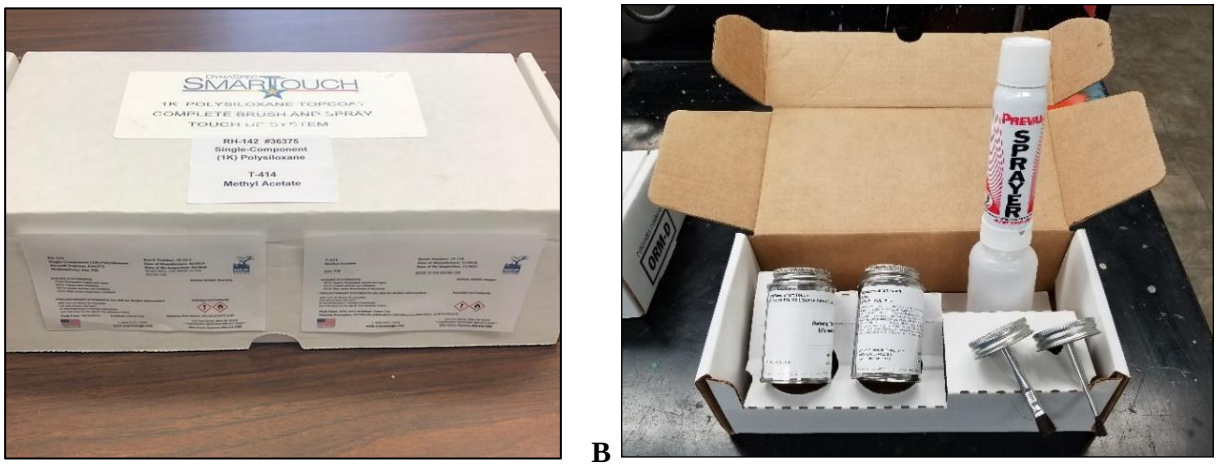


Figure 24 — a) NCP Smart Touch® polysiloxane touch-up kit for topcoat repair on aircraft: a) package as received and b) inside of package.

6.1.1.2 Two-component polysiloxane topcoat from NCP Coatings

The two-component gloss white polysiloxane topcoat for Navy GSE is a solvent-borne system with a 4:1 mixture ratio by volume (4 parts BM1682-2 to 1 part BM1910-2) (figure 25). The 2K topcoat is isocyanate-free, <70 g/l VOCs (no exempt solvents), and HAP-free (see Technical Data Sheet in Appendix XII). The

topcoat does not require a reducer or an induction time, and is easily applied using HVLP spray equipment. All raw materials used in the topcoat were commercially available in large quantities and TSCA registered (see Safety Data Sheets in Appendix XIII and XIV). The formula was produced in multi-gallon quantities by NCP Coating for evaluation to performance requirements at NAWC-AD and demonstrations on GSE.

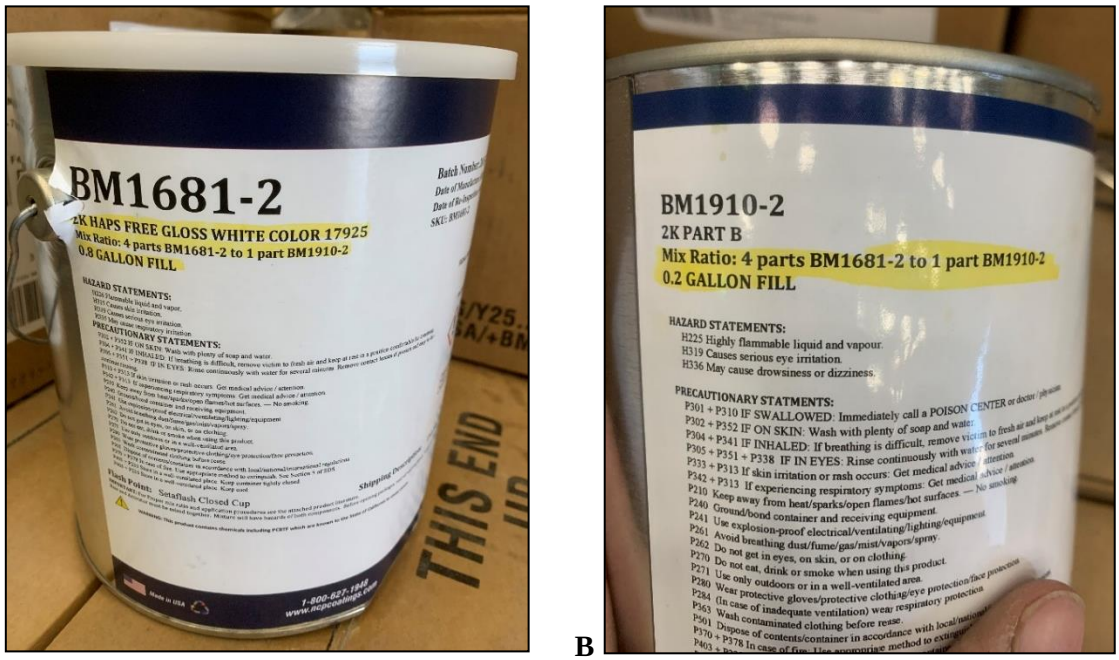


Figure 25 — Two-component gloss white polysiloxane topcoat supplied as: a) gallon container of BM1681-2 white base (Part A) and b) a quart container of BM1910-2 clear activator/hardener (Part B).

6.1.1.3 Polysiloxane topcoat testing by NCP Coatings

Each polysiloxane topcoat was tested to various laboratory performance requirements (see Tables 5-7) by NCP Coatings before being shipped to NAWC-AD, AFRL, or other locations. A summary of the tests and results are shown in Table 16. Specific values for all passing tests were not available.

Table 16 — Results of polysiloxane topcoat testing as performed by NCP Coatings.

Topcoat	Performance Tests	Results
1K camouflage gray polysiloxane	• Color matching to FED-STD-595 #36375, #35237 and #36173 • Viscosity • Gloss • Dry times • Opacity • Appearance • MEK resistance • Wet tape adhesion • VOC content • Wet edge	• ΔE <1.0 to color chip – PASS • <30 seconds – PASS • <5 GU @ 60°, <10 GU @ 85° – PASS • Met dry time requirement • Met opacity requirement • Met appearance requirement • >25 MEK double rubs – PASS • 4A-5A adhesion – PASS • <290 g/l VOCs • Met wet edge requirement

1K camouflage gray polysiloxane touch-up / repair topcoat	• Color matching to FED-STD-595 #36375 • Viscosity • Gloss • Dry times • Opacity • Appearance • MEK resistance • VOC content	• ΔE <1.0 to color chip – PASS • <30 seconds – PASS • <5 GU @ 60°, <10 GU @ 85° – PASS • Met dry time requirement • Met opacity requirement • Met appearance requirement • >25 MEK double rubs – PASS • <290 g/l VOCs before reduced with methyl acetate
2K gloss white polysiloxane	• Color matching to FED-STD-595 #17925 • Viscosity (mixed) • Gloss • Dry times • Opacity • Appearance • MEK resistance • VOC content	• ΔE <1.0 to color chip – PASS • <30 seconds – PASS • >90 GU @ 60° – PASS • Met dry time requirement • Met opacity requirement • Met appearance requirement • >25 MEK double rubs – PASS • <70 g/l VOCs when mixed
1K semi-gloss gray polysiloxane	• Color matching to FED-STD-595 #26173 • Viscosity • Gloss • Dry times • Opacity • Appearance • VOC content	• ΔE <1.0 to color chip – PASS • <30 seconds – PASS • 15-45 GU @ 60° – PASS • Met dry time requirement • Met opacity requirement • Met appearance requirement • <98 g/l VOCs when mixed
1K gloss white polysiloxane	• Color matching to FED-STD-595 #17925 • Viscosity • Gloss (following day) • Gloss (after 2 weeks cure) • Dry times • Opacity • Appearance • VOC content	• ΔE <1.0 to color chip – PASS • <30 seconds – PASS • 92 GU @ 60° – PASS • 88-90 GU @ 60° – FAIL • Met dry time requirement • Met opacity requirement • Slight haze to surface – FAIL • <340 g/l VOCs

As shown above, all polysiloxane topcoats, except for the 1K gloss white, passed the performance requirements when tested at NCP Coatings. The 1K gloss white polysiloxane topcoat would possess a gloss greater than 90 GU (at 60°) the day following HVLP spray application, but would consistently de-gloss to 88-90 GU (at 60°) following two weeks of curing. In addition, the surface of the 1K gloss white polysiloxane topcoat often had a slight haze after two weeks of curing, unlike MIL-PRF-85285, Type IV qualified 2K gloss white polyurethane topcoats that have a clear appearance and a high distinctness of image (DOI) once cured. As a result, the 1K gloss white polysiloxane topcoat was only tested for weatherability by the Navy.

Upon completing of testing at NCP Coatings, quart and gallon quantities of the 1K camouflage gray, 2K gloss white, and 1K semi-gloss gray polysiloxane topcoats were manufactured and shipped to NAWC-AD or AFRL for spray application and testing to the performance requirements shown in Tables 5-8. Numerous Smart Touch® kits of the 1K camouflage gray polysiloxane touch-up topcoat were also manufactured and shipped to NAWC-AD. Quart containers of the 1K gloss white polysiloxane topcoat were manufactured and shipped to FRC-Southeast for spray application and accelerated weathering (UV-B) testing only.

6.1.2 Results for acute inhalation toxicity testing of organosilane polymer

Stakeholders from the Navy, including the ESTCP WP program manager, requested that information on the toxicity of the organosilane polymer used in the 1K camouflage gray polysiloxane topcoat be obtained to ensure the toxicity was not similar to, or greater than, the isocyanate-functional molecules currently found in MIL-PRF-85285 qualified polyurethane topcoats. To prove that the organosilane polymer was less toxic, the Illinois Institute of Technology Research Institute conducted acute inhalation toxicity testing of the clear polymer solution. This performance objective is described in Table 6 and Section 5.2.3.22. For this test, NCP Coatings manufactured a gallon of the organosilane polymer solution, coded as A-213, which was 61.0 Wt.% polymer solids and 39.0 Wt.% pentyl propionate solvent.

The target test concentration of the organosilane polymer was obtained by diluting the A-213 solution with pentyl propionate to achieve an average gravimetrically measured concentration of 2.02 mg/l (2020 mg/m^3) and a particle size distribution within the respirable range (i.e., mean MMAD of 3.09 μm and a GSD range of 2.070-2.272). The study was conducted per Section 5.2.3.22 and was terminated after a single exposure, providing a limit test. All animals survived until scheduled terminal necropsy on Day 15, and no effects on body weight or body weight change were observed for any animal. Based on mortality after exposure to the polymer solution the limit concentration at 50% deaths (LC50) was determined to be >2.02 mg/L (>2020 mg/m^3). For comparison, the 4-hour inhalation LC50 value for 1,6-hexamethylene diisocyanate (HDI) monomer (CAS # 822-06-0) is 124 mg/m^3 (see Sigma-Aldrich SDS in Appendix II), whereas the LC50 value for homopolymers of HDI (CAS# 28182-81-2) is 554 mg/m^3 (see SDS from Covestro, LLC in Appendix III). Thus, the organosilane polymer used in the 1K camouflage gray polysiloxane topcoat was more than 16 times ***less toxic*** than HDI monomer and more than 3.5 times ***less toxic*** than the HDI oligomers commonly found in MIL-PRF-85285 qualified polyurethane topcoats. A summary of the results are shown in Table 17.

Table 17 — Results for acute inhalation toxicity of organosilane polymer.

Performance Test	Success Criteria	Results
Acute inhalation toxicity of organosilane polymer	No death to rodents during 4-hour nose-only inhalation and 14 days post-inhalation; LC50 ≥554 mg/m^3 (value for oligomers of HDI)	No animal deaths; LC50 >2020 mg/m^3 for organosilane polymer; organosilane polymer was 16x less toxic than HDI and 3.5x less toxic than homopolymers of HDI

6.1.3 Results for single-component camouflage gray polysiloxane topcoat tested to Navy requirements

The 1K camouflage gray polysiloxane topcoat, color matched to #36375 medium gray, was provided by NCP Coatings in quart containers to NAWC-AD for testing to standard and extended performance requirements. The topcoat was tested for viscosity and pot life as-received, then applied using HVLP spray equipment to generate stack-ups consisting of a MIL-PRF-85582, Type II, Class C1 anticorrosive epoxy primer and MIL-DTL-81706, Type I, Class 1A pretreatment over bare 3”x6”x0.020” AA 2024-T3 substrate

as detailed in Table 12.[36,37] Topcoat samples for flexibility testing were spray-applied over 3”x6”x0.020” chromic acid anodized AA 2024-0 panels as discussed in Section 5.2.1. A MIL-PRF-85285, Type IV qualified 2K camouflage gray (#36375) polyurethane topcoat was applied over the same primer, pretreatment, and AA substrate for use as a control. The dry film thickness of both topcoats was 1.7-2.3 mils (~43-58 microns).

As shown in Table 18, the 1K camouflage gray polysiloxane aircraft topcoat from NCP Coatings met the standard performance requirements for a Navy aircraft topcoat and performed similarly to the qualified 2K camouflage gray polyurethane control. Wet tape adhesion and GE Impact results are shown in Figures 26a and 26b, respectively. The 1K polysiloxane met the weatherability requirement for a MIL-PRF-85285, Type IV aircraft topcoat, which is a color change of <1.0 after 3000 hours Xenon-Arc WOM exposure. It is worth restating that the 1K polysiloxane topcoat is isocyanate-free and has a VOC content of <290 g/l, which is ~130 g/l less than a Type IV qualified 2K camouflage gray polyurethane topcoat.

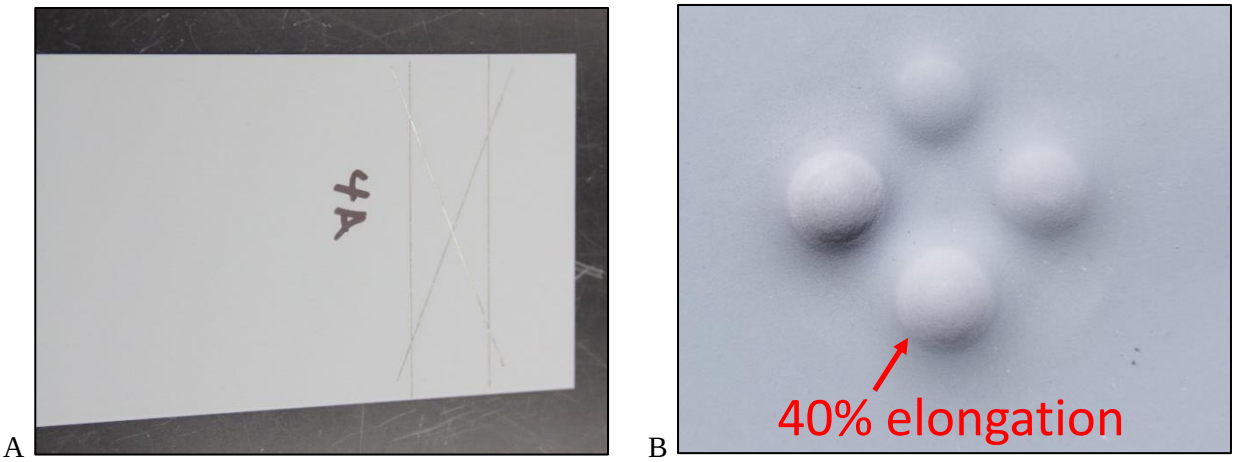


Figure 26 — a) Wet tape adhesion and b) GE Impact results for 1K camouflage gray polysiloxane topcoat.

Table 18 — Standard laboratory performance results for the 1K camouflage gray polysiloxane topcoat and a MIL-PRF-85285, Type IV qualified 2K camouflage gray polyurethane topcoat.

Performance Test	**Requirement**	**Results for 1K Camouflage Gray Polysiloxane Topcoat**	**Results for Type IV 2K Camouflage Gray Polyurethane Topcoat**
Viscosity – #4 Ford Cup	Initial – ≤30 sec.; 4 hours – ≤60 sec; 5 hours – No gelation	PASS	PASS
Drying Times	Set-to-touch – ≤6 hours; Dry-hard – ≤12 hours	PASS	PASS
Adhesion (Wet Tape)	DI H_2O 24 hr. @ RT – ≥4A	4A – PASS	4A – PASS
Gloss	≤5 GU @ 60°	PASS	PASS
	≤10 GU @ 85°	PASS	PASS

Fluid Resistance – Lube Oil	24 hr. @ 250 °F	PASS	PASS
Fluid Resistance – Hydraulic Fluid	24 hr. @ 150 °F	PASS	PASS
Fluid Resistance – JP-5 Jet Fuel	7 days @ RT	PASS	PASS
Room Temperature Flexibility	1" cylindrical mandrel bend – no cracking	PASS	PASS
Room Temperature Impact Flexibility	≥40% elongation after GE Impact	40% – PASS	40% – PASS
Low-Temperature Flexibility	–60 °F and 2" cylindrical mandrel bend - no cracking	PASS	PASS
Heat Resistance	1 hr. @ 250 °F, ΔE <1.0	0.62 – PASS	0.44 – PASS
Humidity Resistance	No blistering, softening or loss of adhesion	PASS	PASS
Solvent Resistance	25 MEK Double Rubs	PASS	PASS
Weather Resistance	3000 hrs. Xenon-Arc WOM: ΔE <1.0, 60° & 85° gloss change <3 GU	ΔE = 0.94 – PASS	ΔE = 0.73 – PASS
Cleanability	>75% efficiency for camo.	PASS	PASS
Strippability (with toxic paint remover)	>90% Method B	PASS	PASS
Tape Resistance	No permanent marring caused by tape	PASS	PASS

As shown in Table 6, the 1K camouflage gray polysiloxane topcoat was not tested to several extended performance requirements, such as Skydrol LD-4 resistance, direct-to-metal pretreatment and metal adhesion, salt spray corrosion resistance, and dry times at various temperatures and humidity.

6.1.4 Results for single-component camouflage gray polysiloxane touch-up topcoat tested to Navy requirements

The 1K camouflage gray polysiloxane touch-up topcoat, color matched to #36375 medium gray, was provided by NCP Coatings in Smart Touch® kits to NAWC-AD for testing to standard and extended performance requirements. The topcoat was diluted with methyl acetate, then spray-applied with the included Preval® spray gun (figure 27a). As shown in Table 12, the coating stack-ups consisted of a MIL-PRF-85582, Type II, Class C1 anticorrosive epoxy primer and MIL-DTL-81706, Type I, Class 1A pretreatment over bare 3"x6"x0.020" AA 2024-T3 substrate. The touch-up topcoat was also applied over 3"x6"x0.020" chromic acid anodized AA 2024-0 panels for flexibility testing. A MIL-PRF-81352 qualified touch-up topcoat (e.g., acrylic, polyurethane dispersion (PUD)) was not applied for use as a control.[26] The DFT of the 1K polysiloxane touch-up topcoat was slightly greater than 1.0 mil once cured, and the topcoat had a smooth, homogenous surface appearance (figure 27b).

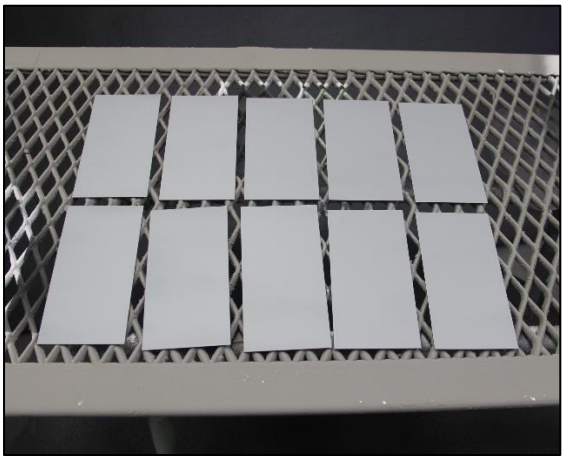
A B 

Figure 27 — 1K camouflage gray polysiloxane touch-up topcoat: a) application with Preval® spray gun and b) appearance after applied and cured.

As shown in Table 19, the 1K camouflage gray polysiloxane touch-up topcoat met all standard laboratory performance requirements for a Navy aircraft touch-up topcoat. The majority of these requirements were taken from MIL-PRF-81352 (aircraft touch-up). The initial batch of 1K polysiloxane touch-up topcoats had a tack-free time of 75 minutes and did not meet the dry time requirement. However, after a slight increase in catalyst the revised version met the requirement with a tack free time of 30 minutes.

Table 19 — Standard laboratory performance results for the 1K camouflage gray polysiloxane touch-up topcoat.

Performance Test	Requirement	Results for 1K Camouflage Gray Polysiloxane Touch-up Topcoat
Drying Times	Tack free <60 minutes	30 min. – PASS
Odor	No odor 48 hours after application	PASS
Surface Appearance	Smooth, uniform, and free of irregularities	PASS
Color	Visual comparison	PASS
Gloss	<5 GU @ 60°	3.9 GU – PASS
Adhesion (Wet Tape)	DI H_2O 24 hr. @ RT – ≥4A	PASS
Opacity	>0.95	0.99 – PASS
Fluid Resistance – Lube Oil	24 hr. @ 250 °F	PASS
Fluid Resistance – Hydraulic Fluid	24 hr. @ 150 °F	PASS
Fluid Resistance – JP-5 Jet Fuel	7 days @ RT	PASS

Room Temperature Flexibility	1” cylindrical mandrel bend – no cracking or loss of adhesion	PASS
Heat Resistance	1 hr. @ 250 °F, ΔE <1.0	ΔE = 0.413 – PASS
Water Resistance	No cracking, blistering or whitening	PASS
Weather Resistance	500 hrs. Xenon-Arc WOM: color change (ΔE) <2.0	ΔE = 0.32 – PASS
Tape Resistance	No permanent marring caused by tape	PASS

NAVAIR stakeholders requested that a test simulating the repair of a polyurethane topcoat on an aircraft, using the 1K camouflage gray polysiloxane touch-up topcoat, be conducted as part of the extended laboratory performance requirements for Navy aircraft. For this test, a polyurethane topcoat that was cured for 14 days was lightly abraded with a maroon-colored 3M Scotch-Brite General Purpose 7447 Pad, wiped with acetone, followed by spray application of the 1K polysiloxane touch-up topcoat. After 14 days of curing the sample was tested for wet tape adhesion in accordance with Section 5.2.3.23. The test passed with a 4A X-cut adhesion rating as shown in Table 20.

Table 20 — Extended laboratory performance results for the 1K camouflage gray polysiloxane touch-up topcoat.

Performance Test	**Requirement**	**Results for 1K Camouflage Gray Polysiloxane Touch-up Topcoat**
Repair Adhesion – for touch-up topcoats only	No less than a 4A rating after immersion in water for 24 hours at RT	4A – PASS

6.1.5 Results for two-component gloss white polysiloxane topcoat tested to Navy requirements

The 2K gloss white polysiloxane topcoat, color matched to #17925 white, was provided to NAWC-AD in gallon kits for testing to standard and extended performance requirements. The topcoat was tested for viscosity and pot life as-received, then applied using HVLP spray equipment to generate stack-ups consisting of a MIL-DTL-53022, Type IV epoxy primer and MIL-DTL-81706, Type I, Class 1A pretreatment over bare 3”x6”x0.020” AA 2024-T3 substrate as shown in Table 12. Topcoat samples for flexibility testing were spray-applied over 3”x6”x0.020” chromic acid anodized AA 2024-0 panels as discussed in Section 5.2.1. A MIL-PRF-85285, Type II qualified 2K gloss white (#17925) polyurethane topcoat with a VOC content of 336 g/l was applied over the same primer, pretreatment, and AA 2024-0 panels for use as a control. The 2K polysiloxane topcoat has a VOC content of 65 g/l, which is 271 g/l less than the Type II polyurethane topcoat. After curing for 14 days, the DFT of both topcoats was 1.7-2.3 mils (~43-58 microns). As shown in Figure 28, the 2K gloss white polysiloxane topcoat possessed less orange peel and a glossier finish compared to the Type II polyurethane topcoat.

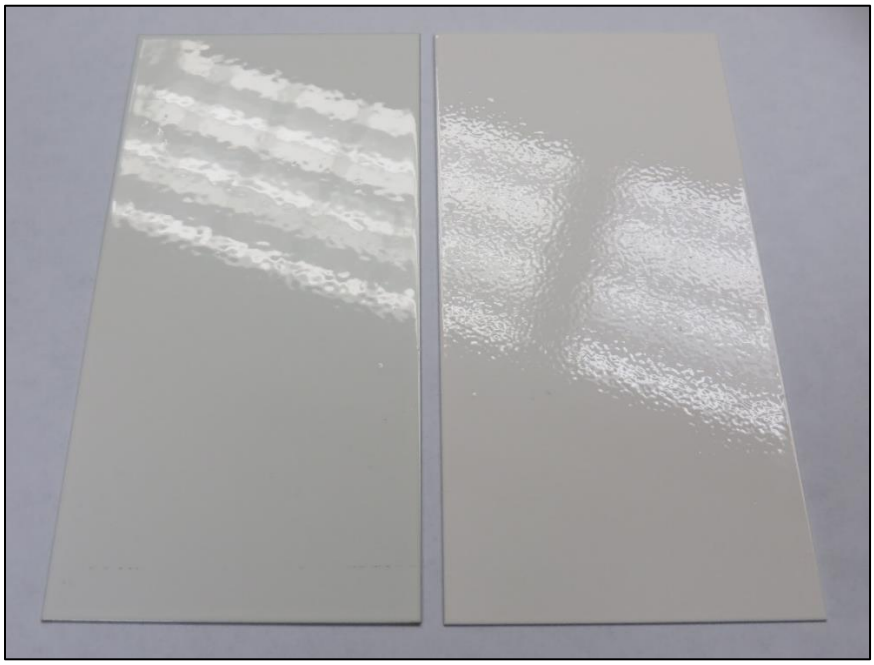


Figure 28 — (left) 2K gloss white polysiloxane topcoat and (right) a MIL-PRF-85285, Type II qualified gloss white polyurethane topcoat.

As shown in Table 21, the 2K gloss white polysiloxane topcoat from NCP Coatings met the standard performance requirements for a Navy GSE topcoat and performed similarly to the qualified 2K polyurethane control. The 2K polysiloxane demonstrated slightly less of a color change compared to the control when tested for weatherability, although the GE Impact flexibility was also slightly less at only 5% elongation. Additional catalyst was added by NCP Coatings to achieve dry times of 2 hours set-to-touch and 4-6 hours dry-hard, thereby eliminating the soft and rubbery texture that was observed in the original NRL-developed 2K gloss white polysiloxane formula.

Table 21 — Standard laboratory performance results for the 2K gloss white polysiloxane topcoat compared to a MIL-PRF-85285, Type II qualified 2K gloss white polyurethane topcoat.

Performance Test	**Requirement**	**Results for 2K Gloss White Polysiloxane Topcoat**	**Results for Type II 2K Gloss White Polyurethane Topcoat**
Viscosity – #4 Ford Cup	Initial – ≤30 sec.; 4 hours – ≤60 sec; 5 hours – No gelation	PASS	PASS
Drying Times	Set-to-touch – ≤6 hours; Dry-hard – ≤12 hours	2 hours STT, 4-6 hours DH – PASS	PASS
Gloss	≥90 GU @ 60°	93.7 GU – PASS	93.6 GU – PASS
Solvent Resistance	25 MEK Double Rubs	PASS	PASS
Fluid Resistance – Lube Oil	24 hr. @ 250 °F	PASS	PASS

Fluid Resistance – Hydraulic Fluid	24 hr. @ 150 °F	PASS	PASS
Fluid Resistance – JP-5 Jet Fuel	7 days @ RT	PASS	PASS
Adhesion – Wet Tape	DI H_2O 24 hr. @ RT – ≥4A	4A – PASS	4A – PASS
GE Impact Flexibility	≥5% Elongation	5% – PASS	10% – PASS
Room Temperature Flexibility	1" cylindrical mandrel bend - no cracking	PASS	PASS
Heat Resistance	1 hr. @ 250 °F, ΔE <1.0	ΔE = 0.72 – PASS	ΔE = 0.39 – PASS
Weather Resistance	500 hrs. Xenon-Arc WOM: ΔE <1.0, 60° gloss >80 GU	ΔE = 0.82, 83.6 GU @ 60° – PASS	ΔE = 0.87, 91.4 GU @ 60° – PASS
Strippability (with toxic paint remover)	≥90% Method B (unexposed)	PASS	PASS

6.1.6 Results for single-component gloss white polysiloxane topcoat tested to Navy requirements

As explained in Section 6.1.1.3, NCP Coatings was unable to optimize the 1K gloss white polysiloxane topcoat formula to consistently meet MIL-PRF-85285, Type IV gloss and surface appearance requirements. As a result, quart quantities of this topcoat were not manufactured for testing to the numerous requirements listed in Table 5. However, NCP did manufacturer quart samples that were color matched to FED-STD-595 #17925 for spray-application and accelerated weathering (UV-B chamber with 340 nm bulb) testing at FRC-Southeast. The 1K gloss white topcoat was spray-applied to generate stack-ups consisting of a MIL-PRF-85582, Type II, Class C1 anticorrosive epoxy primer and MIL-DTL-81706, Type I, Class 1A pretreatment over a bare 3"x6"x0.020" AA 2024-T3 substrate as shown in Table 12. Stack-ups of MIL-PRF-85285, Type I and Type IV qualified 2K gloss white polyurethane topcoats were fabricated over the same primer, pretreatment, and substrate for use as controls. As shown in Tables 22 and 23, the 1K gloss white polysiloxane topcoat demonstrated less of a color change and retained a higher gloss value after both 500 and 1000 hours of exposure compared to the MIL-PRF-85285, Type I qualified 2K gloss white polyurethane. However, the 1K gloss white polysiloxane topcoat underperformed the Type IV qualified 2K gloss polyurethane topcoat in both color and gloss retention after 1000 hours UV-B exposure.

Table 22 — Color change of gloss white topcoats after 1000 hours exposure in UV-B chamber.

Gloss White Topcoat	ΔE after 500 Hours	ΔE after 1000 Hours
1K polysiloxane	0.8	1.0
MIL-PRF-85285, Type I	2.4	2.5
MIL-PRF-85285, Type IV	0.3	0.4

Table 23 — Gloss values of gloss white topcoats after 1000 hours exposure in UV-B chamber.

Gloss White Topcoat	Gloss at 0 Hours	Gloss after 500 Hours	Gloss after 1000 Hours
1K polysiloxane	89.9 GU	83.4 GU	75.0 GU
MIL-PRF-85285, Type I	93.0 GU	72.1 GU	53.2 GU
MIL-PRF-85285, Type IV	94.6 GU	93.8 GU	95.0 GU

6.1.7 Results for single-component camouflage gray polysiloxane topcoat tested to Air Force requirements

The 1K camouflage gray polysiloxane topcoat, color matched to #36173 dark gray, was provided by NCP Coatings in quart containers to AFRL for testing to standard Air Force performance requirements (Table 7). To fabricate test samples, the 1K polysiloxane topcoat was applied via HVLP spray equipment to generate stack-ups consisting of a MIL-PRF-23377, Type I, Class C2 solvent-borne epoxy primer, or Aerodur 2100 magnesium-rich solvent borne epoxy primer, with PreKote pretreatment over bare 12”x12”x0.032” AA 2024-T3 and 12”x12”x0.020” AA 2024-0 panels (Table 13).[52] Control stack-ups were fabricated using a MIL-PRF-85285, Type IV qualified 2K camouflage gray polyurethane topcoat over the same primer, pretreatment, and substrate. The thickness of the chromate primer ranged from 0.74-0.81 mils DFT, whereas the thickness of the Aerodur 2100 primer was 1.94-2.04 mils. The DFT of all topcoats was 1.77-2.30 mils as specified by the Air Force after 14 days of curing at ambient conditions.

A comparison of the standard laboratory performance results for the 1K camouflage gray polysiloxane topcoat system and MIL-PRF-85285, Type IV qualified 2K camouflage gray polyurethane topcoat systems with the magnesium rich primer is shown in Table 24. A comparison of the standard laboratory performance results for the 1K camouflage gray polysiloxane topcoat system and MIL-PRF-85285, Type IV qualified 2K camouflage gray polyurethane topcoat systems with a MIL-PRF-23377 chromate-containing epoxy primer is shown in Table 25.

Table 24 — Standard laboratory performance results for the 1K camouflage gray polysiloxane topcoat with a magnesium-rich primer compared to a MIL-PRF-85285E, Type IV 2K camouflage gray polyurethane topcoat with the same primer.

Performance Test	Requirement	1K Camouflage Gray Polysiloxane Topcoat System	2K Camouflage Gray Polyurethane Topcoat System
Gloss	≤5 GU @ 60°	PASS	PASS
	≤9 GU @ 85°	PASS	PASS
Color	ΔE <1.0 to color chip	PASS	PASS
Adhesion (Wet Tape)	No less than a 4A rating, no delamination or peeling	5A – PASS	5A – PASS

Adhesion (Crosshatch)	No less than a 4B rating, no delamination or peeling	5B – PASS	5B – PASS
Fluid Resistance – Deionized Water	30 days @ 120 °F: no delamination, ≤2 pencil hardness change, ΔE ≤3.0	5B adhesion, -2 pencil hardness change, ΔE = 0.49 – PASS	5B adhesion, -3 pencil hardness change, ΔE = 0.66 – FAIL
Fluid Resistance – Hydraulic Fluid	7 days @ 150 °F: no delamination, ≤2 pencil hardness change, ΔE ≤3.0	4B adhesion, -2 pencil hardness change, ΔE = 1.68 – PASS	5B adhesion, 0 pencil hardness change, ΔE = 0.99 – PASS
Fluid Resistance – JP-8 Jet Fuel	30 days @ 77 °F: no delamination, ≤2 pencil hardness change, ΔE ≤3.0	5B adhesion, 0 pencil hardness change, ΔE = 0.36 – PASS	4B adhesion, +5 pencil hardness change, ΔE = 0.13 – FAIL
Fluid Resistance – Lubricating Oil	24 hours @ 250 °F: no delamination, ≤2 pencil hardness change, ΔE ≤3.0	5B adhesion, +4 pencil hardness change, ΔE = 1.31 – FAIL	4B adhesion, +5 pencil hardness change, ΔE = 1.40 – FAIL
Low-Temperature Flexibility	–60 °F and 2” cylindrical mandrel bend - no cracking	PASS	FAIL
Room Temperature Impact Flexibility (before weathering)	≥10% Elongation	10% – PASS	10% – PASS
Room Temperature Impact Flexibility (after weathering)	≥10% Elongation after 3000 hours Xenon-Arc	10% – PASS	FAIL
Weather Resistance	3000 hrs. Xenon-Arc WOM: ΔE ≤1.0, 60° & 85° gloss change <3 GU	ΔE = 0.81 @ 3000 hours – PASS	ΔE = 0.77 @ 3000 hours – PASS
Humidity Resistance	No blistering, loss of adhesion or changes in pencil hardness	4B adhesion, +6 pencil hardness change – FAIL	4B adhesion, +5 pencil hardness change – FAIL
Solvent Resistance	25 double rubs without rubbing through to bare metal	PASS	PASS
Heat Resistance	60 min. @ 250 °F: No cracking or flaking when bent over a 2” cylindrical mandrel, no less than a 4B adhesion rating, ΔE ≤1.0	5B adhesion, ΔE = 0.11 – PASS	5B adhesion, ΔE = 0.18 – PASS
Cleanability	Cleaning efficiency of no less than 75%	27% – FAIL	30% – FAIL

Skydrol LD-4 resistance	No blistering, loss of adhesion, softening or other irregularities; 2 change in pencil hardness; ΔE ≤3.0	2B adhesion, -3 pencil hardness change, ΔE = 0.34 – FAIL	3B adhesion, -5 pencil hardness change, ΔE = 0.52 – FAIL
Strippability (with toxic and environmentally friendly paint strippers)	>90% removed within 24 hours and with <4 applications using a methylene chloride (toxic) and benzyl alcohol (non-toxic) stripper	100% of topcoat removed with both strippers – PASS	100% of topcoat removed with toxic stripper, but only 75% removed with environmentally friendly stripper – FAIL
Outdoor Exposure (corrosion resistance)	Equivalent or better corrosion resistance than system with chromate primer and polyurethane topcoat	PASS	PASS

Table 25 — Standard laboratory performance results for the 1K camouflage gray polysiloxane topcoat with a chromate-containing primer compared to a MIL-PRF-85285, Type IV 2K camouflage gray polyurethane topcoat with the same primer.

Performance Test	**Requirement**	**1K Camouflage Gray Polysiloxane Topcoat System**	**2K Camouflage Gray Polyurethane Topcoat System**
Gloss	≤5 GU @ 60°	PASS	PASS
	≤9 GU @ 85°	PASS	PASS
Color	ΔE <1.0 to color chip	PASS	PASS
Adhesion (Wet Tape)	No less than a 4A rating, no delamination or peeling	4A – PASS	5A – PASS
Adhesion (Crosshatch)	No less than a 4B rating, no delamination or peeling	3B – FAIL	4B – PASS
Fluid Resistance – Deionized Water	30 days @ 120 °F: no delamination, ≤2 pencil hardness change, ΔE ≤3.0	4B adhesion, -1 pencil hardness change, ΔE = 0.62 – PASS	4B adhesion, -3 pencil hardness change, ΔE = 0.45 – FAIL
Fluid Resistance – Hydraulic Fluid	7 days @ 150 °F: no delamination, ≤2 pencil hardness change, ΔE ≤3.0	3B adhesion, -2 pencil hardness change, ΔE = 2.79 – FAIL	3B adhesion, -1 pencil hardness change, ΔE = 0.84 – PASS

Fluid Resistance – JP-8 Jet Fuel	30 days @ 77 °F: no delamination, ≤2 pencil hardness change, ΔE ≤3.0	0B adhesion, -1 pencil hardness change, ΔE = 0.42 – FAIL	3B adhesion, 0 pencil hardness change, ΔE = 0.19 – PASS
Fluid Resistance – Lubricating Oil	24 hours @ 250 °F: no delamination, ≤2 pencil hardness change, ΔE ≤3.0	4B adhesion, 0 pencil hardness change, ΔE = 1.64 – PASS	4B adhesion, 0 pencil hardness change, ΔE = 1.30 – PASS
Low-Temperature Flexibility	–60 °F and 2" cylindrical mandrel bend - no cracking	FAIL	FAIL
Room Temperature Impact Flexibility (before weathering)	≥10% Elongation	10% – PASS	10% – PASS
Room Temperature Impact Flexibility (after weathering)	≥10% Elongation after 3000 hours Xenon-Arc	FAIL	FAIL
Weather Resistance	3000 hrs. Xenon-Arc WOM: color change (ΔE) ≤1.0, 60° & 85° gloss change <3 GU	ΔE = 1.00 @ 3000 hours – PASS	ΔE = 0.67 @ 3000 hours – PASS
Humidity Resistance	No blistering, loss of adhesion or changes in pencil hardness	4B adhesion, +1 pencil hardness change – FAIL	4B adhesion, +5 pencil hardness change – FAIL
Solvent Resistance	25 double rubs without rubbing through to bare metal	PASS	PASS
Heat Resistance	60 min. @ 250 °F: No cracking or flaking when bent over a 2" cylindrical mandrel, no less than a 4B adhesion rating, ΔE ≤1.0	4B adhesion, ΔE = 0.15 – PASS	4B adhesion, ΔE = 0.32 – PASS
Cleanability	Cleaning efficiency of no less than 75%	47% – FAIL	74% – FAIL
Skydrol LD-4 resistance	No blistering, loss of adhesion, softening or other irregularities; 2 change in pencil hardness; ΔE of ≤3.0	0B adhesion, -3 pencil hardness change, ΔE = 0.41 – FAIL	2B adhesion, -5 pencil hardness change, ΔE = 0.45 – FAIL

Strippability (with toxic and environmentally friendly paint strippers)	>90% removed within 24 hours and with <4 applications when using methylene chloride (toxic) and peroxide activated benzyl alcohol (non-toxic) strippers	100% of topcoat removed with both strippers – PASS	100% of topcoat removed with toxic stripper, 99% removed with environmentally friendly stripper – PASS
Outdoor Exposure (Daytona Beach)	Equivalent or greater corrosion resistance than system with chromate primer and polyurethane topcoat after 12 months	PASS	PASS

As shown by the results, neither the 1K camouflage gray polysiloxane topcoat system or the Type IV qualified 2K camouflage gray polyurethane topcoat system passed all performance requirements. For systems with the magnesium-rich epoxy primer the 1K polysiloxane topcoat outperformed the 2K polyurethane topcoat. The 1K polysiloxane topcoat only failed the lubricating oil immersion, humidity resistance, cleanability, and Skydrol LD-4 resistance tests, whereas the polyurethane topcoat failed JP-8 and lubricating oil immersion, humidity resistance, cleanability, low-temperature flexibility, and impact resistance after 3000 hours weatherability. A change in pencil hardness of greater than 2 was the reason the 1K polysiloxane topcoat system failed the lubrication oil immersion and humidity resistance tests, although it did not show blistering or delamination. The 1K polysiloxane topcoat system also demonstrated greater low-temperature flexibility and room temperature flexibility after weathering than the Type IV polyurethane topcoat system (figure 29), which is likely due to the 1K polysiloxane topcoat bonding differently to the surface of the magnesium-rich primer, thereby enabling slightly greater flexibility.

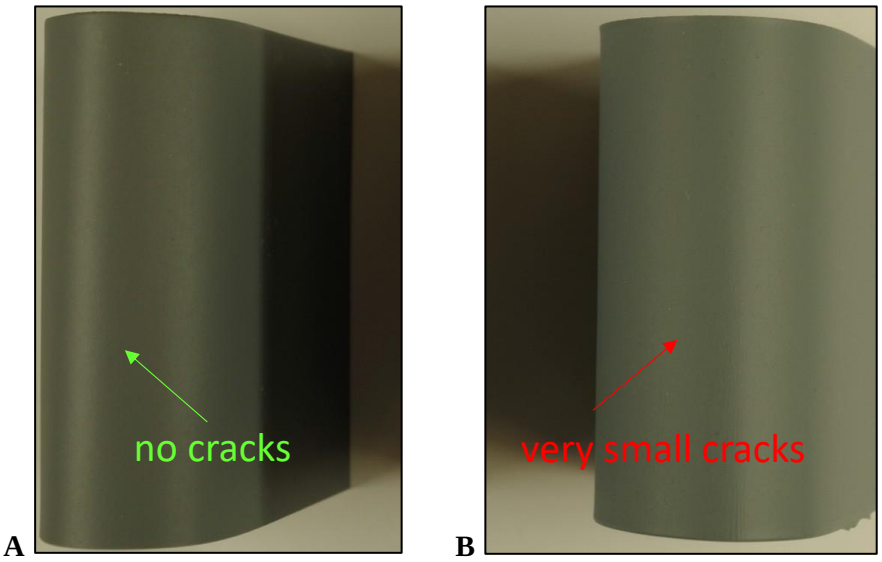


Figure 29 — (a) 1K camouflage gray polysiloxane topcoat over magnesium-rich primer and (b) 2K camouflage gray polyurethane topcoat over magnesium-rich primer after low-temperature flexibility test.

For systems with the chromate-containing epoxy primer the 1K polysiloxane topcoat performed similarly to the 2K polyurethane control, as both systems failed to meet the low-temperature flexibility, room temperature flexibility after weathering, humidity resistance, cleanability, and Skydrol LD-4 resistance.

However, although 1K polysiloxane topcoat system failed the low-temperature flexibility test it still outperformed the polyurethane control system, as the latter cracked the entire way across the panel after bending (figure 30).

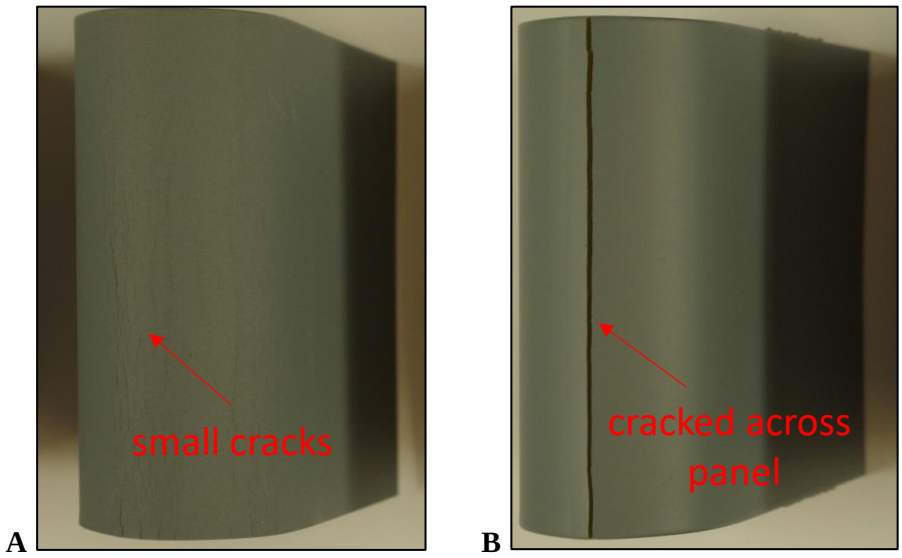


Figure 30 — (a) 1K camouflage gray polysiloxane topcoat over chromate-containing primer and (b) 2K camouflage gray polyurethane topcoat over chromate-containing primer after low-temperature flexibility test.

These system flexibility results are noteworthy because the Air Force has reported cracking in polyurethane systems where paint bridges are formed (e.g., around aircraft fasteners), which leads to the ingress of water and results in corrosion. Thus, utilization of the 1K camouflage gray polysiloxane topcoat over a non-chrome primer may result in a reduction or elimination of these issues on aircraft.

The 1K camouflage gray polysiloxane and 2K camouflage gray polyurethane topcoats over chromate and non-chromate epoxy primers were tested for outdoor exposure (corrosion resistance) at Daytona Beach, Florida for 12 months as discussed in Section 5.2.3.26. All systems passed this test as shown in Tables 24 and 25. For all coating systems, unscribed panels with cadmium-plated steel and titanium fasteners showed no corrosion after 12 months. Similarly, all scribed coating systems with titanium fasteners showed no corrosion after 12 months. Coating systems with cadmium-plated steel fasteners and scribes showed minor corrosion (in the scribe), although the corrosion performance was similar for all system, regardless if the epoxy primer was chromate or non-chromate containing (figures 31 and 32). This demonstrates that the 1K camouflage gray polysiloxane topcoat, as a coating system, can provide equivalent outdoor performance to a qualified 2K camouflage gray polyurethane topcoat system. In addition, the 1K polysiloxane topcoat over a non-chromate epoxy primer can provide a completely non-hazardous and environmentally friendly coating system for Air Force aircraft.

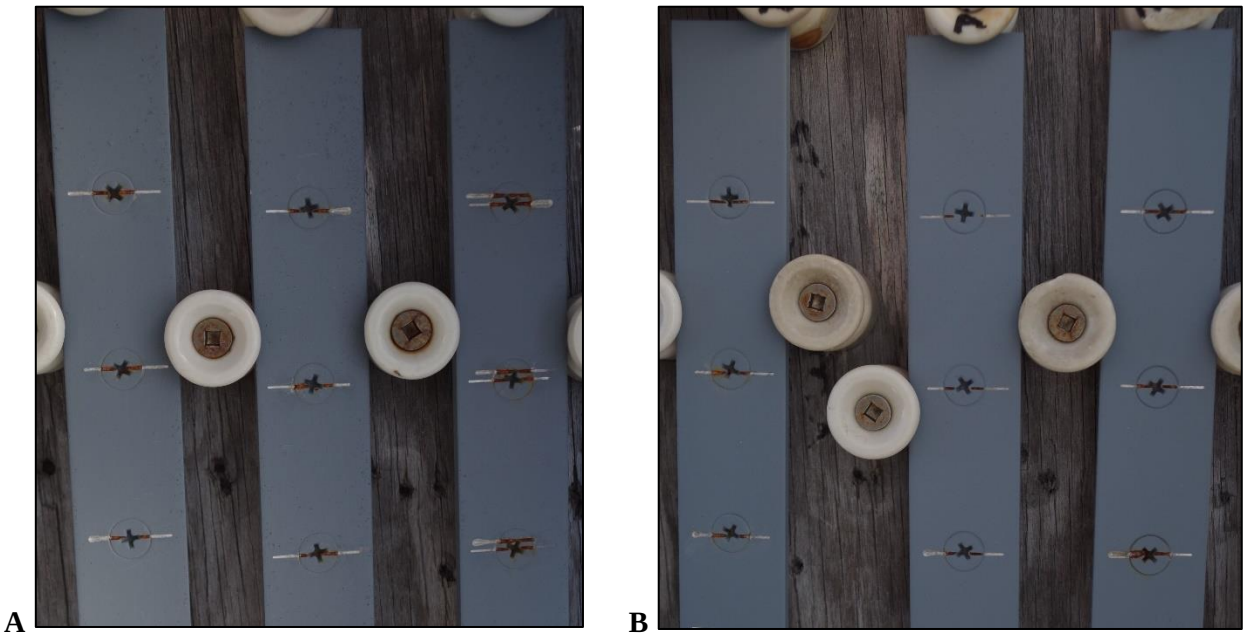


Figure 31 — 12-month outdoor corrosion performance for a) 1K camouflage gray polysiloxane topcoat over magnesium-rich primer and b) 2K camouflage gray polyurethane topcoat over magnesium-rich primer. Both sample sets possessed cadmium-plated steel fasteners and AA 2024-T3 substrate with scribes.

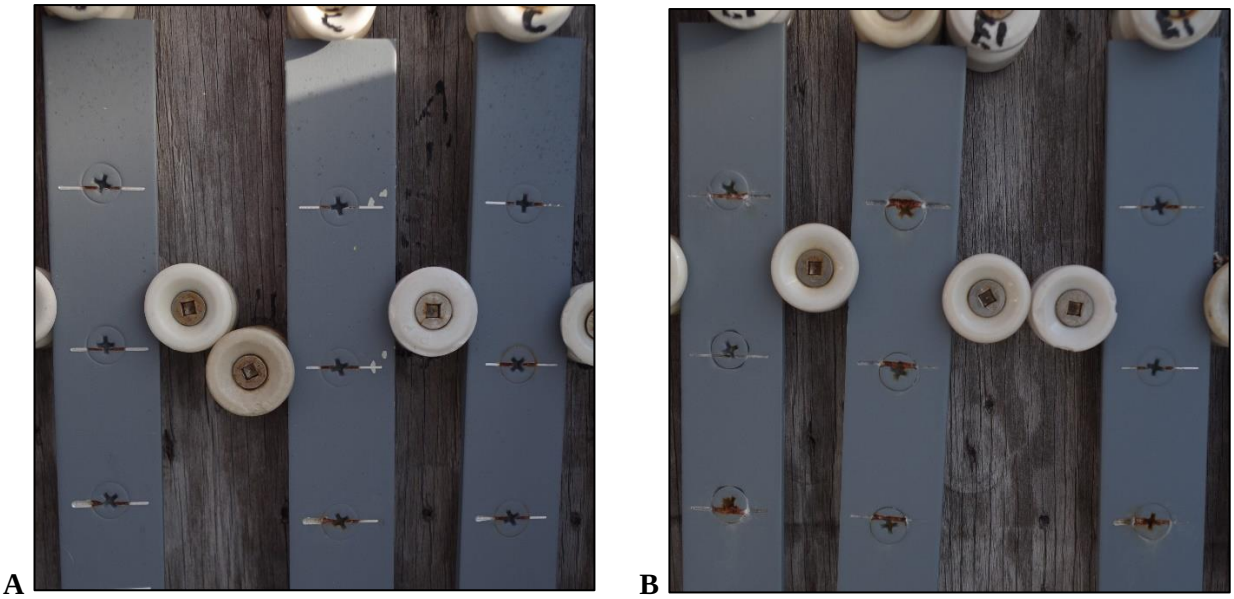


Figure 32 — 12-month outdoor corrosion performance for a) 1K camouflage gray polysiloxane topcoat over chromate-containing primer and b) 2K camouflage gray polyurethane topcoat chromate-containing primer. Both sample sets possessed cadmium-plated steel fasteners and AA 2024-T3 substrate with scribes.

6.1.8 Results for single-component semi-gloss gray polysiloxane topcoat tested to Air Force requirements

The 1K semi-gloss gray polysiloxane topcoat, color matched to #26173 dark gray, was provided by NCP Coatings in a gallon container to AFRL for testing to extended Air Force performance requirements (Table 8). To fabricate the test samples, the 1K polysiloxane topcoat was applied via HVLP spray equipment to generate coating stack-ups that consisted of: 1) Aerodur 2100 magnesium-rich epoxy primer, PreKote pretreatment, and bare 12”x12”x0.032” AA 2024-T3 panels, and 2) 10P3-2 zinc-rich solvent borne epoxy primer from Akzo Nobel, PreKote pretreatment, and bare 6”x12”x0.25” blasted steel panels (Table 13).[45] Control coatings systems were fabricated using a MIL-PRF-85285, Type IV qualified 2K semi-gloss gray polyurethane topcoat over the same primers, pretreatment, and substrates. The thickness of the chromate epoxy primer was 0.74-0.81 mils DFT, whereas the thickness of the Aerodur 2100 primer was 1.94-2.04 mils. The DFT of all topcoats was 1.77-2.30 mils after 14 days of curing at ambient conditions.

After 14 days of coating system cure the panels were separated and prepared as follows: 1) no surface preparation, 2) hand-abraded with 80-100 grit sand paper, followed by application of Sur-Prep® AP-1 paint adhesion promoter from Zip-Chem[57], and 3) hand-abraded with 80-100 grit sand paper, followed by wiping with isopropyl alcohol (IPA). The 1K semi-gloss gray polysiloxane and 2K semi-gloss gray polyurethane topcoats were then resprayed over all panels, followed by another 14 days of curing. This was followed by adhesion (via dolly pull) testing of all systems via ASTM D4541 and in accordance with Pull-Off Adhesion test in Section 5.2.3.27.[58]

All systems had a pull-off test strength (POTS) adhesion greater than 1870 psi, with the majority of samples ranging from 2200-2900 psi, thus passing the extended performance test requirement (Table 26). This test also demonstrated that both the 1K semi-gloss gray polysiloxane topcoat and 2K semi-gloss gray polyurethane topcoat demonstrated good overcoat adhesion under all surface preparation scenarios and over both primers. The point of failure for most samples was between the glue and stud, and there only a minor difference in adhesion results between the various surface preparations. Figure 33 shows a comparison of the 1K semi-gloss gray polysiloxane topcoat over a zinc-rich primer with sanding and IPA wipe compared to the 2K semi-gloss gray polyurethane topcoat with the same primer and surface preparation.

Table 26 — Extended laboratory performance result for the 1K semi-gloss gray polysiloxane topcoat over various surface preparations when tested for pull-off strength adhesion.

Performance Test	**Requirement**	**1K Semi-Gloss Gray Polysiloxane Topcoat System**
Adhesion (Pull-Off Strength)	>1800 psi pull-off strength over various surface preparations; similar performance to a polyurethane control	PASS

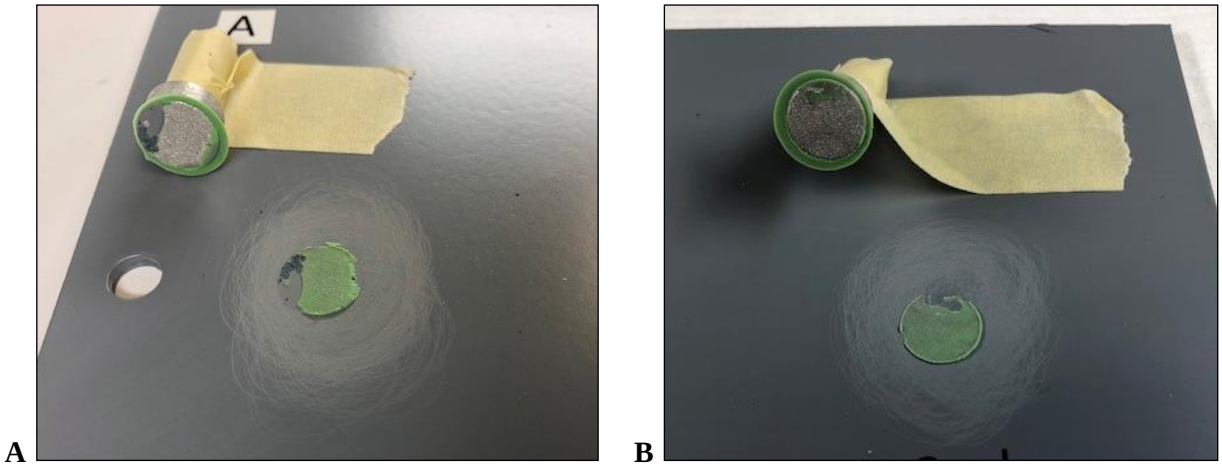


Figure 33 — Photographs of overcoat adhesion for a) 1K semi-gloss gray polysiloxane topcoat over zinc-rich primer and b) 2K semi-gloss gray polyurethane topcoat over zinc-rich when second application of both topcoats were applied over sanded and IPA wiped substrates.

6.2 Industrial Performance Assessment of Polysiloxane Topcoat

As mentioned in Section 5.3, in November of 2017 the 1K camouflage gray polysiloxane topcoat was spray-applied by artisans at NAS North Island, which an industrial setting where aircraft and components are painted. This application was done to determine the HVLP spray gun settings for the 1K topcoat, determine topcoat ease-of-use and preparation time, evaluate the sprayability of the topcoat on scrap parts and components, in addition to evaluating topcoat coverage and appearance once applied. Specifically, the 1K topcoat, color matched to FED-STD-595 #36375, was provided in several quart quantities by NCP Coatings for application on F-18 scrap parts, such as ailerons and an engine inlet (figures 34 and 35). Figure 36 shows the appearance of the 1K topcoat after drying for 4 hours.

Figure 34 — Spray application of 1K camouflage gray polysiloxane topcoat on a scrap F-18 aileron at NAS North Island.

Figure 35 — Spray application of 1K camouflage gray polysiloxane topcoat on a scrap F-18 engine inlet at NAS North Island.

Figure 36 — Appearance of 1K camouflage gray polysiloxane topcoat on F-18 parts after 4 hours of drying.

Overall, the 1K camouflage gray polysiloxane topcoat sprayed well and the painters had zero complaints. They enjoyed the all-in-one-can nature of the 1K topcoat because it did not require mixing of components and could simply be shaken or stirred for a few minutes, then poured into the pressure pot and sprayed. The 1K polysiloxane topcoat sprayed best with 1.8 and 2.0 mm fluid tips, as smaller tip sizes resulted in minor dry spray. When the 1K topcoat was sprayed on the rounded areas of the engine inlet it did not run/sag as easily as a MIL-PRF-85285 qualified 2K camouflage gray polyurethane topcoat, which the artisans stated was beneficial. The 1K polysiloxane topcoat also provided good coverage and hiding, in addition to drying to a low gloss finish within a few hours (figure 36).

7. FIELD PERFORMANCE ASSESSMENT

Successful laboratory testing and industrial spray applications of the 1K camouflage gray and 2K gloss white polysiloxane topcoats resulted in NAVAIR approvals to paint several Navy / Marine Corps assets and track their performance in the field under normal operating conditions. The 1K semi-gloss gray polysiloxane topcoat was also approved by the Air Force for demonstration on AGE. The majority of the painted assets remained at naval air stations and depots, whereas one of the GSE assets, a spotting dolly, was deployed on a Navy CVN for several months. The following sections provide detailed information on the application and performance assessments of the polysiloxane topcoats compared to a MIL-PRF-85285 qualified 2K polyurethane topcoat on the same or similar asset.

7.1 Demonstration of 2K Gloss White Polysiloxane Topcoat on Mid-Range Tow Tractor

7.1.1 Application of topcoat on MRTT – February 2017

In February of 2017, the NCP-produced 2K gloss white polysiloxane topcoat, color matched to FED-STD-595 #17925, was applied on the cab, hood, and chassis of a mid-range tow tractor (MRTT) at NAS Oceana in Virginia Beach, Virginia. All substrates were prepared via abrasive blasting (figure 37), followed by application of a buff-colored MIL-DTL-53022, Type II epoxy primer (figure 38).[44] Once the primer was dry-to-touch, the polysiloxane topcoat was applied via HVLP spray equipment using a 1.5 mm fluid tip in the spray gun. The application was performed at 68 °F and 32% RH by an active duty painter. Two passes (i.e., two coats) of the 2K polysiloxane topcoat were used to cover the primer, although the applicator mentioned that a single pass would have covered sufficiently. A representative from the Oceana IH Office was not present to sample for airborne isocyanates during the application. Less than one gallon of polysiloxane topcoat was required to paint the cab, thus the VOCs emitted were below 0.54 lb/gal. After 22 hours of curing the coating was dry-hard. The DFT of coating system on the roof of the cab ranged from 2.9-4.1 mils, providing 1.6-2.1 mils of topcoat. Measurements on the hood and chassis were not available because they were painted on days when NRL and NAWC-AD representatives were not present.

The 2K gloss white polysiloxane topcoat on the cab had a glossy appearance, although several small particles were observed in the paint due to dust and/or primer overspray. Figures 39 and 40 show the cab immediately after the 2K polysiloxane topcoat was applied. As noted in the aforementioned paragraph, the hood and chassis were painted several days later (figure 41). During this period, the doors of the MRTT were painted with a MIL-PRF-85285, Type II qualified 2K gloss white polyurethane topcoat for use as a control, and two coats were required because it did not hide the primer as well as the 2K polysiloxane topcoat. It is worth noting that the abrasive blast profile on the hood and chassis were greater than that on the cab, thereby generating greater waviness and orange-peel in the finished topcoat. On the contrary, the doors were not abrasive blasted, thus the MIL-PRF-85285, Type II 2K gloss white polyurethane control had a smoother finish than any of the surfaces where the 2K polysiloxane topcoat was applied. All components of the MRTT were assembled at the end of February (figure 42), then decals and stenciling were applied at the beginning of March (figure 43). The stencil on the hood stated "*NAVAIR/NRL Coating Demo In Progress, Do Not Paint*" to inform service men and women that the 2K gloss white polysiloxane topcoat should not be painted or removed.

Figure 37 — Cab of MRTT after abrasive blasting to generate a profile.

Figure 38 — Cab of MRTT after MIL-PRF-53022, Type II primer was applied.

Figure 39 — Cab of MRTT after 2K gloss white polysiloxane topcoat was applied.

Figure 40 — Back, top area of cab of MRTT after 2K gloss white polysiloxane topcoat was applied.

Figure 41 — Hood and chassis of MRTT after 2K gloss white polysiloxane topcoat was applied.

Figure 42 — Fully-assembled MRTT without decals and stencil.

Figure 43 — Fully-assembled MRTT with decals and stencil on hood.

7.1.2 In-service inspections of topcoat on MRTT

7.1.2.1 Initial Inspection of Topcoats – March 2017

On March 17, 2017, the MRTT was inspected by NRL before being placed into service on the flight line at NAS Oceana. The 2K gloss white polysiloxane topcoat and polyurethane control topcoat were visually inspected for defects, such as cracking or delamination, then photographed (figures 44-48). No issues were observed with either topcoat.

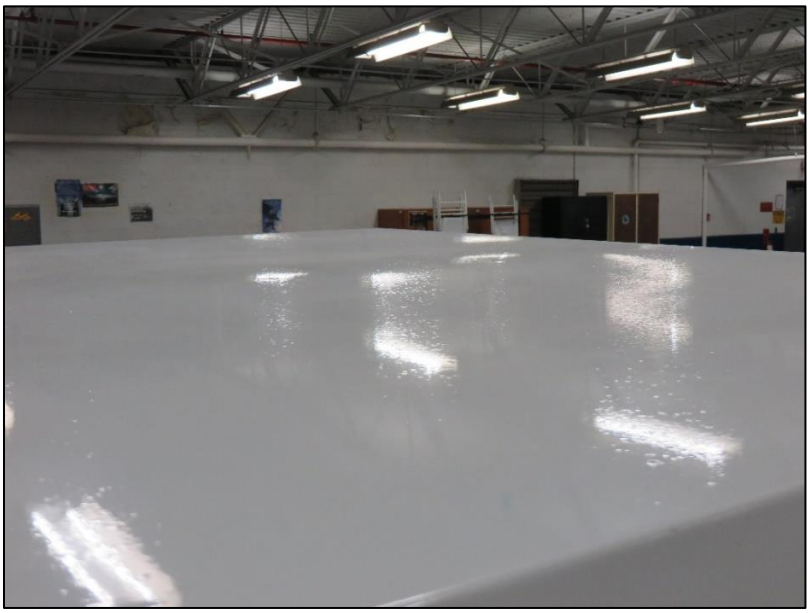


Figure 44 — Roof of cab on MRTT before being placed into service.

Figure 45 — Back, top area of cab on MRTT before being placed into service.

Figure 46 — Front, right side of MRTT before being placed into service.

Figure 47 — Rear of MRTT before being placed into service.

Figure 48 — Door of MRTT before being placed into service.

Initial color and gloss measurements of the topcoats were recorded using a HunterLab MiniScan EZ 4000L Diffuse (spherical) Spectrophotometer and a Byk-Gardner Micro-Tri-Gloss meter, respectively. Color and 60 degree gloss measurements were recorded on the hood, chassis, doors, roof of the cab, and the back, top area of the cab. For each area a minimum of 6 measurements were recorded, and the values are shown in Tables 27-31. Although the 2K polysiloxane topcoat was visually high in gloss, the waviness of the steel substrate on the hood and chassis resulted in recorded gloss values below 90 GU. It should also be noted that dirt/soot was present on the MRTT during measurements, which caused deviations in initial color and gloss values.

Table 27 — Initial color and gloss of 2K gloss white polysiloxane topcoat on hood of MRTT.

	Color			**Gloss (60° angle)**
Measurement #	**L**	**a**	**b**	**Gloss Unit (GU)**
1	92.15	-0.37	2.79	70.3
2	92.68	-0.54	3.02	69.0
3	91.47	-0.33	2.32	70.2
4	91.69	-0.27	2.57	74.4
5	91.40	-0.37	2.20	69.5
6	92.20	-0.94	2.64	76.3
Avg.	**91.93**	**-0.47**	**2.59**	**71.6**

Table 28 — Initial color and gloss of 2K gloss white polysiloxane topcoat on chassis of MRTT.

	Color			**Gloss (60° angle)**
Measurement #	**L**	**a**	**b**	**Gloss Unit (GU)**
1	94.82	-0.66	0.39	44.8
2	90.42	-0.45	1.59	86.1
3	90.67	-0.28	0.82	78.9
4	92.06	-1.33	1.66	68.2
5	91.76	-0.91	2.21	40.4
6	93.15	-1.47	2.37	69.6
7	92.74	-1.44	1.94	55.8
8	92.17	-1.40	1.75	37.3
9	92.15	-1.38	1.63	88.5
10	92.84	-1.40	2.08	72.6
11	91.82	-1.42	2.50	48.0
12	92.13	-1.37	1.83	62.0
Avg.	**92.23**	**-1.13**	**1.73**	**62.7**

Table 29 — Initial color and gloss of 2K gloss white polysiloxane topcoat on roof of MRTT.

	Color			**Gloss (60° angle)**
Measurement #	**L**	**a**	**b**	**Gloss Unit (GU)**
1	93.98	-1.49	2.96	80.4
2	94.20	-1.50	3.26	80.8
3	94.27	-1.49	3.17	79.6
4	94.34	-1.52	3.46	82.7
5	94.45	-1.54	3.42	83.5
6	94.45	-1.52	3.33	80.7
7	94.23	-1.54	3.38	79.4
8	94.01	-1.50	3.01	85.5
9	94.24	-1.53	3.09	80.3
Avg.	**94.24**	**-1.51**	**3.23**	**81.4**

Table 30 — Initial color and gloss of 2K gloss white polysiloxane topcoat on back, top area of cab on MRTT.

	Color			**Gloss (60° angle)**
Measurement #	**L**	**a**	**b**	**Gloss Unit (GU)**
1	92.70	-1.48	2.08	93.0
2	92.59	-1.47	2.03	93.4
3	93.22	-1.56	2.21	91.5
4	92.85	-1.58	2.41	86.2
5	93.92	-1.58	3.10	92.6
6	93.37	-1.50	2.38	89.7
Avg.	**93.11**	**-1.53**	**2.37**	**91.1**

Table 31 — Initial color and gloss of MIL-PRF-85285, Type II qualified 2K gloss white polyurethane topcoat control on doors of MRTT.

	Color			**Gloss (60° angle)**
Measurement #	**L**	**a**	**b**	**Gloss Unit (GU)**
1	94.71	-1.68	2.61	90.5
2	94.36	-1.64	2.39	91.9
3	94.28	-1.63	2.20	86.7
4	93.24	-1.56	1.27	91.1
5	94.93	-1.68	2.84	92.2
6	93.99	-1.62	1.82	91.1
7	94.39	-1.66	2.26	89.1
8	94.94	-1.67	2.93	88.6
9	92.99	-1.49	1.05	92.0
10	94.68	-1.70	2.59	94.0
Avg.	**94.25**	**-1.63**	**2.19**	**90.7**

After the initial color and gloss values were recorded the MRTT was sent to the flight line at NAS Oceana and utilized for service (i.e., pulling aircraft to/from hangers) in a typical operating fashion.

7.1.2.2 *Inspection of MRTT after 3 Months of Service – June 2017*

The 2K gloss white polysiloxane topcoat was inspected at the 3-month (June 2017) period and the coating was in excellent condition. Color and gloss values were recorded. However, it was determined that 3 months of field service was not sufficient to validate the performance of the topcoat. Thus, data from the 3 month period was not reported.

7.1.2.3 Inspection of MRTT after 6 Months of Service – September 2017

A 6-month inspection of the 2K gloss white polysiloxane topcoat on the MRTT was performed by NRL on September 26, 2017 at NAS Oceana. The topcoat was in excellent condition, still appearing glossy and white in color, and service personnel could not visually determine the difference between the 2K polysiloxane topcoat on the majority of the asset and the 2K polyurethane topcoat control on the doors. Minor corrosion was observed between the seal of the cab and chassis, in addition to the crevices and edges of the chassis where the coating system was applied too thin (figure 49a). Tie-downs painted with the 2K polysiloxane also showed minor amounts of corrosion, although loss of the coating system can be attributed to mechanical abrasion (figure 49b). Facial corrosion was not observed on any flat surfaces painted with the 2K polysiloxane topcoat. Based on feedback from active duty personnel, the 2K polysiloxane appeared to be more corrosion, chip, and abrasion-resistant than the 2K polyurethane topcoat on other MRTTs.

A **B**

Figure 49 — 2K gloss white polysiloxane topcoat showing: a) minor crevice corrosion and b) minor loss of topcoat on tie-down (due to abrasion) after 6-months of field service.

The topcoats on the MRTT were cleaned with warm water and rags, followed by air-drying before photographing and collecting color and gloss values. A significant amount of dirt was removed during this process as shown in figure 50. Once dry, the MRTT was photographed from several angles to document appearance (figures 51-55).

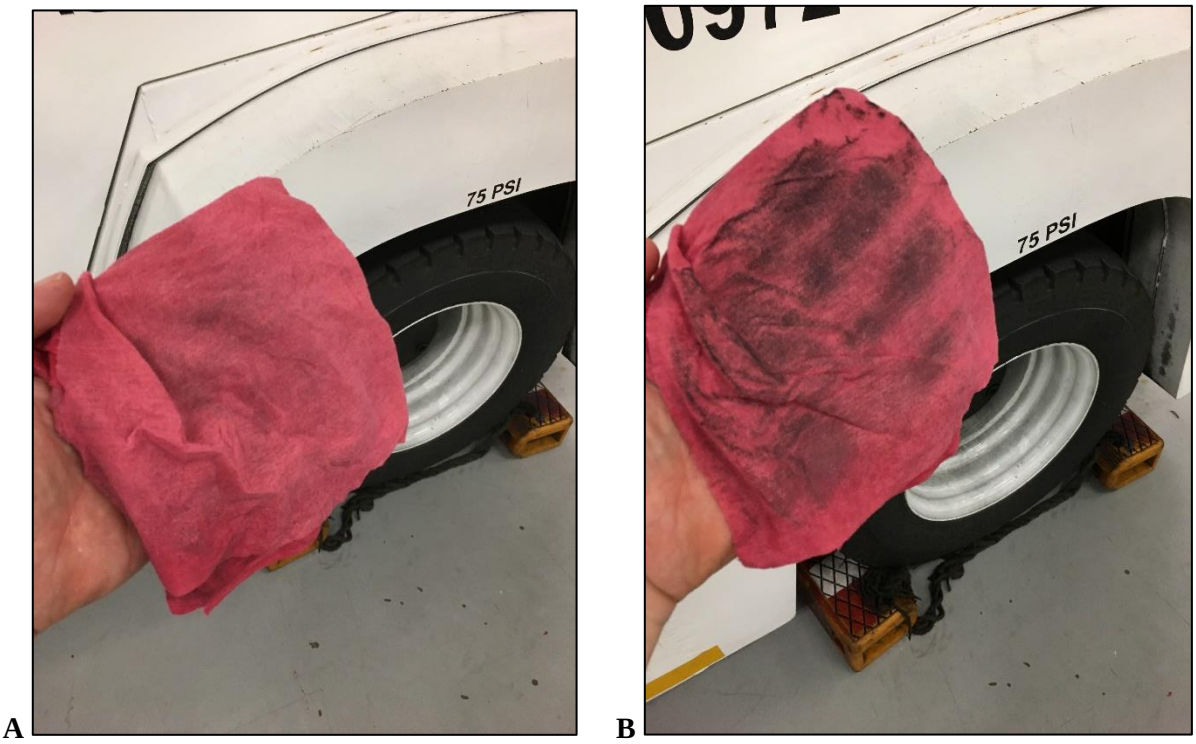


Figure 50 — a) Wet rag before wiping and b) wet rag after wiping the chassis of the MRTT.

Figure 51 — Left side of MRTT after 6-months of field service.

Figure 52 — Right side of MRTT after 6-months of field service.

Figure 53 — Hood of MRTT after 6-months of field service.

Figure 54 — Back, top area of cab on MRTT after 6-months of field service.

A **B**

Figure 55 — MIL-PRF-85285, Type II qualified 2K polyurethane on a) left door and b) right door of MRTT after 6-months of field service.

Color and gloss values were recorded using the same instruments that were utilized to record the initial values in March of 2017. Measurements were recorded on the hood, chassis, roof of cab, the back, top area of the cab, and on the doors. All measurements were recorded in approximately the same location (i.e., within a few inches) as the previous measurements. The spherical L,a,b color values and 60 degree gloss values are reported in Tables 32-36.

Table 32 — Color and gloss values of 2K gloss white polysiloxane topcoat on hood of MRTT after 6-months of service.

	Color			**Gloss (60° angle)**
Measurement #	**L**	**a**	**b**	**Gloss Unit (GU)**
1	91.00	-0.75	3.72	57.8
2	89.38	-0.64	3.10	55.9
3	90.57	-0.72	3.95	59.9
4	91.64	-0.86	3.14	59.6
5	91.85	-0.90	3.37	65.2
6	91.54	-0.94	3.01	61.2
Avg.	**91.00**	**-0.80**	**3.38**	**59.9**

Table 33 — Color and gloss values of 2K gloss white polysiloxane topcoat on chassis of MRTT after 6-months of service.

	Color			**Gloss (60° angle)**
Measurement #	**L**	**a**	**b**	**Gloss Unit**
1	92.64	-1.37	2.51	82.1
2	91.84	-1.35	2.32	80.8
3	93.06	-1.45	3.24	81.1
4	92.95	-1.41	3.39	74.0
5	92.71	-1.37	3.00	82.9
6	91.84	-1.31	2.39	82.5
7	92.27	-1.35	2.54	88.1
8	92.44	-1.36	2.77	82.8
9	91.22	-1.31	3.24	77.9
10	91.96	-1.31	2.93	81.1
11	91.87	-1.29	2.67	82.8
12	92.25	-1.34	2.46	80.8
Avg.	**92.25**	**-1.35**	**2.79**	**81.4**

Table 34 — Color and gloss values of 2K gloss white polysiloxane topcoat on roof of MRTT after 6-months of service.

	Color			**Gloss (60° angle)**
Measurement #	**L**	**a**	**b**	**Gloss Unit**
1	94.18	-1.44	3.94	—
2	94.08	-1.44	4.14	—
3	93.73	-1.48	4.11	—
4	93.97	-1.42	4.27	79.0
5	93.36	-1.43	3.78	76.6
6	93.30	-1.44	3.72	82.1
7	94.07	-1.42	3.93	79.7
8	94.02	-1.42	4.10	78.5
9	93.90	-1.41	4.06	79.9
Avg.	**93.85**	**-1.43**	**4.01**	**79.3**

Table 35 — Color and gloss values of 2K gloss white polysiloxane topcoat on back, top area of cab on MRTT after 6-months of service.

	Color			**Gloss (60° angle)**
Measurement #	**L**	**a**	**b**	**Gloss Unit**
1	93.23	-1.45	3.37	88.6
2	92.64	-1.42	3.03	88.8
3	93.67	-1.47	3.70	86.1
4	93.07	-1.46	3.25	87.3
5	92.76	-1.45	3.11	88.6
6	92.50	-1.42	2.92	84.4
Avg.	**92.98**	**-1.45**	**3.23**	**87.3**

Table 36 — Color and gloss values of 2K gloss white polysiloxane topcoat on back, top area of cab on MRTT after 6-months of service.

	Color			**Gloss (60° angle)**
Measurement #	**L**	**a**	**b**	**Gloss Unit**
1	94.43	-1.63	3.47	78.0
2	94.24	-1.61	3.44	81.8
3	93.79	-1.59	2.96	87.3
4	93.63	-1.61	2.84	84.1
5	93.38	-1.57	2.88	82.2
6	93.43	-1.60	2.27	75.4
7	93.76	-1.61	3.37	86.8
8	94.19	-1.67	2.96	76.5
9	94.59	-1.67	3.55	87.1
10	93.25	-1.56	2.34	88.2
Avg.	**93.87**	**-1.61**	**3.01**	**82.7**

Table 37 — Average color and gloss change of topcoats on MRTT after 6-months of service.

Area of MRTT	ΔL	Δa	Δb	ΔE	Δ Gloss
Hood	0.93	0.33	-0.79	**1.26**	**-16.30%**
Chassis	-0.02	0.22	-1.06	**1.08**	**+29.80%**
Roof of cab	0.39	-0.08	-0.78	**0.88**	**-2.60%**
Back, top area of cab	0.13	-0.08	-0.86	**0.87**	**-4.10%**
Doors	0.38	-0.02	-0.82	**0.90**	**-8.80%**

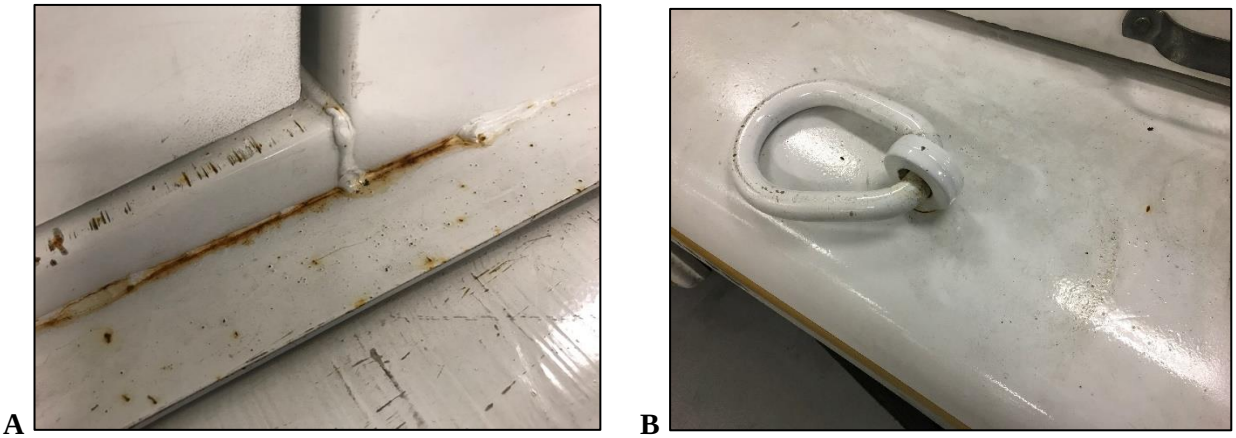
As is shown in Table 37, the color change of the topcoats on each area on the MRTT was calculated in accordance with Section 5.2.3.3 after 6-months of service. As the data shows, the 2K gloss white polysiloxane on the roof and back, top area of the cab had color change values of 0.88 and 0.87, respectively, compared to 0.90 for the MIL-PRF-85285, Type II qualified polyurethane topcoats on the door. The color change for the 2K polysiloxane on the hood and chassis of the MRTT were slightly greater at 1.26 and 1.08, respectively. This proves that the isocyanate-free 2K polysiloxane topcoat performed equivalent to the qualified isocyanate-containing 2K polyurethane topcoat. The color change of 1.26 for the 2K polysiloxane on the hood was the largest for any area. However, it was difficult to determine the extent of contamination and degree of color change, as wiping with water and rags did not remove all surface contaminants. Furthermore, the hood and roof are horizontal areas that were constantly bombarded with UV-radiation from sunlight, whereas vertical areas, such as the doors, were shaded at times depending on the direction of sunlight. As a result, one would expect the horizontal surfaces to degrade faster and have larger color change values. It is worth mentioning that a $\Delta E \leq 1.0$ is imperceptible to the human eye, and a ΔE of 1.0-2.0 is barely perceptible, even with a highly trained eye.[59,60]

The gloss change (Δ Gloss) of the 2K polysiloxane and 2K polyurethane topcoats after 6-months of service was calculated using the difference between the average initial and 6-month values, dividing by the initial value, then multiplying by 100 (Table 37). The gloss loss of the 2K polysiloxane topcoat on the hood was 16.3%, whereas the gloss on the chassis increased by 29.8%. The former is likely due to minor contamination remaining on the surface after cleaning, whereas the latter is likely the result of recording the gloss values in areas where the substrate was smoother and of higher gloss. However, the gloss loss of the 2K polysiloxane topcoat on the roof of the cab and the back, top area of the cab were only 2.6% and 4.1%, respectively, whereas the gloss loss for the 2K polyurethane topcoat on the doors was 8.8%. This shows that areas of the MRTT with minor contamination resulted in a smaller reduction in gloss and slightly better gloss retention than the control.

7.1.2.4 Inspection of Topcoats on MRTT after 12 Months of Service – March 2018

The 12-month inspection of the 2K gloss white polysiloxane topcoat on the MRTT at NAS Oceana was performed by NRL on March 6, 2018. The topcoat was in excellent condition, still appearing glossy and white in color, and service personnel could not visually determine the difference between the 2K polysiloxane topcoat (on the majority of the asset) and the 2K polyurethane topcoat on the doors. Minor corrosion was observed between the seal of the cab and chassis, edges of the chassis where the coating system was applied too thin, and on the roof of the cab (figure 56a). Corrosion was also found on the tie-downs, although this was primarily attributed to mechanical abrasion during service activities. However, it was noted that corrosion and cracking was not present in areas where the tie-downs contacted the chassis (figure 56b), which was noted as an improvement compared to MRTTs painted with a 2K gloss white polyurethane topcoat. Based on feedback from service personnel the 2K polysiloxane topcoat was more

corrosion, chip, and abrasion-resistant than the MIL-PRF-85285, Type II qualified 2K polyurethane on other MRTTs.



A **B**

Figure 56 — MRTT after 12-months of field service showing: a) crevice corrosion along edge of cab and b) no cracking, chipping or corrosion on areas around tie-down on chassis.

The topcoats on the MRTT were cleaned with water and rags, followed by air-drying, before photographing and collecting color and gloss values. A significant amount of dirt was removed during the process, especially on the horizontal surfaces. Once dry, the MRTT was photographed from several angles to document appearance of the 2K gloss white polysiloxane and 2K gloss white polyurethane topcoats (figures 57-62).

Figure 57 — Left side of MRTT after 12-months of field service.

Figure 58 — Right side of MRTT after 12-months of field service.

Figure 59 — Right side of MRTT after 12-months of field service.

Figure 60 — Back, top area of cab on MRTT after 12-months of field service.

A **B**

Figure 61 — MIL-PRF-85285, Type II qualified 2K polyurethane topcoat on a) left door and b) right door of MRTT after 12-months of field service.

Figure 62 — Rear of cab and chassis on MRTT after 12-months of field service.

Color and gloss values were recorded using the same instruments that were utilized during the initial and 6-month inspections. Measurements were recorded on the hood, chassis, roof of cab, the back, top area of the cab, and on the doors. All measurements were recorded in approximately the same location (i.e., within a few inches) as previous measurements, then averaged. The spherical L,a,b color values and 60 degree gloss values are reported in Tables 38-42.

Table 38 — Color and gloss values of 2K gloss white polysiloxane topcoat on hood of MRTT after 12-months of service.

	Color			**Gloss (60° angle)**
Measurement #	**L**	**a**	**b**	**Gloss Unit**
1	89.34	-0.69	4.01	54.2
2	89.43	-0.70	4.18	55.2
3	89.61	-0.76	3.66	54.3
4	89.48	-0.81	3.56	57.3
5	90.14	-0.79	4.42	56.7
6	89.94	-0.73	3.98	55.8
Avg.	**89.66**	**-0.75**	**3.97**	**55.6**

Table 39 — Color and gloss values of 2K gloss white polysiloxane topcoat on chassis (left and right sides) of MRTT after 12-months of service.

	Color			**Gloss (60° angle)**
Measurement #	**L**	**a**	**b**	**Gloss Unit**
1	92.19	-1.33	3.15	81.7
2	91.03	-1.22	3.07	81.5
3	92.33	-1.33	3.07	77.3
4	92.29	-1.37	2.82	82.7
5	91.84	-1.3	2.75	87.3
6	92.76	-1.43	3.63	73.3
7	91.53	-1.29	2.62	78.1
8	93.15	-1.41	3.39	66.4
9	92.19	-1.31	3.07	62.7
10	90.63	-1.20	3.12	65.5
Avg.	**92.14**	**-1.33**	**3.04**	**75.6**

Table 40 — Color and gloss values of 2K gloss white polysiloxane topcoat on roof of MRTT after 12-months of service.

	Color			**Gloss (60° angle)**
Measurement #	**L**	**a**	**b**	**Gloss Unit**
1	93.08	-1.41	4.64	-
2	93.19	-1.44	4.24	-
3	93.65	-1.43	4.67	-
4	94.18	-1.49	4.30	72.2
5	94.02	-1.54	4.02	75.9
6	93.65	-1.48	3.87	72.6
7	93.37	-1.46	4.34	77.8
8	93.41	-1.47	3.94	71.8
9	93.16	-1.45	4.27	72.6
Avg.	**93.52**	**-1.46**	**4.25**	**73.8**

Table 41 — Color and gloss values of 2K gloss white polysiloxane topcoat on back, top area of cab on MRTT after 12-months of service.

	Color			**Gloss (60° angle)**
Measurement #	**L**	**a**	**b**	**Gloss Unit**
1	92.67	-1.41	2.52	85.4
2	92.84	-1.47	2.74	85.8
3	93.33	-1.47	2.87	83.7
4	93.46	-1.47	2.97	86.5
5	93.30	-1.47	2.96	83.5
6	93.47	-1.48	2.97	83.7
Avg.	**93.18**	**-1.46**	**2.84**	**84.8**

Table 42 — Color and gloss values of 2K gloss white polyurethane topcoat control on doors (left and right sides) of MRTT after 12-months of service.

	Color			**Gloss (60° angle)**
Measurement #	**L**	**a**	**b**	**Gloss Unit**
1	93.30	-1.53	3.52	77.6
2	93.70	-1.55	3.65	85.4
3	93.39	-1.55	3.51	86.0
4	94.12	-1.60	3.47	78.0
5	93.28	-1.54	3.17	83.9
6	93.58	-1.60	3.26	86.7
7	93.77	-1.57	3.39	85.9
8	93.57	-1.58	3.52	82.5
9	93.63	-1.57	3.88	74.4
10	93.62	-1.56	3.43	77.7
Avg.	**93.59**	**-1.56**	**3.48**	**81.8**

Table 43 — Average color and gloss change for topcoats on MRTT after 12-months of service.

Area of MRTT	**ΔL**	**Δa**	**Δb**	**ΔE**	**Δ Gloss**
Hood	-2.27	0.28	-1.38	**2.67**	**-22.35%**
Chassis	0.09	0.20	-1.31	**1.33**	**+20.60%**
Roof of cab	0.72	-0.05	-1.02	**1.25**	**-9.37%**
Back, top area of cab	-0.07	-0.07	-0.47	**0.48**	**-6.87%**
Doors	0.66	-0.07	-1.29	**1.45**	**-9.83%**

The color change for each area on the MRTT was calculated according to Section 5.2.3.3 using initial and 12-month inspection values. As Table 43 shows, the average color change for the 2K gloss white polysiloxane topcoat on the hood, chassis, and cab ranged from 0.48-2.67, whereas the average color change of the MIL-PRF-85285, Type II qualified 2K gloss white polyurethane topcoat on the doors was 1.45. The results show that the 2K polysiloxane topcoat performed extremely well compared to the 2K polyurethane control. The color change of 2.67 for the 2K polysiloxane on the hood was the largest for any area, although it is likely that cleaning with water and rags resulted in incomplete removal of contaminants from the wavy surface because the L-values were less positive (i.e., darker) at 12-months than the initial values. However, the average color change for the 2K gloss white polysiloxane on the chassis and cab roof were 1.33 and 1.25, respectively, which were slightly less than the average color change of 1.45 for the 2K polyurethane topcoat on the doors. The best performing area was the back, top area of the cab. This area of 2K gloss white polysiloxane topcoat demonstrated a color change of only 0.48 after 12-months, which was about 1.0 unit less than the control on the doors. This area was also smoother than other areas on the MRTT.

The gloss change of the 2K polysiloxane and 2K polyurethane topcoats after 12-months of service were calculated using the difference between the average initial and average 12-month values, dividing by the initial value, then multiplying by 100 (Table 43). The gloss loss of the 2K polysiloxane topcoat on the hood was 22.35%, whereas the gloss on the chassis increased by 20.6% compared to its original value. The former is likely due to minor contamination remaining on the surface after cleaning, in addition to a non-smooth surface, whereas the latter likely resulted from recording the gloss values in areas where the substrate was smoother and of higher gloss. However, the gloss loss of the 2K polysiloxane topcoat on the

roof of the cab and back, top area of the cab were 9.37% and 6.87%, respectively, whereas the gloss loss of the 2K polyurethane topcoat on the doors was 9.83%. This shows that smoother surfaces painted with the 2K polysiloxane topcoat demonstrated less degradation, and thus greater performance, when compared to the control.

7.1.2.5 Discussion

The 2K gloss white polysiloxane topcoat is isocyanate-free, HAP-free, and possesses only 65 g/l (0.54 lb/gal) VOCs. About two gallons of the topcoat were used to paint the entire MRTT at NAS Oceana, which equates to 1.08 pounds of VOCs released into the air. The MIL-PRF-85285, Type II polyurethane used on the doors possessed 336 g/l (2.8 lb/gal) VOCs, although this topcoat was applied on the majority of MRTTs at Oceana. Assuming 2 gallons of each topcoat are required to paint an entire MRTT the difference in VOCs by applying the 2K polysiloxane topcoat is 4.52 pounds, which meets the success criteria in Table 10 for VOC reductions.

After 12-months of service the 2K gloss white polysiloxane topcoat on the MRTT remained in good condition. The topcoat showed no signs of cracking, delamination, blistering, discoloration due to heat, or discoloration due to fluids, and corrosion was only observed on edges and welds that were poorly coated. Active service members stated that the 2K polysiloxane topcoat appeared to be more corrosion, abrasion, and chip resistant than MRTTs painted with a Type II 2K polyurethane topcoat, thereby exceeding the success criteria in Table 9. Aside from the hood on the MRTT, which was highly contaminated, all color change values for the 2K gloss white polysiloxane topcoat were less than those for the MIL-PRF-85285, Type II qualified 2K gloss white polyurethane topcoat on the doors, thereby exceeding the success criteria for in-service weatherability (quantitative) in Table 10. Furthermore, all smooth areas (i.e., back, top section of cab, roof of cab) painted with the 2K gloss white polysiloxane topcoat demonstrated similar or better gloss retention than the Type II 2K polyurethane topcoat on the doors, again exceed the performance criteria in Table 10.

These results validate that the 2K gloss white polysiloxane topcoat can provide better field performance than a MIL-PRF-85285, Type II qualified 2K gloss white polyurethane topcoat. Better performance can result in improved service life for assets, reduced maintenance painting, and hence a cost savings for the Navy. The 2K polysiloxane topcoat is also more environmentally friendly and can potentially eliminate inhalation and dermal health issues due to a lack of harmful isocyanates, the presence of zero HAPs, and a substantial reduction in VOC emissions.

7.2 Demonstration of 1K Camouflage Gray Polysiloxane Topcoats on AH-1Z Vipers

In 2019, the single-component (1K) camouflage gray polysiloxane topcoat, in FED-STD-595 #36375 medium gray and #35237 blue-gray colors, was produced in multi-gallon quantities by NCP Coatings for application on the entire exterior of three Bell AH-1Z Viper helicopters stationed at Marine Corps Base Camp Pendleton, California. The first application occurred in early March on the aircraft with Bureau Number (BUNO), or tail number, 168798, whereas aircraft with BUNOs 168399 and 168052 were painted in early April and mid-May, respectively. All three AH-1Z aircraft were painted inside a temperature and humidity controlled paint booth in Building 23104, Hangar 1A. The aircraft were then provided to squadrons for use in the field under normal operating conditions, and periodic inspections of the topcoats occurred for up to 25-months.

7.2.1 AH-1Z BUNO 168798 – March 2019

7.2.1.1 Preparation and Painting of BUNO 168798

This aircraft was prepared for painting by first removing the aged polyurethane topcoat and anti-corrosive epoxy primer from the aluminum alloy skin and composite materials (figure 63). This was accomplished using plastic media blast and hand sanding according to NAVAIR established procedures. Once the coatings were removed the aluminum alloy skin was treated with an Alodine 1200 marker, which is a chromate conversion solution that is qualified to MIL-PRF-81706.[37] This was followed by spray-application of PPG/Deft 44GN008A, which is a MIL-PRF-85582, Type II, Class 1 hexavalent chromium based waterborne epoxy primer with low infrared reflective pigments.[36] The primer was spray-applied by artisans using portable pressure-pots at 71 °F and 58% relative humidity to achieve a DFT of 0.6-0.9 mils (figure 64). After two hours the primer had dried to a dark green color as shown in Figure 65. Approximately 2 hours and 15 minutes after the primer was applied the artisans began spraying the medium gray (#36375) colored 1K polysiloxane topcoat (NCP Batch #20-32-1, Date of Manufacture (DoM) 12/2018) using two portable pressure pots. Each pot was connected to a Binks Trophy Series HVLP spray gun with a 1.8 mm fluid tip. The pressures at the wall, inside the pots, and at the gun nozzles were 40-50 psi, 18-20 psi, and 10-12 psi, respectively. The temperature inside the spray booth was 74-75 °F with a relative humidity of 48-56%. Figure 66 shows an artisan spraying the 1K camouflage gray polysiloxane topcoat on the right fuselage of bureau number (BUNO) 168798, whereas Figure 67 shows the left tail boom of the aircraft being painted. The majority of the aircraft, except for the rotor housing, the upper surface of the wings and horizontal stabilizers, the area above the engine nacelles, and the horizontal section of the nose, was painted with the medium gray 1K polysiloxane topcoat. The entire application required 90 minutes and consumed about 3.5 gallon of topcoat. Figure 68 shows the aircraft once application of the medium gray 1K polysiloxane topcoat had finished.

Figure 63 — Prepared surface of BUNO 168798.

Figure 64 — Spray-application of MIL-PRF-85582, Type II primer on BUNO 168798.

Figure 65 — Dark green color of MIL-PRF-85582, Type II epoxy primer on BUNO 168798 after two hours of drying.

Figure 66 — Spray application of medium gray 1K polysiloxane topcoat on right fuselage of BUNO 168798.

Figure 67 — Spray application of medium gray 1K polysiloxane topcoat on left tail boom of BUNO 168798.

Figure 68 — Finished spray application of medium gray 1K polysiloxane topcoat on majority of BUNO 168798.

Once painting had ceased, the two portable pressure pots were opened and the remainder of the medium gray 1K polysiloxane topcoat was poured back into the original cans and sealed (figure 69). The hose from each pressure pot to the spray gun was then flushed with solvent for cleaning. Currently, this action cannot be achieved using MIL-PRF-85285 qualified 2K polyurethane topcoats because unused material will solidify within a few hours and must be discarded as hazardous waste. Thus, this demonstrated that near zero hazardous waste can be generated by painting an aircraft with the 1K polysiloxane topcoat.

Figure 69 — Recovery of unused medium gray 1K polysiloxane topcoat from pressure pot.

The following day, the medium gray colored areas of the aircraft were stenciled using the blue gray (#35237) colored 1K polysiloxane topcoat (NCP Batch #20-33-1, DoM 02/2019). This action was performed using vinyl stencils that adhered to the medium gray topcoat, followed by spray-application of the blue gray 1K polysiloxane using gravity feed cup guns with a 1.2 mm fluid tip. Figure 70 shows several markings that were stenciled onto the right fuselage using the blue gray 1K topcoat. A stencil showing the coating system and date were also applied on the right AFT section of the tail boom as shown in Figure 71. After the blue gray 1K polysiloxane topcoat had dried the vinyl stencils were removed via peeling. None of the underlying medium gray topcoat was removed during peeling of the vinyl stencils, and no marring to the topcoat was observed, thus demonstrating that sufficient curing/cross-linking of the polysiloxane topcoat had occurred. After stenciling of the medium gray 1K topcoat on the rotor housing, the upper surface of the wings, horizontal stabilizers, area above the engine nacelles, and horizontal area of the nose were painted with the blue gray 1K polysiloxane topcoat. Painting of these remaining areas required approximately 70 minutes and consumed about 1.5 gallon of blue gray 1K polysiloxane topcoat.

Two days after painting began the blue gray colored sections of the aircraft were stenciled using the medium gray colored 1K polysiloxane topcoat that was recovered from the two pressure pots, and zero issues were encountered when applying this paint via the gravity feed guns. After the paint had dried the vinyl stencils were removed via peeling with no marring to the topcoat or loss of adhesion to the primer.

Figure 72 shows BUNO 168798 in the squadron hanger one week after the entire exterior was painted with NCP's 1K camouflage gray polysiloxane topcoat.

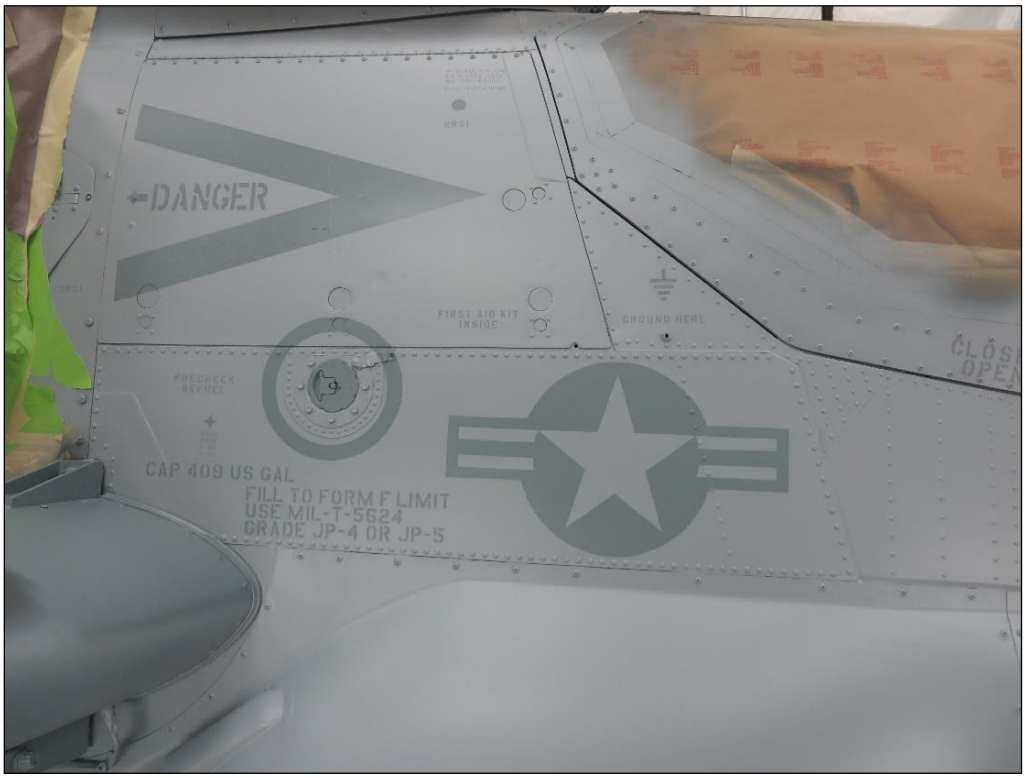


Figure 70 — Markings on BUNO 168798 applied via stenciling with the blue gray 1K polysiloxane topcoat.

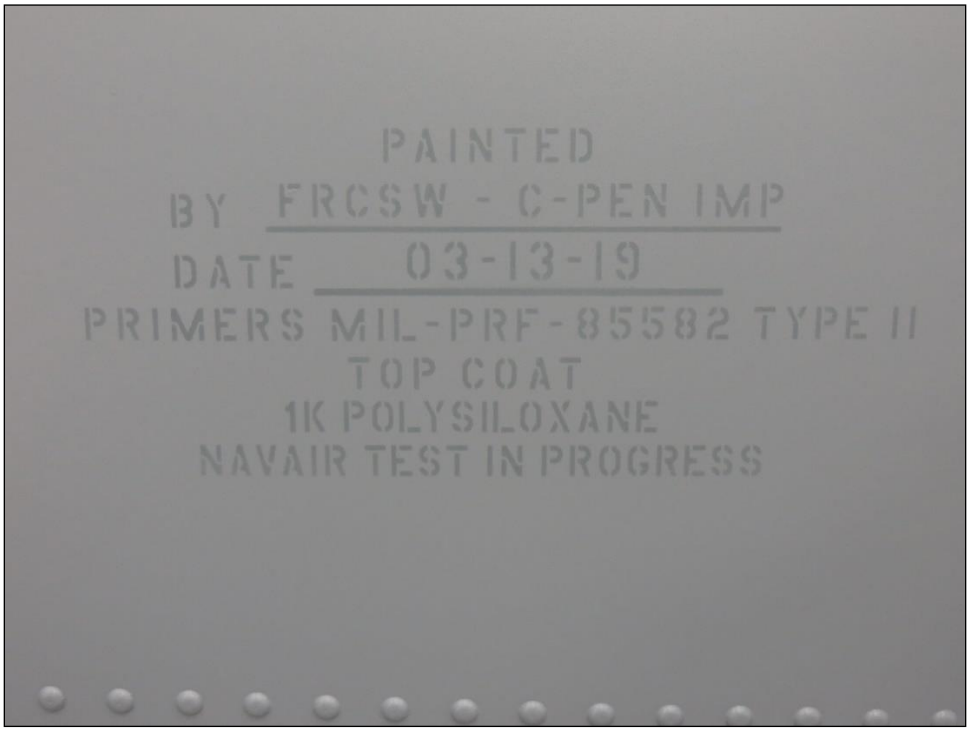


Figure 71 — Stencil of coating system and date on right AFT section of tail boom on BUNO 68798.

Figure 72 — 1K camouflage gray polysiloxane topcoats on exterior of BUNO 168798 after one week.

7.2.1.2 Isocyanate Air Sampling During Painting of BUNO 168798

During the spray-application of the medium gray 1K polysiloxane topcoat on BUNO 168798 a representative from the Camp Pendleton's industrial hygiene office was present to obtain air samples and determine the concentration of airborne isocyanates. This is commonly performed when applying polyurethane topcoats to ensure the PEL of isocyanates are not exceeded during an 8-hour work day (see

Section 1.3). Air samples were collected by attaching air pumps, a hose, and isocyanate collection media to the artisans (figure 66). These air samples were collected during the initial 35 minutes of spraying, followed by extraction and analysis for 1,6-hexamethylene diisocyanate during the following days. The IH report (#42208, 3/20/2019) from Camp Pendleton showed that no isocyanate was detected, which was expected for the isocyanate-free 1K polysiloxane topcoat. Unfortunately, the laboratory did not test for homopolymers of HDI, which are also absent in the polysiloxane topcoat, yet present in qualified 2K polyurethane topcoats. Interestingly, the IH office mentioned that air samples collected from a MIL-PRF-85285 polyurethane topcoat application four months prior showed HDI homopolymer levels of 0.581 mg/m^3, which are above the 8-hour PEL of 0.5 mg/m^3.

7.2.1.3 Volume of Topcoats Utilized and Emitted VOCs

The painting of AH-1Z BUNO 168798 required 4 gallon of medium gray and 2 gallons of blue gray 1K polysiloxane topcoat for a total of 6 gallons, which included the entire exterior and stenciling. For comparison, artisans typically use a total of 6 gallons (i.e., 4 gallons of medium gray and 2 gallons of blue gray) of a MIL-PRF-85285 2K polyurethane topcoat to paint the entire exterior of a AH-1Z Viper, in addition to a half quart of medium gray and half quart of blue gray polyurethane topcoat for stenciling, thus equating to 6.25 gallons. At 286 g/l (2.38 lb/gal) VOC content the 1K polysiloxane topcoats emitted 14.28 pounds of volatiles, whereas a 2K polyurethane, which has a VOC content of 420 g/l (3.50 lb/gal), would emit 21.87 pounds of volatiles. Thus, not only was less paint consumed by painting the aircraft with the 1K polysiloxane topcoat, but 7.59 pounds less VOCs were emitted into the air in comparison to a typical polyurethane topcoat application.

7.2.1.4 Collection of Initial Metrics on BUNO 168798

Initial DFT, gloss, and color values for the 1K polysiloxane topcoats were recorded the day following stenciling with the medium gray topcoat. Typically, topcoats are allowed to cure for a minimal of 14 days before initial metrics are collected, but due to time limitations it was determined that metrics be collected as soon as possible so the aircraft could be returned to the squadron. DFT values were recorded in mils (1 mil = 25.4 microns) with a DeFelsko PosiTest coating thickness gauge for non-ferrous metals, gloss units at 60 and 85 degree angles were recorded with a Byk-Gardner micro-TRI gloss meter, and color values in CIELAB (L*, a*, b*) color space coordinates were recorded with a Hunter Lab Mini-scan D65/10° spherical meter. As shown in Figure 73, metrics were collected from numerous areas on the aircraft, which include the nose, forward (FWD) and rear (AFT) sections below the cockpit, fuselage, engine nacelles, top and sides of tail boom, and top of horizontal stabilizers. Metrics were collected on both the left and right side (i.e., pilot's view) of the aircraft, and three to five measurements were collected from each location, followed by averaging the values.

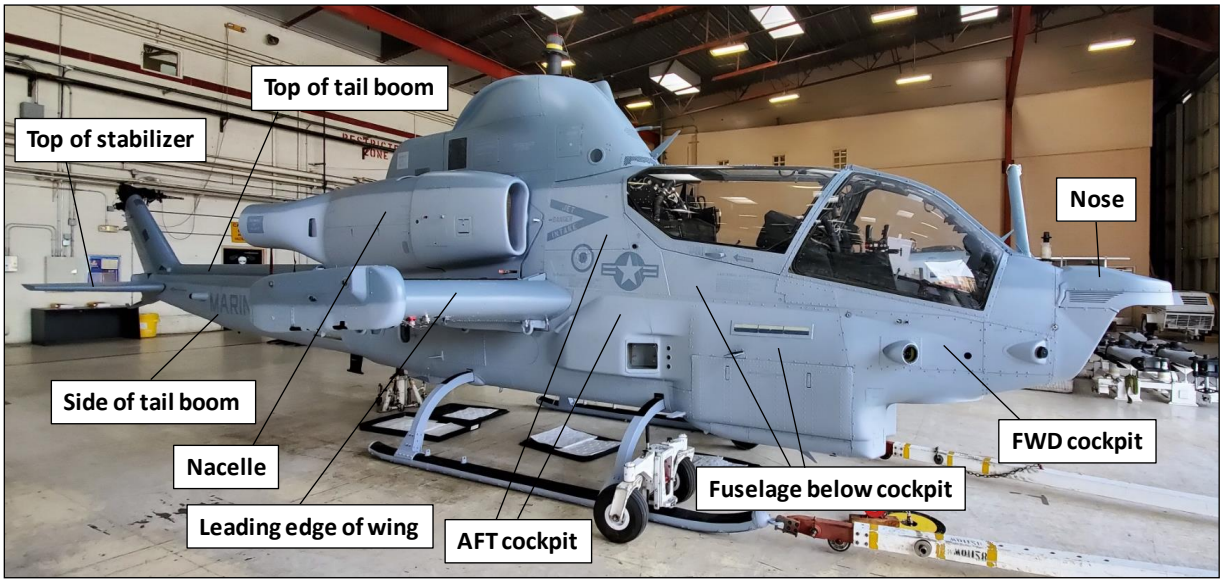


Figure 73 — Locations of topcoat metrics collection on BUNO 168798.

As shown in Tables 44 and 45, the average left and right side DFT values for the medium gray and blue gray 1K polysiloxane topcoats ranged from 2.69-3.29 mils and 2.58-3.11 mils, respectively. These values account for the primer, which was purportedly applied at 0.60-0.90 mils, thus yielding a 1K polysiloxane topcoat thicknesses in the range of 1.90-2.70 mils. However, these values were recorded one-to-two days following topcoat applications, thus the thickness of the system (i.e., primer and topcoat) was expected to decrease slightly as the coatings continued to cure during subsequent days. DFT values on the nose and nacelles could not be obtained because they were composite materials.

Table 44 — Initial average DFT values of medium gray 1K polysiloxane topcoat on BUNO 168798.

Location	Left side, DFT (mils)	Right side, DFT (mils)
FWD Cockpit	3.97	2.13
Fuselage Below Cockpit	3.33	3.20
AFT Cockpit	3.05	2.95
Nacelle	N/A	N/A
Side of Tail Boom	2.82	2.48
AVG.	**3.29**	**2.69**

Table 45 — Initial average DFT values of blue gray 1K polysiloxane topcoat on BUNO 168798.

Location	Left side, DFT (mils)	Right side, DFT (mils)
Nose	N/A	N/A
Leading edge of wing	3.70	2.80
Top of tail boom	3.03	2.50
Top of stabilizer	2.60	2.45
AVG.	**3.11**	**2.58**

The initial color coordinates for the medium gray and blue gray colored 1K polysiloxane topcoats are shown in Tables 46 and 47. These topcoats visually matched 2K polyurethanes with #36375 and #35237 colors, respectively, and the applicators stated that the polysiloxane topcoat colors blended well at transition points on the aircraft with no signs of delamination or peeling. The colors also appeared homogenous across all areas of the aircraft, and there were zero sags/runs or other unsightly blemishes.

Table 46 — Initial average color values of medium gray 1K polysiloxane topcoat on BUNO 168798.

Location	Left side, color coordinates			Right side, color coordinates		
	L	**a**	**b**	**L**	**a**	**b**
FWD Cockpit	65.69	-2.40	-4.58	65.38	-2.40	-4.56
Fuselage Below Cockpit	65.71	-2.39	-4.60	64.85	-2.39	-4.53
AFT Cockpit	65.69	-2.41	-4.58	65.66	-2.42	-4.53
Nacelle	65.04	-2.36	-4.63	64.89	-2.40	-4.59
Side of Tail Boom	65.51	-2.39	-4.58	65.54	-2.42	-4.54
AVG.	**65.53**	**-2.39**	**-4.59**	**65.26**	**-2.41**	**-4.55**

Table 47 — Initial average color values of blue gray 1K polysiloxane topcoat on BUNO 168798.

Location	Left side, color coordinates			Right side, color coordinates		
	L	**a**	**b**	**L**	**a**	**b**
Nose	56.34	-3.90	-4.64	56.34	-3.90	-4.64
Leading edge of wing	56.38	-3.89	-4.57	56.00	-3.90	-4.59
Top of tail boom	56.19	-3.88	-4.62	56.26	-3.87	-4.59
Top of stabilizer	56.31	-3.91	-4.59	56.38	-3.87	-4.66
AVG.	**56.31**	**-3.90**	**-4.61**	**56.25**	**-3.89**	**-4.62**

The initial gloss values of the medium gray and blue gray 1K polysiloxane topcoats are provided in Tables 48 and 49. Similar to the color, the gloss values were recorded one-to-two days after the topcoats were applied and curing/crosslinking was still occurring. The gloss of the 1K polysiloxane topcoats decrease as they react with atmospheric moisture, thus the gloss values were expected to decrease slightly in subsequent days. The target gloss for camouflage topcoats is ≤5 GU at 60 degrees and ≤10 GU at 85 degrees. On both sides of the aircraft, the average 60 degree gloss values for the medium gray 1K polysiloxane topcoat were slightly greater than specified, whereas the 85 degree values were within range. However, the 60 degree gloss for the forward area of the cockpit and fuselage below the cockpit ranged from 9.10-11.1 GU, which increased the average of all values. These values were likely elevated due to the curvature of these areas and the inability to exclude surrounding light when the gloss meter was pressed onto the topcoat. Average gloss values for the blue gray 1K polysiloxane topcoat ranged from 10.0-10.2 GU at 60 degrees and 14.2-14.7 GU at 85 degrees, which were significantly above the NAVAIR specified values. However, the use of different pigments (i.e., compared to the medium gray topcoat) to form the blue gray color resulted in a slightly slower cure time for the topcoat, which was evident by the minute tackiness of the topcoat the day after application. Similar to the medium gray color, the blue gray 1K polysiloxane topcoat was expected to decrease in gloss as the coating continued to cure during subsequent days.

Table 48 — Initial average gloss values of medium gray 1K polysiloxane topcoat on BUNO 168798.

Location	**Left side, gloss units (GU)**		**Right side, gloss units (GU)**	
	60°	**85°**	**60°**	**85°**
FWD Cockpit	9.50	12.6	11.1	10.2
Fuselage Below Cockpit	9.10	11.9	8.80	11.8
AFT Cockpit	6.80	7.80	8.30	10.5
Nacelle	3.90	3.00	6.70	7.20
Side of Tail Boom	5.70	5.90	6.60	8.00
AVG.	**7.00**	**8.20**	**8.30**	**9.50**

Table 49 — Initial average gloss values of blue gray 1K polysiloxane topcoat on BUNO 168798.

Location	**Left side, gloss units (GU)**		**Right side, gloss units (GU)**	
	60°	**85°**	**60°**	**85°**
Nose	10.1	14.0	10.1	14.0
Leading edge of wing	9.70	14.4	8.90	12.5
Top of tail boom	11.4	17.3	11.7	18.2
Top of stabilizer	9.50	13.1	9.50	12.1
AVG.	**10.2**	**14.7**	**10.0**	**14.2**

7.2.2 AH-1Z BUNO 168399 – April 2019

7.2.2.1 Preparation and Painting of BUNO 168399

Similar to BUNO 168798, this aircraft was prepared for painting by first removing the aged polyurethane topcoat and anti-corrosive epoxy primer from the aluminum alloy skin and composite components via plastic media blast and hand sanding according to NAVAIR established procedures. Once the coatings were removed the aluminum alloy skin was treated with an Alodine 1200 marker to apply the chromate conversion coating, followed by spray-application of PPG/Deft 44GN008A hexavalent chromium based waterborne epoxy primer with low infrared reflective pigments. Approximately 2 hours after the primer was applied the artisans sprayed the medium gray colored 1K polysiloxane topcoat on the majority of the aircraft using a portable pressure pot and Binks Trophy Series HVLP spray gun with 1.8 mm fluid tip. The temperature and relative humidity during application were not recorded by the artisans, although conditions were likely similar to when BUNO 168798 was painted because the same temperature and humidity controlled spray booth was utilized. The following day, the blue gray colored 1K polysiloxane topcoat was applied on the remaining areas of BUNO 168399 using the same spray equipment (figure 74). The aircraft was also stenciled using the medium gray 1K polysiloxane topcoat that was recovered from the pressure pot the day prior. Similar to the painting of BUNO 168798 a total of 6 gallons of 1K camouflage gray polysiloxane topcoats were used to paint the entire aircraft. Photographs of BUNO 168399 approximately 5 weeks after application of the 1K polysiloxane topcoats are shown in Figures 75 and 76.

Figure 74 — BUNO 168399 after stenciling the fuselage with blue gray 1K polysiloxane topcoat.

Figure 75 — Wide view of BUNO 168399 approximately 5 weeks after the 1K polysiloxane topcoats were applied.

Figure 76 — Close-up of BUNO 168399 approximately 5 weeks after the 1K polysiloxane topcoats were applied.

7.2.2.2 Collection of Initial Metrics on BUNO 168399

The initial metrics for BUNO 168399 were collected approximately two weeks after the aircraft was painted with 1K polysiloxane topcoats. Initial DFT values for various areas of the aircraft, which are found in Tables 50 and 51, show the film thickness ranged from 2.37-3.42 mils for the medium gray topcoat and 2.37-3.41 mils for the blue gray 1K polysiloxane topcoat. Assuming an average DFT of 0.75 mils for the anti-corrosive epoxy primer the polysiloxane topcoat thickness was within the target range of 1.70-2.30 mils. DFT values could not be obtained from the nacelles and nose of the aircraft because they are composite materials. As shown in Tables 52 and 53, color values recorded for the medium gray and blue gray 1K topcoats were relatively consistent, suggesting a homogeneous color across the aircraft. This could also be observed visually as shown in Figures 75 and 76. Furthermore, the colors appeared to visually match AH-1Zs on the nearby flight line that were painted with a MIL-PRF-85285 camouflage gray polyurethane topcoat. The average gloss values for areas with medium gray 1K topcoat ranged from 6.08-

6.63 GU at 60 degrees and 4.27-4.65 GU at 85 degrees, with the highest values recorded from the left side fuselage below the cockpit (table 54). This area also had the highest DFT, which explains the slightly elevated gloss values. The average gloss for areas with blue gray 1K topcoat ranged from 9.64-10.7 GU at 60 degrees and 7.39-9.29 GU at 85 degrees, with the highest values attributed to the leading edge of the wings and top of tail boom (table 55). All gloss values at 85 degrees, for both colors, were within the NAVAIR requirement of ≤10 GU. However, the gloss values at 60 degrees, for both colors, remained above the NAVAIR specification of ≤5 GU. These values were expected to decrease slightly as post-application curing occurred within the coatings.

Table 50 — Initial average DFT values of medium gray 1K polysiloxane topcoat on BUNO 168399.

Location	Left side, DFT (mils)	Right side, DFT (mils)
FWD Cockpit	2.90	2.47
Fuselage Below Cockpit	3.42	2.48
AFT Cockpit	2.89	2.51
Nacelle	N/A	N/A
Side of Tail Boom	3.13	2.37
AVG.	**3.08**	**2.46**

Table 51 — Initial average DFT values of medium gray 1K polysiloxane topcoat on BUNO 168399.

Location	Left side, DFT (mils)	Right side, DFT (mils)
Nose	N/A	N/A
Leading edge of wing	2.37	3.41
Top of tail boom	2.67	2.67
Top of stabilizer	2.47	2.66
AVG.	**2.50**	**2.91**

Table 52 — Initial average color values of medium gray 1K polysiloxane topcoat on BUNO 168399.

Location	Left side, color coordinates			Right side, color coordinates		
	L	**a**	**b**	**L**	**a**	**b**
FWD Cockpit	65.09	-2.37	-3.71	65.02	-2.41	-3.79
Fuselage Below Cockpit	65.26	-2.35	-3.58	65.11	-2.38	-3.83
AFT Cockpit	64.63	-2.38	-3.63	64.7	-2.39	-3.73
Nacelle	64.97	-2.36	-3.70	64.81	-2.4	-3.68
Side of Tail Boom	65.28	-2.38	-3.77	65.04	-0.24	-3.81
AVG.	**65.05**	**-2.37**	**-3.68**	**64.94**	**-1.96**	**-3.77**

Table 53 — Initial average color values of blue gray 1K polysiloxane topcoat on BUNO 168399.

Location	**Left side, color coordinates**			**Right side, color coordinates**		
	L	**a**	**b**	**L**	**a**	**b**
Nose	55.53	-3.69	-3.64	N/A	N/A	N/A
Leading edge of wing	55.41	-3.73	-3.63	55.34	-3.76	-3.73
Top of tail boom	55.23	-3.73	-3.73	N/A	N/A	N/A
Top of stabilizer	55.11	-3.81	-3.67	55.19	-3.78	-3.69
AVG.	**55.32**	**-3.74**	**-3.67**	**55.27**	**-3.77**	**-3.71**

Table 54 — Initial average gloss values of medium gray 1K polysiloxane topcoat on BUNO 168399.

Location	**Left side, gloss units (GU)**		**Right side, gloss units (GU)**	
	60°	**85°**	**60°**	**85°**
FWD Cockpit	6.80	4.80	6.20	4.00
Fuselage Below Cockpit	8.07	5.43	6.07	4.37
AFT Cockpit	5.80	3.60	6.40	4.60
Nacelle	5.43	4.33	5.57	4.03
Side of Tail Boom	7.10	5.20	6.20	4.30
AVG.	**6.63**	**4.65**	**6.08**	**4.27**

Table 55 — Initial average gloss values of blue gray 1K polysiloxane topcoat on BUNO 168399.

Location	**Left side, gloss units (GU)**		**Right side, gloss units (GU)**	
	60°	**85°**	**60°**	**85°**
Nose	7.23	4.93	N/A	N/A
Leading edge of wing	10.5	8.00	12.1	10.7
Top of tail boom	11.0	8.40	N/A	N/A
Top of stabilizer	9.80	8.20	9.40	7.90
AVG.	**9.64**	**7.39**	**10.7**	**9.29**

7.2.3 AH-1Z BUNO 168052 – May 2019

7.2.3.1 Preparation and Painting of BUNO 168052

Similar to BUNOs 168798 and 168399, this aircraft was prepared for painting by first removing the aged polyurethane topcoat and anti-corrosive epoxy primer from the aluminum alloy skin and composite materials using plastic media blast and hand sanding according to NAVAIR established procedures. Once the coatings were removed the aluminum alloy skin was treated with an Alodine 1200 marker to apply the chromate conversion coating, followed by spray-application of PPG/Deft 44GN008A hexavalent chromium based waterborne epoxy primer with low infrared reflective pigments. Approximately 2 hours after the primer was applied the artisans sprayed the medium gray colored 1K polysiloxane topcoat on the majority of the aircraft skin using a portable pressure pot and Binks Trophy Series HVLP spray gun with 1.8 mm fluid tip. The temperature and relative humidity during application were not recorded by the artisans, although conditions were likely similar to when BUNO 168798 was painted because the same temperature and humidity controlled spray booth was utilized. The following day, the blue gray colored 1K polysiloxane topcoat was applied to the remaining areas of BUNO 168052 using the same spray equipment. The aircraft was also stenciled using the medium gray 1K polysiloxane that was recovered from the pressure pot on Day 1 of painting. A total of 6 gallons of 1K polysiloxane topcoats were used to paint the entire aircraft. Photographs of BUNO 168052 less than 1 week after the entire aircraft was painted with 1K polysiloxane topcoats are shown in Figures 77-79.

Figure 77 — Wide view of BUNO 168052 less than 1 week after the 1K polysiloxane topcoats were applied.

Figure 78 — Right side of BUNO 168052 less than 1 week after the 1K polysiloxane topcoats were applied.

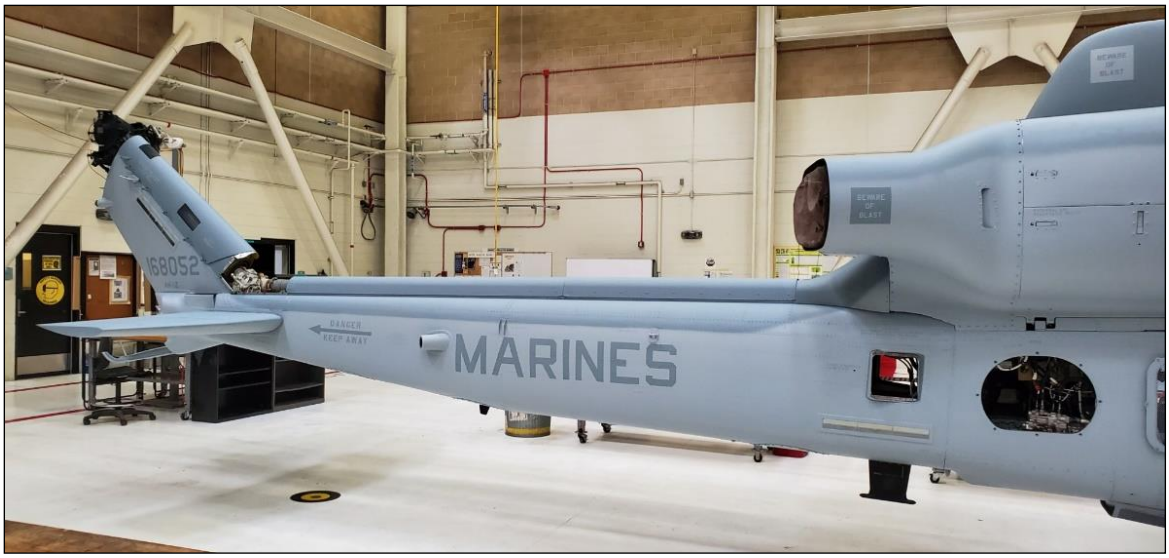


Figure 79 — Right tail of BUNO 168052 less than 1 week after the 1K polysiloxane topcoats were applied.

7.2.3.2 Collection of Initial Metrics on BUNO 168052

The initial metrics for BUNO 168052 were collected approximately two weeks after the aircraft was painted with the 1K polysiloxane topcoats. Initial DFT values for various areas of the aircraft range from 3.28-3.39 mils for the medium gray 1K topcoat and 2.60-4.10 mils for the blue gray 1K polysiloxane topcoat (tables 56 and 57). Assuming an average DFT of 0.75 mils for the anti-corrosive primer the polysiloxane topcoat thickness was within the range of 1.85-3.35 mils. The high end of this range is nearly 1.0 mils above the NAVAIR recommended DFT, although the average was likely skewed due to the greater thickness on the leading edge of the right wing and top of horizontal stabilizer. DFT values could not be obtained from the nacelles and nose because they are composite materials. As shown in Tables 58 and 59, color values recorded for the medium gray and blue gray 1K topcoats were relatively consistent, suggesting a homogeneous color across the aircraft. This could also be observed visually as shown in Figures 77-79.

Furthermore, the colors appeared to visually match other AH-1Z aircraft in the hanger that were painted with a 2K camouflage gray polyurethane topcoat. The average gloss for areas with medium gray 1K topcoat ranged from 4.64-5.97 GU at 60 degrees and 3.31-4.39 GU at 85 degrees, with the highest values recorded on the left side fuselage below the cockpit (tables 60 and 61). The average gloss for areas with blue gray 1K topcoat ranged from 2.94-3.07 GU at 60 degrees and 1.97-2.02 GU at 85 degrees, with the highest values attributed to the left side of the nose. All 60 and 85 degree gloss values for the medium gray and blue gray topcoats on the right side of the aircraft were below the recommended values of ≤5 GU and ≤10 GU, respectively, whereas the blue gray topcoat on the left side of the aircraft was also below these recommended values. The medium gray topcoat on the left side possessed an average gloss at 60 degrees that was 0.97 GU greater than the recommended value of ≤5 GU, although all gloss values at 85 degrees were below 6.0 GU. Similar to other aircraft painted with 1K camouflage gray polysiloxane topcoats, these values were expected to decrease slightly as post-application reactions occurred.

Table 56 — Initial average DFT values of medium gray 1K polysiloxane topcoat on BUNO 168052.

Location	Left side, DFT (mils)	Right side, DFT (mils)
FWD Cockpit	3.43	3.14
Fuselage Below Cockpit	2.86	3.07
AFT Cockpit	3.06	3.47
Nacelle	N/A	N/A
Side of Tail Boom	4.21	3.44
AVG.	**3.39**	**3.28**

Table 57 — Initial average DFT values of medium gray 1K polysiloxane topcoat on BUNO 168052.

Location	Left side, DFT (mils)	Right side, DFT (mils)
Nose	N/A	N/A
Leading edge of wing	2.06	4.05
Top of tail boom	2.61	3.04
Top of stabilizer	3.14	5.20
AVG.	**2.60**	**4.10**

Table 58 — Initial average color values of medium gray 1K polysiloxane topcoat on BUNO 168052.

Location	Left side, color coordinates			Right side, color coordinates		
	L	**a**	**b**	**L**	**a**	**b**
FWD Cockpit	66.15	-2.60	-3.27	65.96	-2.63	-3.29
Fuselage Below Cockpit	66.28	-2.60	-3.29	66.11	-2.63	-3.30
AFT Cockpit	66.26	-2.65	-3.24	66.09	-2.64	-3.28
Nacelle	66.09	-2.63	-3.31	66.08	-2.65	-3.31
Side of Tail Boom	66.30	-2.36	-3.27	66.08	-2.64	-3.29
AVG.	**66.22**	**-2.57**	**-3.28**	**66.06**	**-2.64**	**-3.29**

Table 59 — Initial average color values of blue gray 1K polysiloxane topcoat on BUNO 168052.

Location	Left side, color coordinates			Right side, color coordinates		
	L	**a**	**b**	**L**	**a**	**b**
Nose	56.44	-3.92	-4.47	59.55	-3.34	-3.58
Leading edge of wing	55.65	-3.79	-3.73	55.96	-3.81	-3.69
Top of tail boom	55.64	-3.75	-3.75	55.61	-3.78	-3.81
Top of stabilizer	55.75	-3.84	-3.82	55.82	-3.83	-3.79
AVG.	**55.87**	**-3.82**	**-3.94**	**56.74**	**-3.69**	**-3.72**

Table 60 — Initial average gloss values of medium gray 1K polysiloxane topcoat on BUNO 168052.

Location	Left side, gloss units (GU)		Right side, gloss units (GU)	
	60°	**85°**	**60°**	**85°**
FWD Cockpit	4.20	1.80	4.40	2.50
Fuselage Below Cockpit	7.03	5.93	4.23	3.00
AFT Cockpit	5.20	3.90	5.20	3.80
Nacelle	6.53	4.83	4.67	3.67
Side of Tail Boom	6.90	5.50	4.70	3.50
AVG.	**5.97**	**4.39**	**4.64**	**3.31**

Table 61 — Initial average gloss values of blue gray 1K polysiloxane topcoat on BUNO 168052.

Location	Left side, gloss units (GU)		Right side, gloss units (GU)	
	60°	**85°**	**60°**	**85°**
Nose	4.73	2.20	3.90	2.30
Leading edge of wing	2.70	2.20	2.80	2.20
Top of tail boom	2.70	2.00	2.80	1.50
Top of stabilizer	2.20	1.70	2.30	1.90
AVG.	**3.07**	**2.02**	**2.94**	**1.97**

7.2.4 In-service inspections of 1K polysiloxane topcoats on AH-1Z Vipers

7.2.4.1 Inspection of AH-1Z BUNO 168798 after 8 Months of Service – November 2019

The 1K camouflage gray polysiloxane topcoats on BUNO 168798 were inspected in November of 2019 after 8 months of active service at Camp Pendleton (figure 80). In general, the topcoats were in excellent condition with no signs of mechanical damage, blistering, cracking, delamination, or facial corrosion. However, the aircraft was extremely dirty / contaminated as shown in Figures 81 and 82, and the fuselage below the nacelles were stained with engine oil that was seeping from areas above (figure 83). Attempts to remove the dark contamination marks and engine oil with water and rags were unsuccessful.

Figure 80 — 1K polysiloxane topcoats on right tail boom and vertical stabilizer of BUNO 168798 after 8 months of service.

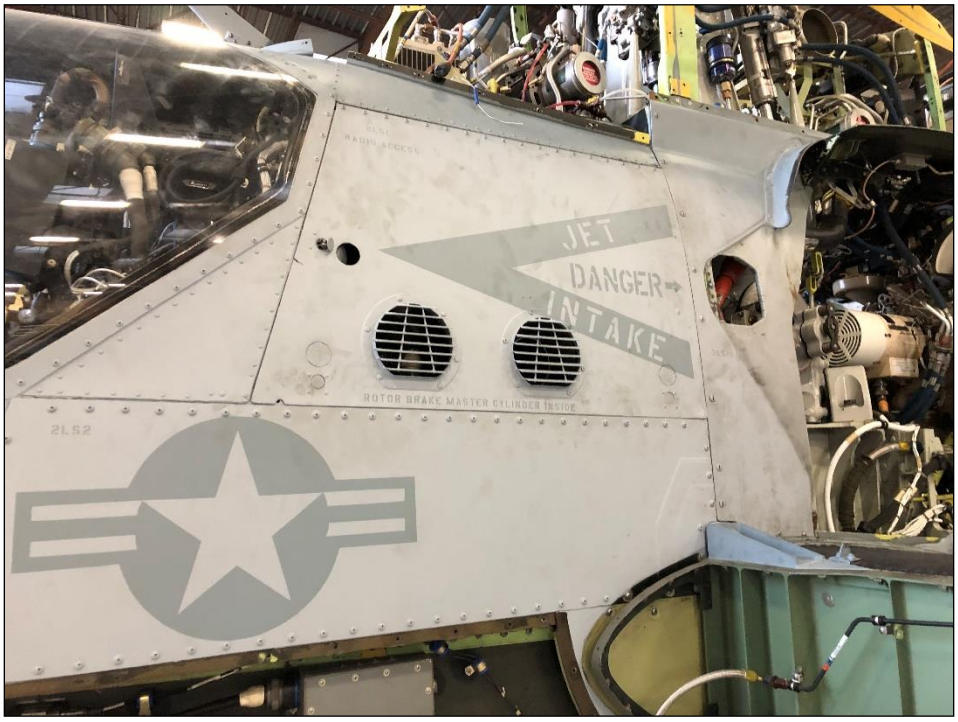


Figure 81 — 1K polysiloxane topcoat on left AFT area of cockpit on BUNO 168798 after 8 months of service.

Figure 82 — 1K polysiloxane topcoat on nacelle of BUNO 168798 after 8 months of service.

Figure 83 — 1K polysiloxane topcoat below nacelle of BUNO 168798 after 8 months of service.

The color and gloss of the 1K polysiloxane topcoats were determined using the same instruments that were used to obtain the initial values, and measurements were collected on the left and right side of the forward cockpit area, fuselage below cockpit, rear area of cockpit, side of tail boom, top of tail boom, and top of horizontal stabilizers. Metrics could not be collected from the nose, leading edge of wings, and nacelles because the covers were removed for maintenance purposes. Furthermore, the nose and nacelle covers are composite materials, thus DFT values could not be obtained from these surfaces.

Visually, the color of the medium gray and blue gray 1K polysiloxane topcoats were similar to AH-1Zs in the hanger that were painted with 2K camouflage gray polyurethane topcoats. However, as shown in Tables 62 and 63, the average color values collected from the aircraft reveal the topcoats were slightly darker (i.e., decrease in "L" value) and less blue (i.e., positive increase in "b" value, more yellow) than initial measurements. The darker values are likely due to the dirt / contamination on the aircraft, and the increase in yellowness is likely due to minor degradation at the surface of the topcoats due to exposure in sunlight. As a result, the color change values for the medium gray and blue gray 1K topcoats, as calculated per Section 5.2.3.3, were 0.46 and 0.69, respectively. It is worth restating that a color change of $\leq$1.0 is imperceptible to the human eye, and a color change of 1.0-2.0 is barely perceptible with a highly trained eye.[59,60]

Table 62 — Average color values of medium gray 1K polysiloxane topcoat on BUNO 168798 after 8 months of service.

Location	**Left side, color coordinates**			**Right side, color coordinates**		
	L	**a**	**b**	**L**	**a**	**b**
FWD Cockpit	64.72	-2.38	-4.04	64.91	-2.37	-4.27
Fuselage Below Cockpit	65.55	-2.37	-4.38	65.27	-2.38	-4.22
AFT Cockpit	65.07	-2.31	-3.99	64.60	-2.33	-3.89
Nacelle	64.69	-2.33	-4.18	65.46	-2.38	-4.39
Side of Tail Boom	65.50	-2.35	-4.45	65.21	-2.40	-4.42
AVG.	**65.11**	**-2.35**	**-4.21**	**65.09**	**-2.37**	**-4.24**

Table 63 — Average color values of blue gray 1K polysiloxane topcoat on BUNO 168798 after 8 months of service.

Location	**Left side, color coordinates**			**Right side, color coordinates**		
	L	**a**	**b**	**L**	**a**	**b**
Nose	N/A	N/A	N/A	N/A	N/A	N/A
Leading edge of wing	N/A	N/A	N/A	N/A	N/A	N/A
Top of tail boom	55.64	-3.87	-4.27	55.81	-3.85	-4.39
Top of stabilizer	55.58	-3.88	-4.23	55.72	-3.85	-4.39
AVG.	**55.61**	**-3.88**	**-4.25**	**55.77**	**-3.85**	**-4.39**

The average gloss values for the medium gray 1K polysiloxane topcoat had decreased to 5.04 GU at 60 degrees and 6.81 GU at 85 degrees, whereas the average gloss values for the blue gray 1K polysiloxane topcoat had decreased to 3.10 GU at 60 degrees and 5.51 GU at 85 degrees (tables 64 and 65). These values were within the NAVAIR specified values of ≤5 GU at 60 degrees and ≤10 GU at 85 degrees. It is unknown how many days were required after application for the topcoats to meet these values.

Table 64 — Average gloss values of medium gray 1K polysiloxane topcoat on BUNO 168798 after 8 months of service.

Location	**Left side, gloss units (GU)**		**Right side, gloss units (GU)**	
	60°	**85°**	**60°**	**85°**
FWD Cockpit	5.70	7.80	5.20	5.90
Fuselage Below Cockpit	4.70	6.80	5.00	9.30
AFT Cockpit	4.90	7.40	5.90	8.70
Nacelle	4.60	7.70	4.80	5.90
Side of Tail Boom	4.40	3.40	5.20	5.20
AVG.	**4.86**	**6.62**	**5.22**	**7.00**

Table 65 — Average gloss values of blue gray 1K polysiloxane topcoat on BUNO 168798 after 8 months of service.

Location	**Left side, gloss units (GU)**		**Right side, gloss units (GU)**	
	60°	**85°**	**60°**	**85°**
Nose	N/A	N/A	N/A	N/A
Leading edge of wing	N/A	N/A	N/A	N/A
Top of tail boom	6.40	11.1	6.70	13.1
Top of stabilizer	6.50	11.6	5.20	8.30
AVG.	**3.23**	**5.68**	**2.98**	**5.35**

7.2.4.2 Inspection of AH-1Z BUNO 168798 after 12 Months of Service – March 2020

The 1K polysiloxane topcoats on BUNO 168798 were not be inspected at the 1-year service period due to travel restrictions and limited base access as a result of the COVID-19 pandemic.

7.2.4.3 Inspection of AH-1Z BUNO 168798 after 17 Months of Service – August 2020

The 1K polysiloxane topcoats on BUNO 168798 were inspected in August of 2020 after 17 months of active service at Camp Pendleton. In general, the topcoats were in excellent condition with limited mechanical damage, no blistering, no cracking, no delamination, and no facial corrosion (figures 84-89). The aircraft had been washed prior to inspection, although it remained dirty / contaminated in several locations, such as the nacelles. Most of the engine oil on the fuselage below the nacelles was removed, although several yellow stains remained on the topcoat (figure 90). Attempts were not made to remove the remaining dark contamination marks using a commercial cleaner or water and rags.

The color, and gloss of the 1K polysiloxane topcoats were determined using the same instruments that were used to obtain the initial and 8-month values, and measurements were collected on the left and right side of the forward cockpit area, fuselage below cockpit, rear area of cockpit, nose, leading edge of wing, side of tail boom, top of tail boom, and top of horizontal stabilizers.

Figure 84 — 1K polysiloxane topcoats on right tail boom and vertical stabilizer of BUNO 168798 after 17 months of service.

Figure 85 — 1K polysiloxane topcoats on front left side of BUNO 168798 after 17 months of service.

Figure 86 — 1K polysiloxane topcoat on left AFT cockpit of BUNO 168798 after 17 months of service.

Figure 87 — 1K polysiloxane topcoats on left nacelle of BUNO 168798 after 17 months of service.

Figure 88 — 1K polysiloxane topcoats on left tail boom of BUNO 168798 after 17 months of service.

Figure 89 — 1K polysiloxane topcoats on left top horizontal stabilizer of BUNO 168798 after 17 months of service.

Figure 90 — Staining of 1K polysiloxane topcoat on the right fuselage below the nacelle of BUNO 168798 after 17 months of service.

As shown in Tables 66 and 67, the average color values collected from the aircraft showed the topcoats were slightly darker (i.e., decreased "L" value) and less blue / more yellow than initial measurements. The darker values can be attributed to contamination (e.g., grease, soot) on the surface, whereas the increase in yellowness is likely the result of surface contaminants and/or UV-degradation at the surface of the topcoats due to sunlight. Specifically, the color values collected from the top of the horizontal stabilizers and tail boom were darker and more yellow than other areas that possessed the blue gray topcoat (table 67); however, it is common for these areas of the aircraft to become extremely dirty / contaminated due to engine exhaust. After 17 months of active service, the color change values for the medium gray and blue gray 1K polysiloxane topcoats were 1.81 and 2.95, respectively. Visually, the color of the medium gray and blue gray 1K polysiloxane topcoats were similar to other AH-1Z aircraft on the nearby flight line that were painted with 2K camouflage gray polyurethane topcoats.

Table 66 — Average color values of medium gray 1K polysiloxane topcoat on BUNO 168798 after 17 months of service.

Location	**Left side, color coordinates**			**Right side, color coordinates**		
	L	**a**	**b**	**L**	**a**	**b**
FWD Cockpit	64.84	-2.37	-3.08	64.65	-2.31	-2.99
Fuselage Below Cockpit	64.99	-2.41	-3.24	65.08	-2.36	-3.31
AFT Cockpit	64.05	-2.38	-3.09	64.65	-2.28	-2.79
Nacelle	64.26	-2.25	-2.38	64.73	-2.29	-2.69
Side of Tail Boom	64.49	-2.29	-2.68	64.62	-2.28	-2.98
AVG.	**64.53**	**-2.34**	**-2.89**	**64.75**	**-2.30**	**-2.95**

Table 67 — Average color values of blue gray 1K polysiloxane topcoat on BUNO 168798 after 17 months of service.

Location	**Left side, color coordinates**			**Right side, color coordinates**		
	L	**a**	**b**	**L**	**a**	**b**
Nose	55.05	-3.59	-2.84	55.13	-3.54	-2.77
Leading edge of wing	55.26	-3.56	-2.65	55.06	-3.55	-2.81
Top of tail boom	54.23	-3.3	-1.89	54.33	-3.29	-2.91
Top of stabilizer	53.9	-3.2	-1.62	52.66	-2.99	-1.42
AVG.	**54.61**	**-3.41**	**-2.25**	**54.30**	**-3.34**	**-2.48**

The average gloss for the medium gray and blue gray 1K polysiloxane topcoats had decreased to ≤5 GU at 60 degrees and ≤10 GU at 85 degrees at the 8-month inspection, yet all values increased slight at 17-months. For the medium gray 1K topcoat the average gloss was 8.14 GU at 60 degrees and 8.25 GU at 85 degrees, whereas for the blue gray 1K topcoat the average gloss was 7.34 GU at 60 degrees and 7.74 GU at 85 degrees (tables 68 and 69). It is unknown why the values at 17-months were greater than those at 8-months, as visually the topcoats had a flat finish. However, it could be that elevated values were obtained because the gloss meter was not pressed firmly against the coating surface, or the measurements were collected on surfaces areas with slight curvature, thereby preventing the exclusion of external light to the meter.

Table 68 — Average gloss values of medium gray 1K polysiloxane topcoat on BUNO 168798 after 17 months of service.

Location	**Left side, gloss units (GU)**		**Right side, gloss units (GU)**	
	60°	**85°**	**60°**	**85°**
FWD Cockpit	9.23	7.83	8.77	8.93
Fuselage Below Cockpit	10.1	11.1	8.80	8.37
AFT Cockpit	8.73	8.27	7.90	8.43
Nacelle	7.90	8.97	7.33	9.00
Side of Tail Boom	5.40	5.13	7.27	6.53
AVG.	**8.28**	**8.25**	**8.01**	**8.25**

Table 69 — Average gloss values of blue gray 1K polysiloxane topcoat on BUNO 168798 after 17 months of service.

Location	**Left side, gloss units (GU)**		**Right side, gloss units (GU)**	
	60°	**85°**	**60°**	**85°**
Nose	7.30	6.37	7.00	7.70
Leading edge of wing	10.3	13.6	8.07	10.6
Top of tail boom	5.40	6.03	6.20	3.97
Top of stabilizer	7.43	6.87	7.10	6.73
AVG.	**7.60**	**8.23**	**7.09**	**7.26**

7.2.4.4 Inspection of AH-1Z BUNO 168798 after 20 Months of Service – November 2020

The 1K polysiloxane topcoats on BUNO 168798 were inspected in November of 2020 after 20 months of active service at Camp Pendleton. In general, the topcoats continued to remain in excellent condition with limited mechanical damage and no blistering, cracking, delamination, or facial corrosion (figures 91-96). The aircraft was washed prior to inspection, although it remained dirty / contaminated in several locations, such as the nacelles. There was no presence of engine oil on the fuselage below the nacelles. Attempts were not made to remove the remaining dark contamination marks on the topcoat.

Figure 91 — 1K polysiloxane topcoats on left tail boom of BUNO 168798 after 20 months of service.

Figure 92 — 1K polysiloxane topcoat on nose and left FWD cockpit of BUNO 168798 after 20 months of service.

Figure 93 — 1K polysiloxane topcoat on right AFT cockpit of BUNO 168798 after 20 months of service.

Figure 94 — 1K polysiloxane topcoat on left engine exhaust of BUNO 168798 after 20 months of service.

Figure 95 — 1K polysiloxane topcoat on right horizontal stabilizer of BUNO 168798 after 20 months of service.

Figure 96 — 1K polysiloxane topcoat on left side of vertical stabilizer of BUNO 168798 after 20 months of service.

DFT, color, and gloss values of the 1K camouflage gray polysiloxane topcoats were determined using the same instruments that were used during the initial, 8-month, and 17-month inspections, and measurements were collected on the left and right side of the forward cockpit area, fuselage below cockpit, rear area of cockpit, nose, leading edge of wing, side of tail boom, top of tail boom, and top of horizontal stabilizers.

The average DFT values decreased from 2.99 mils to 2.44 mils for the medium gray 1K topcoat after 20 months, which was a decrease of 18.4%. The average DFT values decreased from 2.45 mils to 2.01 mils for the blue gray 1K topcoat after 20 months, which was decrease in 17.9%. The decrease in values is likely the result of recording values on thinner areas on the right side of the aircraft, specifically the AFT cockpit and side of tail boom, as the average values on the left FWD cockpit, left fuselage, and left AFT cockpit indicate sufficient topcoat thickness. Likewise, values from the top of the stabilizer were lower compared to the leading edge of wing and top of tail boom, which reduced the average. It should be noted that it is extremely difficult to record thickness values in the same location during each inspect because the locations on the aircraft cannot be marked with a pen or tape.

Table 70 — Average DFT values of medium gray 1K polysiloxane topcoat on BUNO 168052 after 20 months of service.

Location	Left side, DFT (mils)	Right side, DFT (mils)
FWD Cockpit	2.87	2.89
Fuselage Below Cockpit	2.49	1.97
AFT Cockpit	2.77	2.19
Nacelle	N/A	N/A
Side of Tail Boom	2.41	1.96
AVG.	**2.41**	**2.09**

Table 71 — Average DFT values of medium gray 1K polysiloxane topcoat on BUNO 168052 after 20 months of service.

Location	Left side, DFT (mils)	Right side, DFT (mils)
Nose	N/A	N/A
Leading edge of wing	2.02	3.27
Top of tail boom	2.13	1.97
Top of stabilizer	1.48	1.18
AVG.	**1.41**	**1.61**

As shown in Tables 72 and 73, the average color values of the topcoats were slightly darker (i.e., decreased "L" value) and more yellow (i.e., less blue) than initial measurements. Similar to the earlier inspections, the darker values can be attributed to contamination on the surface, whereas the increase in yellowness is likely the result of surface contaminants and/or UV-degradation due to sunlight. During this inspection, the top of the tail boom and horizontal stabilizers were not nearly as yellow as during the 17-month inspection, which could be due to removing contaminants via washing. After 20 months of active service at Camp Pendleton the average color change for the medium gray and blue gray 1K polysiloxane topcoats

were 2.03 and 2.19, respectively (table 74). Visually, the color of the medium gray and blue gray 1K polysiloxane topcoats were similar to other AH-1Zs on the nearby flight line that were painted with 2K camouflage gray polyurethane topcoats, and maintainers in the squadron stated they did not notice a difference between the two topcoat technologies.

Table 72 — Average color values of medium gray 1K polysiloxane topcoat on BUNO 168798 after 20 months of service.

Location	**Left side, color coordinates**			**Right side, color coordinates**		
	L	**a**	**b**	**L**	**a**	**b**
FWD Cockpit	64.05	-2.33	-3.14	65.21	-2.39	-3.03
Fuselage Below Cockpit	64.97	-2.31	-2.84	65.21	-2.38	-2.84
AFT Cockpit	64.94	-2.3	-2.97	65.31	-2.36	-3.24
Nacelle	63.62	-2.16	-1.43	64.57	-2.29	-2.35
Side of Tail Boom	64.72	-2.29	-2.79	64.67	-2.18	-2.33
AVG.	**64.46**	**-2.28**	**-2.63**	**64.99**	**-2.32**	**-2.76**

Table 73 — Average color values of blue gray 1K polysiloxane topcoat on BUNO 168798 after 20 months of service.

Location	**Left side, color coordinates**			**Right side, color coordinates**		
	L	**a**	**b**	**L**	**a**	**b**
Nose	55.63	-3.54	-2.56	N/A	N/A	N/A
Leading edge of wing	55.33	-3.36	-2.44	55.7	-3.47	-2.51
Top of tail boom	55.49	-3.6	-3.16	55.06	-3.56	-2.8
Top of stabilizer	55.56	-3.43	-2.55	55.61	-3.4	-2.25
AVG.	**55.50**	**-3.48**	**-2.68**	**55.46**	**-3.48**	**-2.52**

Table 74 — Color change of medium gray (#36375) and blue gray (#35237) 1K polysiloxane topcoats on AH-1Z BUNO 168798 after 20 months of service.

BUNO	**1K Polysiloxane Color**	**March 2019**			**November 2020**			**ΔE**
		L*	**a***	**b***	**L***	**a***	**b***	
168798	Medium Gray	65.39	-2.4	-4.57	64.67	-2.26	-2.68	**2.03**
	Blue Gray	56.28	-3.89	-4.61	55.48	-3.48	-2.61	**2.19**

The average gloss for the medium gray and blue gray 1K polysiloxane topcoats after 20-months of service had decreased slightly compared to initial values. For the medium gray 1K topcoat the average gloss was 8.05 GU at 60 degrees and 8.15 GU at 85 degrees, whereas for the blue gray 1K topcoat the average gloss was 8.59 GU at 60 degrees and 11.9 GU at 85 degrees (tables 75 and 76). It is unknown why the values at 20-months were slightly greater than those at 17-months, as the topcoats visually had a flat finish. However, it could be that elevated values were obtained because the gloss meter was not pressed firmly against the coating surface, or measurements were collected on surfaces areas with slight curvature, thereby allowing external light to enter the meter and distort the values.

Table 75 — Average gloss values of medium gray 1K polysiloxane topcoat on BUNO 168798 after 20 months of service.

Location	**Left side, gloss units (GU)**		**Right side, gloss units (GU)**	
	60°	**85°**	**60°**	**85°**
FWD Cockpit	10.8	11.4	8.53	8.77
Fuselage Below Cockpit	6.37	5.40	9.17	6.87
AFT Cockpit	10.0	6.53	8.17	9.00
Nacelle	7.67	10.9	6.67	9.03
Side of Tail Boom	5.53	6.30	7.60	7.27
AVG.	**8.08**	**8.11**	**8.03**	**8.19**

Table 76 — Average gloss values of blue gray 1K polysiloxane topcoat on BUNO 168798 after 20 months of service.

Location	**Left side, gloss units (GU)**		**Right side, gloss units (GU)**	
	60°	**85°**	**60°**	**85°**
Nose	N/A	N/A	6.00	9.30
Leading edge of wing	10.8	17.2	7.43	9.30
Top of tail boom	7.93	11.3	11.0	13.8
Top of stabilizer	8.10	10.2	8.50	11.3
AVG.	**8.94**	**12.9**	**8.24**	**10.9**

This aircraft was placed into preservation under authority of the NAVAIR type commander (TYCOM) in December of 2020 and was unavailable for inspection at the 24-month period (March 2021).

7.2.4.5 Inspection of AH-1Z BUNO 168399 after 7 Months of Service – November 2019

The 1K polysiloxane topcoats on BUNO 168399 were inspected in November of 2019 after 7 months of active service at Camp Pendleton (figures 97-49). In general, the topcoats were in excellent condition with minor mechanical damage (i.e., scratches) and no sign of blistering, cracking, delamination, or facial corrosion. The medium gray 1K topcoat possessed a few areas with dirt / contamination on the AFT area of the cockpit and horizontal stabilizers (figure 100), but visually there was no oil leaking from the nacelles or other mechanical areas. Attempts to remove the dark contamination marks on the AFT cockpit area with water and rags were unsuccessful; however, the majority of the contamination on the horizontal stabilizers was removed using this method.

Figure 97 — 1K polysiloxane topcoats on left AFT side of BUNO 168399 after 7 months of service.

Figure 98 — 1K polysiloxane topcoats on left FWD side of BUNO 168399 after 7 months of service.

Figure 99 — 1K polysiloxane topcoat on the right AFT cockpit area of BUNO 168399 after 7 months of service.

Figure 100 — Dirt on the left top horizontal stabilizer of BUNO 168399 after 7 months of service.

The color and gloss of the 1K polysiloxane topcoats were determined using the same instruments that were used to obtain the initial values, and measurements were collected on left and right sides of the forward cockpit area, fuselage below cockpit, rear area of cockpit, side of tail boom, top of tail boom, and top of horizontal stabilizers.

Visually, the color of the medium gray and blue gray polysiloxane topcoats were similar to AH-1Z aircraft on the nearby flight line that were painted with 2K polyurethane topcoats. However, as shown in Tables 77 and 78, the average color values collected from the aircraft showed there were minimal changes in the L,a,b color space. As a result, the average color change for the medium gray and blue gray 1K polysiloxane topcoats were 0.24 and 0.28, respectively.

Table 77 — Average color values of medium gray 1K polysiloxane topcoat on BUNO 168399 after 7 months of service.

Location	Left side, color coordinates			Right side, color coordinates		
	L	**a**	**b**	**L**	**a**	**b**
FWD Cockpit	65.10	-2.18	-3.26	64.10	-2.38	-4.00
Fuselage Below Cockpit	64.57	-2.28	-3.26	64.23	-2.28	-3.46
AFT Cockpit	64.70	-2.30	-3.34	65.19	-2.34	-4.01
Nacelle	N/A	N/A	N/A	64.68	-2.28	-4.09
Side of Tail Boom	65.19	-2.34	-3.72	65.34	-2.36	-4.08
AVG.	**64.89**	**-2.27**	**-3.40**	**64.71**	**-2.33**	**-3.93**

Table 78 — Average color values of blue gray 1K polysiloxane topcoat on BUNO 168399 after 7 months of service.

Location	Left side, color coordinates			Right side, color coordinates		
	L	**a**	**b**	**L**	**a**	**b**
Nose	55.27	-3.94	-3.92	55.09	-3.97	-3.56
Leading edge of wing	55.43	-3.73	-3.21	55.74	-3.86	-3.69
Top of tail boom	55.77	-3.91	-3.86	55.75	-3.88	-4.03
Top of stabilizer	55.51	-3.99	-3.95	55.56	-3.98	-3.97
AVG.	**55.49**	**-3.89**	**-3.74**	**55.53**	**-3.92**	**-3.81**

After 7 months of service, the average gloss values for the medium gray 1K topcoat had decreased to 4.28 GU at 60 degrees and 6.10 GU at 85 degrees, whereas the average gloss values for the blue gray 1K polysiloxane topcoat had decreased to 7.42 GU at 60 degrees and increased to 17.6 GU at 85 degrees (tables 79 and 80). All gloss values for the medium gray 1K topcoat were within the NAVAIR specified range of ≤5 GU at 60 degrees and ≤10 GU at 85 degrees, yet it is not understood why the gloss for the blue gray topcoat was above the specified range. Furthermore, it is not understood why the average gloss at 85 degrees for the blue gray topcoat had increased from 8.34 GU to 17.6 GU. The only likely explanations for this increase are as follows: 1) the gloss meter was not flush with the topcoat when values were collected, thus allowing external light to enter the meter and alter the value, and 2) a minor amount of a contaminant, such as oil, was on the surface of the coating, thus decreasing the ability of the coating to scatter light. Visually, both topcoats had a low gloss finish and were similar in gloss to AH-1Zs on the nearby flight line.

Table 79 — Average gloss values of medium gray 1K polysiloxane topcoat on BUNO 168399 after 7 months of service.

Location	**Left side, gloss units (GU)**		**Right side, gloss units (GU)**	
	60°	**85°**	**60°**	**85°**
FWD Cockpit	3.70	4.70	4.10	5.50
Fuselage Below Cockpit	4.40	7.70	4.20	7.40
AFT Cockpit	3.30	5.60	4.80	5.70
Nacelle	4.20	6.40	4.30	4.70
Side of Tail Boom	4.70	6.60	5.10	6.70
AVG.	**4.06**	**6.20**	**4.50**	**6.00**

Table 80 — Average gloss values of blue gray 1K polysiloxane topcoat on BUNO 168399 after 7 months of service.

Location	**Left side, gloss units (GU)**		**Right side, gloss units (GU)**	
	60°	**85°**	**60°**	**85°**
Nose	5.20	11.5	4.70	9.10
Leading edge of wing	6.70	18.3	10.8	26.3
Top of tail boom	8.40	19.0	8.30	18.7
Top of stabilizer	7.30	18.2	8.00	19.5
AVG.	**6.90**	**16.7**	**7.95**	**18.4**

7.2.4.6 Inspection of AH-1Z BUNO 168399 after 12 Months of Service – April 2020

The 1K polysiloxane topcoats on BUNO 168399 were not be inspected at the 1-year service period due to travel restrictions and limited base access as a result of the COVID-19 pandemic.

7.2.4.7 Inspection of AH-1Z BUNO 168399 after 16 Months of Service – August 2020

The 1K polysiloxane topcoats on BUNO 168399 were inspected in August of 2020 after 16 months of active service at Camp Pendleton (figures 101-106). In general, the topcoats were in excellent condition with minor mechanical damage (e.g., scratches) to the medium gray 1K topcoat found on areas around the cockpit and right nacelle (figure 106). The topcoats showed no signs of blistering, cracking, delamination, or facial corrosion. Due to mechanical issues the aircraft had spent limited time on the flight line after it was painted in April of 2019. As a result, the topcoats were dirty / contaminated in numerous areas due to maintenance activities, and attempts were not made to remove the remaining dark contamination marks using water and rags or a commercial cleaner.

Figure 101 — 1K polysiloxane topcoats on tail section of BUNO 168399 after 16 months of service.

Figure 102 — 1K polysiloxane topcoat on right AFT cockpit of BUNO 168399 after 16 months of service.

Figure 103 — 1K polysiloxane topcoat on left fuselage below cockpit of BUNO 168399 after 16 months of service.

Figure 104 — 1K polysiloxane topcoats on left tail boom of BUNO 168399 after 16 months of service.

Figure 105 — 1K polysiloxane topcoats on left horizontal and vertical stabilizers of BUNO 168399 after 16 months of service.

Figure 106 — Mechanical damage to 1K topcoat on right nacelle of BUNO 168399 after 16 months of service.

The color and gloss of the 1K polysiloxane topcoats were determined using the same instruments that were used to obtain the initial and 7-month values, and measurements were collected on the left and right side of the forward cockpit area, fuselage below cockpit, rear area of cockpit, nose, leading edge of wing, side of tail boom, top of tail boom, and top of horizontal stabilizers.

After 16 months, the color of the medium gray and blue gray 1K polysiloxane topcoats were visually similar to AH-1Z aircraft in the hanger were painted with 2K polyurethane topcoats. However, as shown in Tables 81 and 82, the average color values collected from the aircraft show the topcoats were slightly darker and slightly yellower than initial measurements. The darker values can be attributed to contamination (e.g., soot, grease) on the aircraft, and the increase in yellowness is potentially due to minor degradation at the surface of the topcoats due to exposure in sunlight. After 16 months of active service, the color change for the medium gray and blue gray 1K polysiloxane topcoats were 0.88 and 1.66, respectively.

Table 81 — Average color values of medium gray 1K polysiloxane topcoat on BUNO 168399 after 16 months of service.

Location	**Left side, color coordinates**			**Right side, color coordinates**		
	L	**a**	**b**	**L**	**a**	**b**
FWD Cockpit	64.52	-2.32	-2.78	64.34	-2.35	-2.87
Fuselage Below Cockpit	65.14	-2.36	-3.16	62.52	-1.92	-1.85
AFT Cockpit	64.48	-2.32	-2.83	64.67	-2.31	-2.9
Nacelle	65.45	-2.38	-3.42	65.00	-2.37	-3.36
Side of Tail Boom	64.64	-2.37	-2.79	65.95	-2.39	-3.18
AVG.	**64.85**	**-2.35**	**-3.00**	**64.50**	**-2.27**	**-2.83**

Table 82 — Average color values of blue gray 1K polysiloxane topcoat on BUNO 168399 after 16 months of service.

Location	**Left side, color coordinates**			**Right side, color coordinates**		
	L	**a**	**b**	**L**	**a**	**b**
Nose	N/A	N/A	N/A	N/A	N/A	N/A
Leading edge of wing	54.43	-3.72	-2.51	54.43	-3.69	-2.29
Top of tail boom	53.76	-3.45	-2.21	53.34	-3.48	-2.63
Top of stabilizer	54.44	-3.74	-2.65	54.51	-3.69	-2.64
AVG.	**54.21**	**-3.64**	**-2.46**	**54.09**	**-3.62**	**-2.52**

After 16 months of service, the average gloss values the medium gray 1K topcoat were 5.11 GU at 60 degrees and 5.28 GU at 85 degrees, whereas average gloss values for the blue gray 1K topcoat were 7.77 GU at 60 degrees and 8.13 GU at 85 degrees (tables 83 and 84). For the medium gray 1K topcoat, the majority of the 60-degree gloss values were less than 5 GU, although recorded values on the FWD cockpit and fuselage below cockpit were slightly above 5 GU, thus increasing the average. These slightly elevated values could be attributed to minor contaminants on the surface or the inability to exclude all external light when collecting values on curved surfaces. For the blue gray 1K topcoat, 60 and 85 degree gloss values for the top of the tail boom were within the specified range, yet values recorded on the leading edge of wings and top of horizontal stabilizers were slightly elevated. It is unknown why these values were slightly elevated because all sections were painted at the same time, although it is possible the values are elevated due to the inability of the meter to exclude external light on highly curved sections of the aircraft, such as the leading edge of wings. Visually, the topcoats on all locations had a flat finish.

Table 83 — Average gloss values of medium gray 1K polysiloxane topcoat on BUNO 168399 after 16 months of service.

Location	**Left side, gloss units (GU)**		**Right side, gloss units (GU)**	
	60°	**85°**	**60°**	**85°**
FWD Cockpit	6.83	7.10	5.07	5.03
Fuselage Below Cockpit	6.60	6.37	2.97	4.37
AFT Cockpit	5.03	3.60	6.33	4.93
Nacelle	4.67	5.77	3.70	5.83
Side of Tail Boom	4.17	5.43	5.77	4.43
AVG.	**5.46**	**5.65**	**4.77**	**4.92**

Table 84 — Average gloss values of blue gray 1K polysiloxane topcoat on BUNO 168399 after 16 months of service.

Location	**Left side, gloss units (GU)**		**Right side, gloss units (GU)**	
	60°	**85°**	**60°**	**85°**
Nose	N/A	N/A	N/A	N/A
Leading edge of wing	7.60	10.9	10.3	14.6
Top of tail boom	4.10	2.30	7.23	4.57
Top of stabilizer	8.53	8.10	8.40	8.30
AVG.	**6.74**	**7.10**	**8.66**	**9.16**

7.2.4.8 Inspection of AH-1Z BUNO 168399 after 19 Months of Service – November 2020

The 1K polysiloxane topcoats on BUNO 168399 were inspected in November of 2020 after 19 months of active service at Camp Pendleton (figures 107-109). In general, the topcoats were in excellent condition, although several panels were removed from the aircraft. The topcoats showed no signs of blistering, cracking, delamination, or facial corrosion. Due to mechanical issues the aircraft had spent limited time on the flight line, thus the topcoats were contaminated with grease and smudge marks in numerous areas due to maintenance activities (figure 109). The aircraft was not washed prior to inspection, and attempts were not made to remove the dark contamination marks using a commercial cleaner or water and rags.

Figure 107 —1K topcoats on vertical stabilizer of BUNO 168399 after 19 months of service.

Figure 108 —1K topcoats on left side of tail boom of BUNO 168399 after 19 months of service.

Figure 109 —1K topcoats on left side of tail boom of BUNO 168399 after 19 months of service.

The color and gloss of the 1K polysiloxane topcoats were determined using the same color and gloss meters that were used to obtain the initial and other inspection values. Measurements were collected on the left and right side of the forward cockpit area, fuselage below cockpit, rear area of cockpit, nose, leading edge of wing, side of tail boom, top of tail boom, and top of horizontal stabilizers.

After 19 months, the color of the medium gray and blue gray 1K polysiloxane topcoats were visually similar to AH-1Zs in the hanger that were painted with 2K camouflage gray polyurethane topcoats. However, as shown in Tables 85 and 86, the average color values collected from the aircraft were slightly darker and slightly yellower than initial measurements. The darker values can be attributed to contamination (e.g., soot, grease) on the aircraft (figure 109), whereas the increase in yellowness is potentially due to minor degradation at the surface due to exposure in sunlight. After 19 months of active service the color change for the medium gray and blue gray 1K polysiloxane topcoats were 1.88 and 1.46, respectively.

Table 85 — Average color values of medium gray 1K polysiloxane topcoat on BUNO 168399 after 19 months of service.

Location	**Left side, color coordinates**			**Right side, color coordinates**		
	L	**a**	**b**	**L**	**a**	**b**
FWD Cockpit	63.77	-2.18	-2.19	63.04	-2.07	-1.71
Fuselage Below Cockpit	63.45	-2.17	-2.27	64.00	-2.19	-2.05
AFT Cockpit	63.85	-2.21	-2.47	63.67	-2.21	-2.13
Nacelle	62.99	-2.19	-2.09	64.19	-2.20	-2.66
Side of Tail Boom	64.49	-2.31	-2.94	64.81	-2.33	-3.02
AVG.	**63.71**	**-2.21**	**-2.39**	**63.94**	**-2.20**	**-2.31**

Table 86 — Average color values of blue gray 1K polysiloxane topcoat on BUNO 168399 after 19 months of service.

Location	**Left side, color coordinates**			**Right side, color coordinates**		
	L	**a**	**b**	**L**	**a**	**b**
Nose	54.87	-3.64	-2.39	N/A	N/A	N/A
Leading edge of wing	53.92	-3.46	-2.05	53.96	-3.47	-2.13
Top of tail boom	54.81	-3.57	-2.78	54.39	-3.46	-2.46
Top of stabilizer	54.92	-3.75	-2.94	54.78	-3.71	-2.66
AVG.	**54.63**	**-3.61**	**-2.54**	**54.38**	**-3.55**	**-2.42**

After 19 months of service, the average gloss values the medium gray 1K topcoat were 5.28 GU at 60 degrees and 5.69 GU at 85 degrees, whereas average gloss values for the blue gray 1K topcoat were 8.99 GU at 60 degrees and 12.66 GU at 85 degrees (tables 87 and 88). For the medium gray topcoat, the majority of the 60-degree gloss values were slightly above or less than 5 GU, except on the sides of the tail boom and right AFT cockpit. These slightly elevated values, especially on the tail boom, are likely due to external light entering the meter due to the curved aircraft surface, as the coating was visually low in gloss. The 60 degree and 85 degree gloss values decreased by 16.8% and 11.8%, respectively, compared to the initial measurements in April of 2019. For the blue gray 1K polysiloxane topcoat, the gloss values had increased by 27.6% at 60 degrees and 51.8% at 85 degrees. These increases were significant, yet it's likely the meter was not completely flat when measuring the gloss on these curved surfaces (e.g., leading edge of wing, top if tail boom). Visually, the blue gray 1K topcoat was low gloss in all locations, such as the top of the tail boom (figure 108). The visual gloss of both topcoats were similar to aircraft in the hanger that were painted with qualified 2K polyurethane topcoats.

Table 87 — Average gloss values of medium gray 1K polysiloxane topcoat on BUNO 168399 after 19 months of service.

Location	**Left side, gloss units (GU)**		**Right side, gloss units (GU)**	
	60°	**85°**	**60°**	**85°**
FWD Cockpit	4.97	5.37	4.93	4.23
Fuselage Below Cockpit	5.37	5.23	4.90	5.27
AFT Cockpit	3.83	2.30	6.30	7.13
Nacelle	4.67	7.20	5.47	8.93
Side of Tail Boom	6.17	6.03	6.23	5.20
AVG.	**5.00**	**5.23**	**5.57**	**6.15**

Table 88 — Average gloss values of blue gray 1K polysiloxane topcoat on BUNO 168399 after 19 months of service.

Location	**Left side, gloss units (GU)**		**Right side, gloss units (GU)**	
	60°	**85°**	**60°**	**85°**
Nose	N/A	N/A	N/A	N/A
Leading edge of wing	12.90	17.37	11.37	16.33
Top of tail boom	6.13	7.43	5.33	6.07
Top of stabilizer	8.80	12.90	9.40	15.87
AVG.	**9.28**	**12.57**	**8.70**	**12.76**

7.2.4.9 Inspection of AH-1Z BUNO 168399 after 25 Months of Service – May 2021

The 1K polysiloxane topcoats on BUNO 168399 were inspected in May of 2021 after 25 months of active service at Camp Pendleton (figures 110-113), and this was the final inspection of this aircraft. After 2 years the topcoats remained in excellent condition and showed no signs of blistering, cracking, delamination, facial corrosion, or damage due to heat and fluids. However, the aircraft was extremely contaminated with smudge marks due to maintenance activities, and there was a thin layer of soot on the horizontal stabilizes and top of tail boom. Cleaning rags and isopropanol (IPA) were used to remove contaminants from the surface because the aircraft was not washed prior to inspection. As shown in Figure 114, use of the rags and IPA removed a significant amount of contaminants from the surface, thereby providing a clean surface to record color and gloss values. Cleaning of the 1K polysiloxane topcoats was performed on several areas of the aircraft.

Figure 110 —1K polysiloxane topcoat on left fuselage below nacelles on BUNO 168399 after 25 months of service.

Figure 111 —1K polysiloxane topcoats on left side tail boom of BUNO 168399 after 25 months of service.

Figure 112 —1K polysiloxane topcoat on right AFT cockpit area of BUNO 168399 after 25 months of service.

Figure 113 —1K polysiloxane topcoat on leading edge of left wing on BUNO 168399 after 25 months of service.

Figure 114 —Area of cleaned 1K polysiloxane topcoat on BUNO 168399 after 25 months of service.

DFT values were determined using the same PosiTector instrument that was used to obtain initial values (Tables 89 and 90). The average DFT for the medium gray 1K polysiloxane topcoat changed from 2.77 mils in April of 2019 to 2.76 mils in May of 2021, which is a decrease of 0.36%, whereas the average DFT for the blue gray 1K polysiloxane topcoat changed from 2.70 mils in April of 2019 to 2.47 mils in May of 2021, which is a decrease of 8.52%. It is unclear why there was a greater change in thickness for the blue gray topcoat, although the difference can likely be attributed to thickness measurements being collected in different areas, as the aircraft cannot be marked or labeled to ensure repeatability.

Table 89 — Average DFT values of medium gray 1K polysiloxane topcoat on BUNO 168399 after 25 months of service.

Location	Left side, DFT (mils)	Right side, DFT (mils)
FWD Cockpit	2.66	2.27
Fuselage Below Cockpit	3.17	3.08
AFT Cockpit	2.61	2.66
Nacelle	N/A	N/A
Side of Tail Boom	3.21	2.43
AVG.	**2.91**	**2.61**

Table 90 — Average DFT values of medium gray 1K polysiloxane topcoat on BUNO 168399 after 25 months of service.

Location	Left side, DFT (mils)	Right side, DFT (mils)
Nose	N/A	N/A
Leading edge of wing	3.35	2.04
Top of tail boom	1.90	2.41
Top of stabilizer	2.56	2.61
AVG.	**2.60**	**2.35**

The color and gloss of the 1K camouflage gray polysiloxane topcoats were determined using the same color and gloss meters that were used to obtain the initial and periodic inspection values. Measurements were collected on the left and right side of the forward cockpit area, fuselage below cockpit, rear area of cockpit, nose, leading edge of wing, side of tail boom, top of tail boom, and top of horizontal stabilizers. After 25 months, the color of the medium gray and blue gray 1K polysiloxane topcoats were visually similar to AH-1Z aircraft in the hanger that were painted with 2K camouflage gray polyurethane topcoats. However, as shown in Tables 91 and 92, the average color values collected from the aircraft were slightly darker for the medium gray 1K topcoat and slightly yellower for the blue gray 1K polysiloxane topcoat than initial values. The darker values can be attributed to remaining contaminants on the aircraft, whereas the increase in yellowness is potentially due to minor degradation at the surface from exposure in sunlight and/or degradation of the blue pigment in the topcoat. After 25 months of active service the average color change for the medium gray and blue gray 1K polysiloxane topcoats were 1.45 and 0.83, respectively, which is a decrease from the values calculated during the 19 month inspection (table 93). The lower color change was

likely the result of cleaning the topcoats with rags and IPA, thereby resulting in more accurate CIELAB values.

Table 91 — Average color values of medium gray 1K polysiloxane topcoat on BUNO 168399 after 25 months of service.

Location	**Left side, color coordinates**			**Right side, color coordinates**		
	L	**a**	**b**	**L**	**a**	**b**
FWD Cockpit	64.3	-2.25	-2.45	64.24	-2.31	-2.46
Fuselage Below Cockpit	64.99	-2.36	-3	61.94	-1.87	-1.57
AFT Cockpit	63.69	-2.21	-2.32	64.84	-2.29	-2.56
Nacelle	N/A	N/A	N/A	64.53	-2.31	-2.91
Side of Tail Boom	64.89	-2.31	-2.77	64.28	-2.27	-2.21
AVG.	**64.47**	**-2.28**	**-2.64**	**63.97**	**-2.21**	**-2.34**

Table 92 — Average color values of blue gray 1K polysiloxane topcoat on BUNO 168399 after 25 months of service.

Location	**Left side, color coordinates**			**Right side, color coordinates**		
	L	**a**	**b**	**L**	**a**	**b**
Nose	N/A	N/A	N/A	N/A	N/A	N/A
Leading edge of wing	55.56	-3.7	-2.67	55.85	-3.7	-2.69
Top of tail boom	54.58	-3.59	-2.41	55	-3.74	-3.16
Top of stabilizer	55.5	-3.86	-3.03	55.83	-3.84	-3.23
AVG.	**55.21**	**-3.72**	**-2.70**	**55.56**	**-3.76**	**-3.03**

Table 93 — Color change of medium gray (#36375) and blue gray (#35237) 1K polysiloxane topcoats on AH-1Z BUNO 168399 after 25 months of service.

BUNO	**1K Polysiloxane Color**	**April 2019**			**May 2021**			**ΔE**
		L*	**a***	**b***	**L***	**a***	**b***	
168399	Medium Gray	64.99	-2.16	-3.72	64.22	-2.24	-2.49	**1.45**
	Blue Gray	55.29	-3.75	-3.69	55.38	-3.74	-2.86	**0.83**

After 25 months, the gloss of the medium gray 1K topcoat had decreased to an average of 5.19 GU at 60 degrees and increased to an average of 6.17 GU at 85 degrees, whereas the gloss of the blue gray 1K topcoat had decreased to an average of 8.17 GU at 60-degrees and increased to an average of 16.23 GU at 85 degrees (tables 94 and 95). Many of the gloss values for the medium gray 1K topcoat, such as on the right side FWD cockpit, right side fuselage below cockpit, right nacelle, left AFT cockpit, and right side of tail boom, were all <5 GU at 60 degrees, which is required by NAVAIR. However, most 60 degree values on the left side of the aircraft were >5 GU, thus increasing the overall average. For the blue gray 1K topcoat, the right side top of tail boom was the only value <10 GU at 85 degrees. It is unknown why there was a significant increase in gloss at 85 degrees for the blue gray 1K topcoat after 25 months of service, but it is likely the curvature of these surfaces affected the ability of the meter to exclude light, thus providing misleading values. Visually, and as can be seen in Figures 110-113, both topcoats were low in gloss and appeared similar to aircraft in the hanger and nearby flight line that were painted with 2K polyurethane topcoats. Furthermore, squadron maintainers stated they did not notice a difference in appearance between this aircraft and other AH-1Zs that were painted with 2K polyurethane topcoats.

Table 94 — Average gloss values of medium gray 1K polysiloxane topcoat on BUNO 168399 after 25 months of service.

Location	**Left side, gloss units (GU)**		**Right side, gloss units (GU)**	
	60°	**85°**	**60°**	**85°**
FWD Cockpit	5.73	6.60	4.10	5.17
Fuselage Below Cockpit	5.73	6.60	4.23	9.77
AFT Cockpit	4.17	3.47	6.30	7.20
Nacelle	N/A	N/A	4.90	3.87
Side of Tail Boom	6.53	6.90	4.67	6.30
AVG.	**5.54**	**5.89**	**4.84**	**6.46**

Table 95 — Average gloss values of blue gray 1K polysiloxane topcoat on BUNO 168399 after 25 months of service.

Location	**Left side, gloss units (GU)**		**Right side, gloss units (GU)**	
	60°	**85°**	**60°**	**85°**
Nose	N/A	N/A	N/A	N/A
Leading edge of wing	9.33	21.00	8.77	21.93
Top of tail boom	8.33	12.57	7.77	8.43
Top of stabilizer	9.90	18.57	8.10	14.87
AVG.	**9.19**	**17.38**	**8.21**	**15.08**

7.2.4.10 Inspection of AH-1Z BUNO 168052 after 6 Months of Service – November 2019

The 1K polysiloxane topcoats on BUNO 168052 were inspected in November of 2019 after 6 months of active service at Camp Pendleton (figures 115-119). In general, the topcoats were in excellent condition with minor mechanical damage (i.e., scratches, chips) observed on the wings, nacelles, and fuselage below the nacelles. Staining was observed on the fuselage below the nacelles due to leaking engine oil. No signs of topcoat blistering, cracking, delamination, damage due to heat, or facial corrosion were observed. The 1K polysiloxane topcoats possessed several areas with dark contamination, especially on the wings where boot prints were discernable, yet attempts to remove these marks with water and rags were unsuccessful.

Figure 115 — Wide view of 1K polysiloxane topcoats on BUNO 168052 after 6 months of service.

Figure 116 — 1K polysiloxane topcoats on AFT cockpit, rotor housing, left leading edge of wing, and left nacelle of BUNO 168052 after 6 months of service.

Figure 117 — 1K polysiloxane topcoat on right nacelle of BUNO 168052 after 6 months of service.

Figure 118 — 1K polysiloxane topcoats on right tail boom of BUNO 168052 after 6 months of service.

Figure 119 — 1K polysiloxane topcoats on right horizontal and vertical stabilizers and of BUNO 168052 after 6 months of service.

Color and gloss of the 1K polysiloxane topcoats were determined using the same instruments that were used to obtain the initial values, and measurements were collected on the left and right side of the forward cockpit area, fuselage below cockpit, rear area of cockpit, side of tail boom, top of tail boom, and top of horizontal stabilizers.

Visually, the color of the medium gray and blue gray 1K polysiloxane topcoats were similar to AH-1Z aircraft on the nearby flight line that were painted with 2K polyurethane topcoats. However, as shown in Tables 96 and 97, the average color values collected from the aircraft showed there were minimal changes in the CIELAB values for both colors. At 6 months, the average color change for the medium gray and blue gray topcoats were 0.35 and 0.34, respectively. As stated previously, a color change of ≤1.0 is imperceptible to the human eye.

Table 96 — Average color values of medium gray 1K polysiloxane topcoat on BUNO 168052 after 6 months of service.

Location	**Left side, color coordinates**			**Right side, color coordinates**		
	L	**a**	**b**	**L**	**a**	**b**
FWD Cockpit	65.04	-2.56	-3.98	65.68	-2.51	-3.68
Fuselage Below Cockpit	66.83	-2.42	-3.73	65.73	-2.43	-3.40
AFT Cockpit	66.12	-2.45	-3.57	66.65	-2.51	-3.79
Nacelle	66.70	-2.22	-2.94	66.26	-2.45	-3.32
Side of Tail Boom	66.92	-2.41	-3.71	65.90	-2.39	-3.66
AVG.	**66.32**	**-2.41**	**-3.59**	**66.04**	**-2.46**	**-3.57**

Table 97 — Average color values of blue gray 1K polysiloxane topcoat on BUNO 168052 after 6 months of service.

Location	**Left side, color coordinates**			**Right side, color coordinates**		
	L	**a**	**b**	**L**	**a**	**b**
Nose	56.17	-3.72	-3.99	56.24	-3.73	-3.92
Leading edge of wing	55.92	-3.72	-4.00	55.84	-3.58	-3.50
Top of tail boom	56.16	-3.71	-4.15	55.72	-3.67	-3.86
Top of stabilizer	56.09	-3.74	-4.06	55.69	-3.72	-3.83
AVG.	**56.08**	**-3.72**	**-4.05**	**55.87**	**-3.68**	**-3.78**

After 6 months of service, the average gloss values for the medium gray 1K topcoat had changed from 5.31 GU to 4.09 GU at 60 degrees and from 3.82 GU to 5.57 GU at 85 degrees, whereas the average gloss values for the blue gray 1K polysiloxane topcoat changed from 3.00 GU to 2.06 GU at 60 degrees and 1.99 GU to 3.69 GU at 85 degrees (tables 98 and 99). The increase or decrease in average value at 6 months is likely the result of measurements being collected from different locations compared to the initial inspection. Regardless, the values were within the NAVAIR specified range of <5 GU at 60 degrees and <10 GU at 85 degrees. Visually, both topcoats possessed a flat finish and appeared similar to other AH-1Zs on the nearby flight line.

Table 98 — Average gloss values of medium gray 1K polysiloxane topcoat on BUNO 168052 after 6 months of service.

Location	**Left side, gloss units (GU)**		**Right side, gloss units (GU)**	
	60°	**85°**	**60°**	**85°**
FWD Cockpit	3.00	2.20	3.10	2.80
Fuselage Below Cockpit	5.20	8.90	3.50	5.40
AFT Cockpit	3.80	5.30	3.80	5.30
Nacelle	5.80	9.10	3.00	4.90
Side of Tail Boom	5.60	9.40	4.10	4.20
AVG.	**4.68**	**6.98**	**3.50**	**4.52**

Table 99 — Average gloss values of blue gray 1K polysiloxane topcoat on BUNO 168052 after 6 months of service.

Location	**Left side, gloss units (GU)**		**Right side, gloss units (GU)**	
	60°	**85°**	**60°**	**85°**
Nose	2.30	3.80	2.10	3.50
Leading edge of wing	2.30	5.30	2.20	5.20
Top of tail boom	2.40	4.00	2.10	2.90
Top of stabilizer	1.60	2.10	1.50	2.70
AVG.	**2.14**	**3.80**	**1.98**	**3.58**

7.2.4.11 Inspection of AH-1Z BUNO 168052 after 12 Months of Service – May 2020

The 1K polysiloxane topcoats on BUNO 168052 were not be inspected at the 1-year service period due to travel restrictions and limited base access as a result of the COVID-19 pandemic.

7.2.4.12 Inspection of AH-1Z BUNO 168052 after 15 Months of Service – August 2020

The 1K polysiloxane topcoats on BUNO 168052 were inspected in August of 2020 after 15 months of active service at Camp Pendleton (figures 120-124). In general, the topcoats were in excellent condition with no mechanical damage, staining from fluids, blistering, cracking, delamination, or facial corrosion. Due to mechanical issues the aircraft was in the hanger where the nose cover, horizontal stabilizers, and sections of the vertical stabilizer were removed for maintenance purposes. The doors of the fuselage below the cockpit were also opened, thus preventing inspection of the topcoat in this area. The topcoats were contaminated with soot and grease in several areas due to maintenance activities, and the presence of hand and boot prints could be visually observed on the wings. The aircraft was not cleaned prior to inspection.

Figure 120 — 1K polysiloxane topcoats on tail section of BUNO 168052 after 15 months of service.

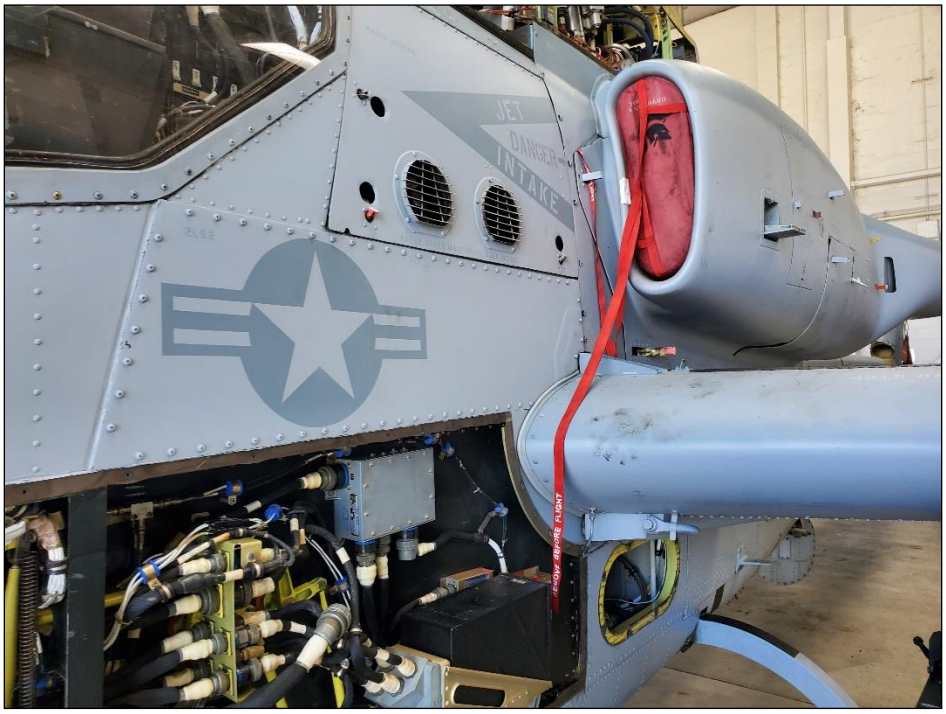


Figure 121 — 1K polysiloxane topcoats on AFT cockpit of BUNO 168052 after 15 months of service.

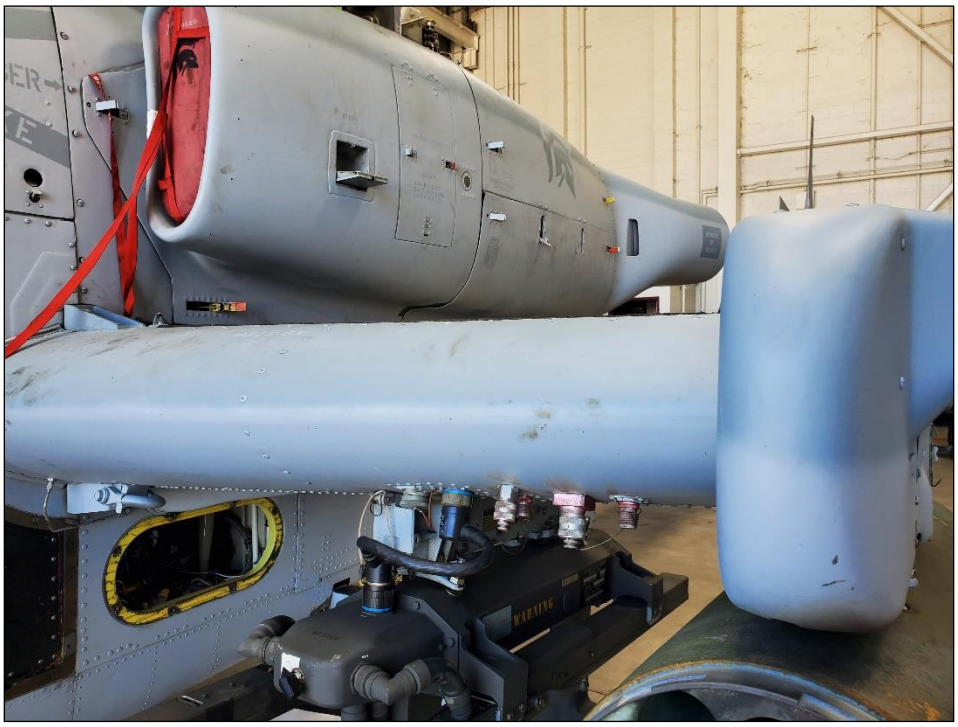


Figure 122 — 1K polysiloxane topcoats on left leading edge of wing and nacelle of BUNO 168052 after 15 months of service.

Figure 123 — 1K polysiloxane topcoats on left tail boom of BUNO 168052 after 15 months of service.

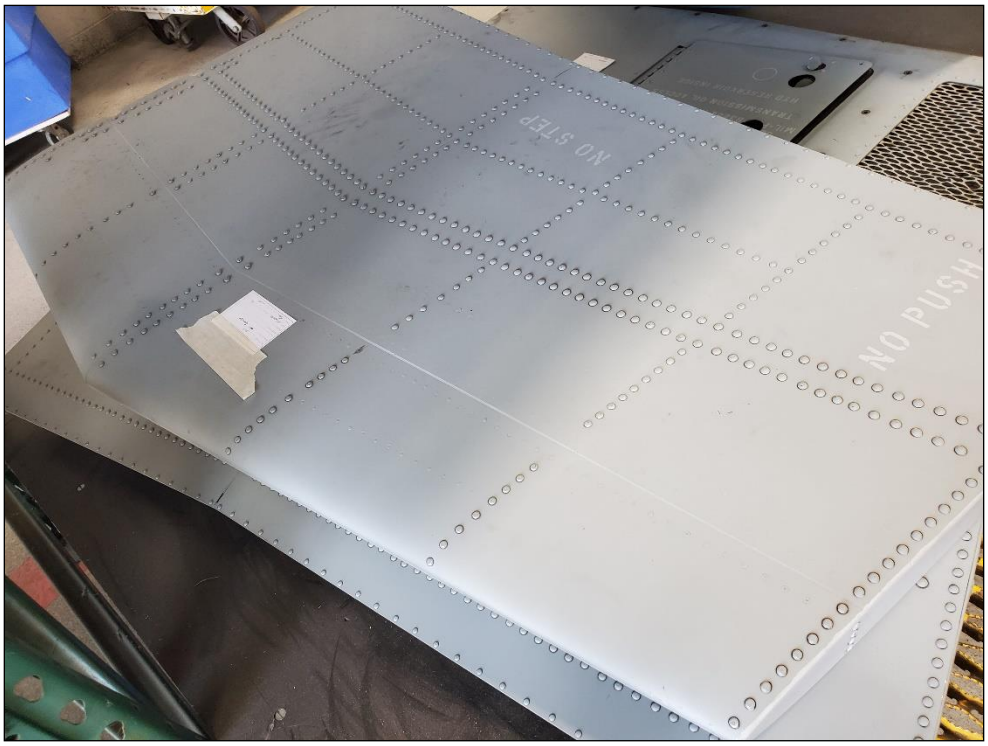


Figure 124 — 1K polysiloxane topcoat on horizontal stabilizer (removed) of BUNO 168052 after 15 months of service.

The color and gloss of the 1K polysiloxane topcoats were determined using the same instruments that were used to obtain the initial and 6-month values, and measurements were collected on the left and right side of the forward cockpit area, fuselage below cockpit, rear area of cockpit, nose, leading edge of wing, side of tail boom, top of tail boom, and top of horizontal stabilizers.

After 15 months of service, the color of the medium gray and blue gray 1K polysiloxane topcoats were visually similar to AH-1Zs in the hanger that were painted with 2K polyurethane topcoats. As shown in Tables 100 and 101, the average color values collected from the aircraft were slightly darker and less blue than the initial measurements. The slightly darker values can be attributed to the contaminants on the aircraft, and the increase in yellowness is potentially due to minor UV-degradation at the surface of the topcoats upon exposure in sunlight during active service periods. However, the "b" values for the medium gray topcoat on the nacelle and side of tail boom were significantly more positive than in other areas, which biased the average "b" value for this color. It is unknown why there was large variance in the data, as the colors across the aircraft were visually uniform. However, it is possible that the color meter did not exclude all external light when placed on curved areas of the nacelle or side of tail boom, thereby allowing light to enter the meter and alter the values. After 15 months of service, the color change for the medium gray and blue gray 1K polysiloxane topcoats were 1.69 and 1.27, respectively.

Table 100 — Average color values of medium gray 1K polysiloxane topcoat on BUNO 168052 after 15 months of service.

Location	**Left side, color coordinates**			**Right side, color coordinates**		
	L	**a**	**b**	**L**	**a**	**b**
FWD Cockpit	66.06	-2.39	-2.56	65.90	-2.50	-2.66
Fuselage Below Cockpit	66.16	-2.39	-2.64	65.54	-2.50	-2.60
AFT Cockpit	66.12	-2.43	-2.75	65.98	-2.45	-2.47
Nacelle	64.70	-2.13	0.81	65.15	-2.33	-1.26
Side of Tail Boom	65.85	-2.11	-0.87	65.29	-2.03	0.19
AVG.	**65.78**	**-2.29**	**-1.60**	**65.57**	**-2.36**	**-1.76**

Table 101 — Average color values of blue gray 1K polysiloxane topcoat on BUNO 168052 after 15 months of service.

Location	Left side, color coordinates			Right side, color coordinates		
	L	**a**	**b**	**L**	**a**	**b**
Nose	56.46	-3.53	-3.10	56.06	-3.00	-3.00
Leading edge of wing	56.39	-3.44	-2.94	56.36	-3.49	-2.79
Top of tail boom	55.48	-3.22	-2.61	54.04	-3.12	-2.19
Top of stabilizer	56.19	-3.27	-2.15	56.20	-3.40	-2.66
AVG.	**56.13**	**-3.37**	**-2.70**	**55.67**	**-3.40**	**-2.66**

After 15 months of service, the average gloss values the medium gray 1K topcoat increased from 5.31 GU to 6.55 GU at 60 degrees and 3.82 GU to 7.71 GU at 85 degrees (table 102), whereas the average gloss values for the blue gray 1K topcoat increased slightly from 3.00 GU to 3.67 GU at 60 degrees and 1.99 GU to 4.49 GU at 85 degrees (table 103). It is unclear why there was an increase in gloss for several areas of the medium gray topcoat, as the average 60 degree gloss at 6 months was <5 GU. However, the average value at 85 degrees remained <10 GU, even with the increase in several locations. As shown in Table 102, these elevated values appear to be greatest on the nacelle and side of tail boom, which are highly curved surfaces, thus it is possible that all external light was not excluded when the values were recorded. All gloss values for the blue gray 1K topcoat remained <5 GU at 60 degrees and <10 GU at 85 degrees, which met the NAVAIR gloss requirement for a camouflage topcoat. Visually, the gloss on all locations was flat and the aircraft appeared similar to other AH-1Zs in the hanger that were painted with 2K polyurethane topcoats.

Table 102 — Average gloss values of medium gray 1K polysiloxane topcoat on BUNO 168052 after 15 months of service.

Location	Left side, gloss units (GU)		Right side, gloss units (GU)	
	60°	**85°**	**60°**	**85°**
FWD Cockpit	5.43	4.37	5.47	4.70
Fuselage Below Cockpit	7.23	8.77	5.00	5.63
AFT Cockpit	6.33	6.40	7.50	9.53
Nacelle	7.90	10.57	5.60	8.37
Side of Tail Boom	9.20	11.27	5.87	7.50
AVG.	**7.22**	**8.27**	**5.89**	**7.15**

Table 103 — Average gloss values of blue gray 1K polysiloxane topcoat on BUNO 168052 after 15 months of service.

Location	Left side, gloss units (GU)		Right side, gloss units (GU)	
	60°	**85°**	**60°**	**85°**
Nose	4.40	4.47	3.37	4.47
Leading edge of wing	3.73	5.30	4.37	5.60
Top of tail boom	3.23	2.93	3.30	2.93
Top of stabilizer	3.13	4.43	3.80	5.80
AVG.	**3.63**	**4.28**	**3.71**	**4.70**

7.2.4.13 Inspection of AH-1Z BUNO 168052 after 18 Months of Service – November 2020

The 1K polysiloxane topcoats on BUNO 168052 were inspected in November of 2020 after 18 months of active service at Camp Pendleton (figures 125 to 130). In general, the topcoats were in good condition with no blistering, cracking, delamination, or facial corrosion. The fuselage, leading edge of wings, and nose (figure 127) all possessed minor mechanical damage (e.g., scratches) due to normal operations. Engine fluid was leaking on the fuselage, and there appeared to be some light staining on the forward area of the tail boom. The topcoats were also contaminated with soot in several area, such as on the horizontal stabilizers and top of tail boom (figure 130). The aircraft was not washed prior to inspection, and attempts to remove the staining and dark contaminants with water and rags were unsuccessful.

Figure 125 — 1K polysiloxane topcoat on forward cockpit area of BUNO 168052 after 20 months of service.

Figure 126 — 1K polysiloxane topcoats on AFT cockpit and rotor housing of BUNO 168052 after 20 months of service.

Figure 127 — 1K polysiloxane topcoat on nose of BUNO 168052 after 20 months of service.

Figure 128 — 1K polysiloxane topcoat on left nacelle of BUNO 168052 after 20 months of service.

Figure 129 — 1K polysiloxane topcoats on left side tail boom of BUNO 168052 after 20 months of service.

Figure 130 — 1K polysiloxane topcoat on left horizontal stabilizer of BUNO 168052 after 20 months of service.

The color and gloss of the 1K polysiloxane topcoats were determined using the same instruments that were used to obtain the initial and periodic inspections, and measurements were collected on the left and right side of the forward cockpit area, fuselage below cockpit, rear area of cockpit, nose, leading edge of wing, side of tail boom, top of tail boom, and top of horizontal stabilizers.

After 18 months of service, the color of the medium gray and blue gray 1K polysiloxane topcoats were visually similar to AH-1Zs on the flight line that were painted with 2K polyurethane topcoats. As shown in Tables 104 and 105, the average color values collected from the aircraft were slightly darker and less blue than the initial measurements. The slightly darker values can be attributed to the contaminants on the aircraft, and the slight increase in yellowness is potentially due to minor UV-degradation at the surface upon exposure in sunlight during active service periods. However, the "b" values for the medium gray topcoat on the nacelle and side of tail boom were significantly more positive than in other areas, which biased the overall average "b" value. It is unknown why there was large variance in the data, but minor staining on the tail boom likely caused the larger change in color value. After 18 months of service, the average color change for the medium gray and blue gray 1K polysiloxane topcoats were 1.74 and 2.55, respectively.

Table 104 — Average color values of medium gray 1K polysiloxane topcoat on BUNO 168052 after 18 months of service.

Location	**Left side, color coordinates**			**Right side, color coordinates**		
	L	**a**	**b**	**L**	**a**	**b**
FWD Cockpit	64.84	-2.38	-2.66	65.82	-2.35	-2.49
Fuselage Below Cockpit	65.55	-2.39	-2.61	65.84	-2.34	-2.61
AFT Cockpit	65.80	-2.38	-2.54	65.93	-2.39	-2.59
Nacelle	65.11	-2.23	-1.46	65.10	-2.16	-1.43
Side of Tail Boom	63.72	-1.65	0.82	64.83	-1.94	-0.71
AVG.	**65.00**	**-2.21**	**-1.69**	**65.50**	**-2.24**	**-1.97**

Table 105 — Average color values of blue gray 1K polysiloxane topcoat on BUNO 168052 after 18 months of service.

Location	**Left side, color coordinates**			**Right side, color coordinates**		
	L	**a**	**b**	**L**	**a**	**b**
Nose	56.37	-3.41	-2.82	N/A	N/A	N/A
Leading edge of wing	56.02	-3.27	-2.42	56.01	-3.24	-2.46
Top of tail boom	55.72	-3.16	-2.34	55.42	-3.00	-1.84
Top of stabilizer	51.49	-2.40	0.24	53.93	-2.75	-0.67
AVG.	**54.90**	**-3.06**	**-1.84**	**55.12**	**-3.00**	**-1.66**

After 18 months of service, the average gloss values the medium gray 1K topcoat increased from 5.31 GU to 7.79 GU at 60 degrees and 3.82 GU to 8.77 GU at 85 degrees (table 106), whereas the average gloss values for the blue gray 1K topcoat increased slightly from 3.00 GU to 4.34 GU at 60 degrees and 1.99 GU to 6.09 GU at 85 degrees (table 107). It is unclear why the 60-degree gloss for the medium gray topcoat increased to greater than 5 GU, but the presence of oil and contaminants on the surface likely distorted the true gloss values. However, the average 60 and 85 degree values for the blue gray topcoat were within the NAVAIR specified range of ≤5 GU at 60 degrees and ≤10 GU at 85 degrees. Visually, the gloss across the aircraft was flat and the appearance was similar to 2K polyurethane topcoats on surrounding AH-1Zs on the flight line.

Table 106 — Average gloss values of medium gray 1K polysiloxane topcoat on BUNO 168052 after 18 months of service.

Location	**Left side, gloss units (GU)**		**Right side, gloss units (GU)**	
	60°	**85°**	**60°**	**85°**
FWD Cockpit	9.87	13.70	6.60	9.37
Fuselage Below Cockpit	7.53	8.57	5.20	5.70
AFT Cockpit	5.00	4.63	7.37	7.80
Nacelle	8.03	8.13	5.43	6.97
Side of Tail Boom	13.80	14.73	9.07	8.10
AVG.	**8.85**	**9.95**	**6.73**	**7.59**

Table 107 — Average gloss values of blue gray 1K polysiloxane topcoat on BUNO 168052 after 18 months of service.

Location	**Left side, gloss units (GU)**		**Right side, gloss units (GU)**	
	60°	**85°**	**60°**	**85°**
Nose	3.40	3.83	N/A	N/A
Leading edge of wing	4.37	7.10	4.10	5.57
Top of tail boom	3.10	3.33	5.43	7.53
Top of stabilizer	4.23	5.97	5.20	8.30
AVG.	**3.78**	**5.06**	**4.91**	**7.13**

7.2.4.14 Inspection of AH-1Z BUNO 168052 after 24 Months of Service – May 2021

The 1K polysiloxane topcoats on BUNO 168052 were inspected in May of 2021 after 24 months of active service at Camp Pendleton, which served as the final inspection of this aircraft. The aircraft was washed by the squadron prior to the inspection, although small areas of contamination remained. However, these contaminants could not be removed with rags and IPA because solvent was not allowed on the flight line. The topcoats were in good to excellent condition, showing no signs of blistering, cracking, delamination, facial corrosion, or damage due to heat and fluids (figures 131-136). Visually, the 1K polysiloxane topcoats were identical to other AH-1Zs that were painted with 2K polyurethane topcoats.

Figure 131 — 1K polysiloxane topcoat on left side forward cockpit area of BUNO 168052 after 24 months of service.

Figure 132 — 1K polysiloxane topcoat on right side below cockpit of BUNO 168052 after 24 months of service.

Figure 133 — 1K polysiloxane topcoat on left nacelle of BUNO 168052 after 24 months of service.

Figure 134 — 1K polysiloxane topcoats on tail boom and horizontal stabilizer of BUNO 168052 after 24 months of service.

Figure 135 — 1K polysiloxane topcoats on left nacelle, fuselage, and tail boom of BUNO 168052 after 24 months of service.

Figure 136 — 1K polysiloxane topcoat on top of tail boom of BUNO 168052 after 24 months of service.

Final DFT values were determined using the same PosiTector instrument that was used to collect initial values (Tables 108 and 109). The average DFT for the medium gray 1K polysiloxane topcoat changed from 3.33 mils in May of 2019 to 3.69 mils in May of 2021, which is an increase of 10.8%, whereas the average DFT for the blue gray 1K polysiloxane topcoat changed from 3.35 mils in May of 2019 to 3.39 mils in May of 2021, which is an increase of only 1.19%. The thickness of the topcoat cannot increase over time, so it is likely the increase in DFT was due to recording values from thicker areas, such as on the left side of the tail boom. As mentioned previously, the aircraft cannot be marked or labeled to ensure repeatability, especially when recording film thickness values.

Table 108 — Average DFT values of medium gray 1K polysiloxane topcoat on BUNO 168052 after 24 months of service.

Location	Left side, DFT (mils)	Right side, DFT (mils)
FWD Cockpit	2.99	3.09
Fuselage Below Cockpit	3.05	3.40
AFT Cockpit	4.50	3.01
Nacelle	N/A	N/A
Side of Tail Boom	5.46	4.04
AVG.	**4.00**	**3.39**

Table 109 — Average DFT values of blue gray 1K polysiloxane topcoat on BUNO 168052 after 24 months of service.

Location	Left side, DFT (mils)	Right side, DFT (mils)
Nose	N/A	N/A
Leading edge of wing	4.44	2.60
Top of tail boom	2.84	2.60
Top of stabilizer	5.22	2.64
AVG.	**4.17**	**2.61**

The color and gloss values of the 1K polysiloxane topcoats were determined using the same instruments that were used to obtain the initial and periodic inspection values. Measurements were collected on the left and right side of the forward cockpit area, fuselage below cockpit, rear area of cockpit, nose, leading edge of wing, side of tail boom, top of tail boom, and top of horizontal stabilizers. After 25 months, the average color for the medium gray 1K polysiloxane was slightly darker and more yellow than the initial values, whereas the average color for the blue gray 1K polysiloxane topcoat was slightly lighter and more yellow (Tables 110 and 111). The darker values for the medium gray 1K topcoat can be attributed to contaminants remaining on the aircraft, whereas the increase in yellowness is potentially due to degradation at the coating surface due to sunlight. The “b” value on the right side of the tail boom was positive, which significantly altered the average. However, it is possible this value was incorrectly transcribed from the meter, as the “b” value on the left side of the tail boom is negative. After 25 months of active service the color change for the medium gray and blue gray 1K polysiloxane topcoats were 1.69 and 2.08, respectively (table 112), which is a decrease from the values calculated during the 18 month inspection (table 93). The lower color

change is likely due to maintainers washing the aircraft prior to inspection, thereby providing more accurate CIELAB values for the topcoats. It is also worth mentioning that the medium gray and blue gray 1K polysiloxane topcoats were visually similar to AH-1Z aircraft on the flight line that were painted with 2K polyurethane topcoats, and maintainers did not notice a difference between the topcoats on this aircraft and those on other AH-1Zs.

Table 110 — Average color values of medium gray 1K polysiloxane topcoat on BUNO 168052 after 24 months of service.

Location	**Left side, color coordinates**			**Right side, color coordinates**		
	L	**a**	**b**	**L**	**a**	**b**
FWD Cockpit	66.18	-2.38	-2.55	66.13	-2.4	-2.54
Fuselage Below Cockpit	66.15	-2.36	-2.46	65.95	-2.44	-2.36
AFT Cockpit	66.28	-2.46	-2.55	65.73	-2.37	-2.20
Nacelle	66.08	-2.05	-1.22	65.64	-2.19	-1.21
Side of Tail Boom	65.00	-1.13	-1.23	64.69	-1.51	1.29
AVG.	**65.94**	**-2.08**	**-2.00**	**65.63**	**-2.18**	**-1.40**

Table 111 — Average color values of blue gray 1K polysiloxane topcoat on BUNO 168052 after 24 months of service.

Location	**Left side, color coordinates**			**Right side, color coordinates**		
	L	**a**	**b**	**L**	**a**	**b**
Nose	56.98	-3.39	-2.73	N/A	N/A	N/A
Leading edge of wing	57.18	-3.17	-2.40	56.63	-3.24	-2.30
Top of tail boom	57.40	-2.91	-1.92	57.53	-2.95	-1.98
Top of stabilizer	56.36	-2.89	-1.23	56.09	-2.78	-1.28
AVG.	**56.98**	**-3.09**	**-2.07**	**56.75**	**-2.99**	**-1.85**

Table 112 — Color change of medium gray (#36375) and blue gray (#35237) 1K polysiloxane topcoats on AH-1Z BUNO 168052 after 24 months of service.

BUNO	1K Polysiloxane Color	May 2019			May 2021			ΔE
		L*	a*	b*	L*	a*	b*	
168052	Medium Gray	66.14	-2.60	-3.28	65.78	-2.13	-1.70	**1.69**
	Blue Gray	56.30	-3.75	-3.83	56.86	-3.04	-1.96	**2.08**

After 25 months of service the average gloss of the medium gray 1K topcoat had increased from 5.13 GU to 7.19 GU at 60 degrees and 3.82 GU to 8.90 GU at 85 degrees, whereas the average gloss of the blue gray 1K topcoat had increased from 3.0 GU to 3.43 GU at 60 degrees and 1.99 GU to 4.76 GU at 85 degrees (tables 113 and 114). The average at 60 degrees for the medium gray 1K topcoat had exceeded the NAVAIR specified value of ≤5 GU, although the average at 85 degrees remained below 10 GU. For the blue gray 1K topcoat, the average values at both 60 and 85 degrees remained at <5 GU and <10 GU, respectively. It is unknown why there was a significant increase in gloss at 85 degrees for the medium gray 1K topcoat, especially on the left side of the tail boom, but it is likely the surface curvature affected the ability of the meter to remain flat and exclude light, thus generating misleading values. Visually, and as can be seen in Figures 131-136, both topcoats were low in gloss and similar to aircraft on the flight line that were painted with 2K polyurethane topcoats. As stated previously, maintainers within the squadron stated they did not notice a difference in appearance between this aircraft and other AH-1Zs that were painted with 2K polyurethane topcoats.

Table 113 — Average gloss values of medium gray 1K polysiloxane topcoat on BUNO 168052 after 24 months of service.

Location	Left side, gloss units (GU)		Right side, gloss units (GU)	
	60°	85°	60°	85°
FWD Cockpit	5.47	4.57	5.87	2.97
Fuselage Below Cockpit	8.03	10.53	6.67	8.67
AFT Cockpit	8.23	7.37	7.80	9.00
Nacelle	N/A	N/A	6.23	10.00
Side of Tail Boom	9.70	16.80	6.03	9.27
AVG.	**7.86**	**9.82**	**6.52**	**7.98**

Table 114 — Average gloss values of blue gray 1K polysiloxane topcoat on BUNO 168052 after 24 months of service.

Location	**Left side, gloss units (GU)**		**Right side, gloss units (GU)**	
	60°	**85°**	**60°**	**85°**
Nose	3.57	4.60	N/A	N/A
Leading edge of wing	4.77	7.33	4.37	6.47
Top of tail boom	3.83	5.40	4.27	4.97
Top of stabilizer	2.90	3.90	3.77	5.43
AVG.	**3.77**	**5.31**	**3.10**	**4.22**

7.2.4.15 Discussion

The entire OML of three AH-1Z Viper aircraft (BUNOs 168798, 168399 and 168052) at Camp Pendleton were painted with NCP's single-component camouflage gray polysiloxane topcoats, in FED-STD-595 #36375 medium gray and #35237 blue gray colors, during the Spring of 2019. Because of its all-in-one-can nature the artisans were not required to meter and mix components, thereby saving 10-15 minutes of preparation time, which met the success criteria for ease-of-use as shown in Table 9. The gallon cans of 1K topcoat were agitated for only few minutes on a mechanical shaker, opened, poured into the pressure pot, and the coating was sprayed using an HVLP spray gun with a 1.8 mm fluid tip. This is the same equipment that is commonly used to apply MIL-PRF-85285 qualified 2K camouflage gray polyurethane topcoats, which met the success criteria for equipment and method of application as shown in Table 9.

Artisans did not experience issues with sagging of the 1K topcoats during applications, nor did they experience adhesion issues when colors were blended at transition points. After the applications, the medium gray and blue gray colored 1K polysiloxane topcoats were visually homogenous across all three aircraft, which met the success criteria for appearance as shown in Table 9. Unused medium gray 1K topcoat was recovered from the pressure pot after each aircraft was painted, the paint was returned to the original gallon cans, the cans were closed, and the topcoat was utilized for stenciling the following day, This demonstrated that essentially zero hazardous paint waste was generated by using the 1K topcoat, which met the success criteria as shown in Table 10. Both topcoats were dry hard the day following the spray applications, even though they were still curing. Furthermore, the topcoats did not mar or lose adhesion (i.e., between layers or the underlying primer) when the vinyl stencils were removed via peeling.

During each aircraft application the artisans utilized 4 gallons of the medium gray 1K topcoat and 2 gallons of the blue gray 1K polysiloxane topcoat to paint the entire exterior of each aircraft, which included stenciling, as opposed to requiring approximately 6.25 gallons of a MIL-PRF-85285 qualified 2K polyurethane topcoat. However, the VOC content for the 1K polysiloxane topcoat is only 286 g/l (2.38 lb/gal) versus 420 g/l (3.50 lb/gal) for a 2K polyurethane, which equates to a difference of 7.59 pounds of VOCs emitted into the air during the painting of each aircraft. There are about 74 AH-1Z aircraft (i.e., 64 for squadron, 10 for reserve squadron) at Camp Pendleton, which equates to a potential reduction of approximately 562 pounds of VOCs if all aircraft were painted with the 1K camouflage gray polysiloxane topcoats instead of 2K camouflage gray polyurethane topcoats. A reduction in VOCs by applying the 1K topcoats resulted in successfully meeting the criteria shown in Table 10.

HDI isocyanate was not detected when air samples were collected and analyzed by the Industrial Hygiene office at Camp Pendleton during application of the medium gray 1K polysiloxane topcoat on BUNO 168798 in March of 2019. This demonstrated that airborne isocyanates could be eliminated by using the 1K camouflage gray polysiloxane topcoat, which met the success criteria for isocyanate elimination shown in Table 10.

Overall, the medium gray and blue gray 1K polysiloxane topcoats performed well on the three AH-1Z helicopters after approximately 2 years of active field service at Camp Pendleton. During the inspections, the topcoats had only a few small areas of mechanical damage (i.e., scrapes, chips), which were due to maintenance on the aircraft. Leaking engine oil was occasionally observed on the fuselage during inspections, which is common for these aircraft, although little-to-no staining of the topcoats was observed. There were also no signs of topcoat blistering, cracking, delamination, heat damage, or facial corrosion, which met the success criteria in Table 9. The aircraft were contaminated (e.g., soot, grease) in several areas during the majority of inspections, especially when maintenance was occurring inside a hanger, although the majority of contaminants were removed upon washing by the squadron. Additional contaminants were removed when water and isopropanol was used during inspections, although water and rags were unable to remove these same surface contaminants.

After approximately 2 years of service, all three AH-1Zs that were painted with the 1K polysiloxane camouflage gray topcoat had a similar appearance to aircraft on the flight line and inside hangers that were painted with a MIL-PRF-85285 qualified 2K camouflage gray polyurethane topcoat, which the success criteria for visual in-service weatherability shown in Table 9. Furthermore, aircraft maintainers in the squadrons stated the 1K polysiloxane topcoats cleaned well when washed, and they could not discern a difference in appearance, nor did they observe a difference in performance, between the 1K polysiloxane topcoats and aircraft painted with 2K polyurethane topcoats.

The medium gray 1K polysiloxane topcoat on BUNO 168798 demonstrated an average color change of 2.03 after 20 months of service, whereas the same topcoat on BUNOs 168399 and 168052 demonstrated an average color change of 1.45 and 1.69 after 25 and 24 months of service, respectively (figure 137). Similarly, the blue gray 1K polysiloxane topcoat on BUNO 168798 demonstrated an average color change of 2.19 after 20 months, whereas the same topcoat on BUNOs 168399 and 168052 demonstrated an average color change of 0.83 and 2.08 after 25 and 24 months of service, respectively. A few of the color change values exceeded 2.0 between the 16-18 month inspection periods, although the elevated values can be attributed to contaminants on the aircraft, which were not removed prior to inspections (see Section 7.2.4). In general, both colors of the 1K polysiloxane topcoat were successful at retaining a ΔE of ≤ 2.0 after 2 years of service, which met the in-service weathering criteria as shown in Table 10.

The gloss values of the medium gray and blue gray 1K polysiloxane topcoats were relatively consistent when comparing the initial and final inspection values, whereas periodic inspections demonstrated both increases and decreases in values. The variability during inspections was most likely due to the gloss meter not being flush with the surface when values were collected, especially when collecting values on areas of the aircraft with high curvature (e.g., leading edge of wings, top of tail boom). As a result, external light was allowed to enter the meter and alter the values. The aircraft with the most consistent gloss values was BUNO 168052, which possessed an average 60-degree gloss of 7.19 GU and 3.43 GU for the medium gray and blue gray topcoats, respectively, after 24 months, in addition to an average 85 degree gloss of 8.90 GU and 4.76 GU for the medium gray and blue gray topcoats, respectively (figure 138). Aside from the average gloss value for the medium gray 1K topcoat at 60 degrees, which was higher due to areas of high curvature, all other values met the NAVAIR requirement of ≤ 5 GU at 60 degrees and ≤ 10 GU at 85 degrees, thus meeting the success criteria in Table 10. Furthermore, as stated previously, the gloss on all three aircraft

had a flat appearance and were visually similar to other AH-1Z aircraft that were painted with MIL-PRF-85285 qualified 2K camouflage gray polyurethane topcoats.

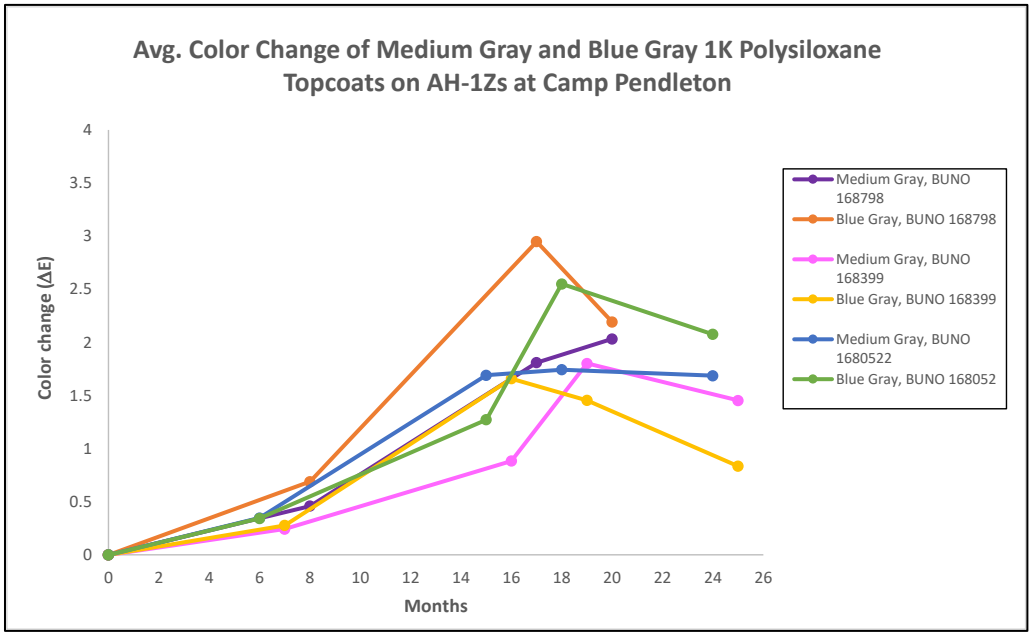


Figure 137 — Average color change of 1K polysiloxane topcoats after approximately 2 years of service on AH-1Zs.

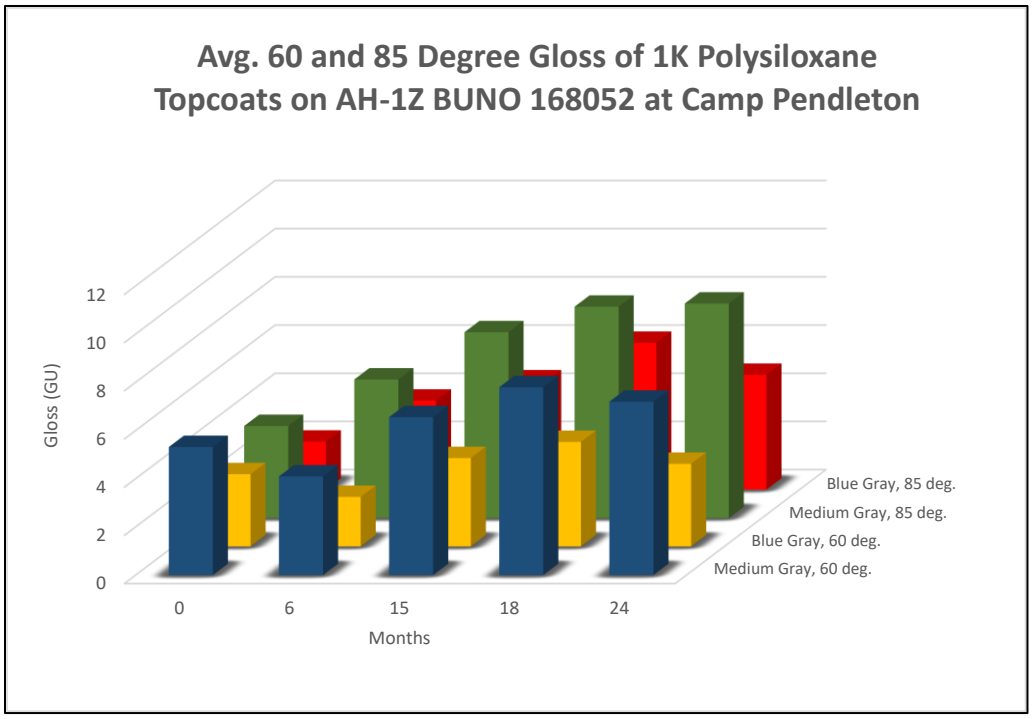


Figure 138 — Average gloss of 1K polysiloxane topcoats after 24 months of service on AH-1Z BUNO 168052.

7.3 Demonstration of 1K Camouflage Gray Polysiloxane Topcoats on UH-1Y Venoms

In 2019, the single-component camouflage gray polysiloxane topcoat, in FED-STD-595 #36375 medium gray and #35237 blue-gray colors, was produced in multi-gallon quantities by NCP Coatings for application on the entire OML of two Bell UH-1Y helicopters stationed at Marine Corps Air Station New River, Jacksonville, North Carolina. The first application occurred in mid-February on BUNO 168416, whereas BUNO 167807 was painted in August of 2019. Both aircraft were painted inside a temperature and humidity controlled paint booth. The aircraft were then provided to squadrons for use in the field under normal operating conditions, and periodic inspections of the topcoats occurred over the course of approximately 2 years.

7.3.1 UH-1Y BUNO 168416 – February 2019

7.3.1.1 Preparation and Painting of BUNO 168416

This aircraft was prepared for painting by first removing the aged polyurethane topcoat and anti-corrosive epoxy primer from the aluminum alloy skin and composite materials (figure 139). This was accomplished using plastic media blast and hand sanding according to NAVAIR established procedures. Once the coatings were removed the aluminum alloy skin was treated with an Alodine 1200 marker, followed by a MIL-PRF-81706 chromate conversion solution. This was followed by spray-application of PPG/Deft 44GN008A, which is a MIL-PRF-85582, Type II, Class 1 hexavalent chromium based waterborne epoxy primer with low infrared reflective pigments.[36] The primer was at 72 °F and 40% relative humidity to achieve an average DFT of 0.61 mils (figure 140). Once finished, the hanger was closed and the temperature was increased to 100 °F for 4 hours. This decreased to humidity in the hanger to 10-15%.

After the primer was baked for 4 hours the artisans agitated gallon cans of the medium gray 1K polysiloxane topcoat (NCP Batch #20-32-1, DoM 11/2018) for several minutes each using a paint shaker (figure 141), then opened the cans and poured the liquid coating into 3M paint preparation system (PPS)™ gravity feed cups. These cups were attached to Binks Mach 1 HVLP spray guns with a 1.2 mm fluid tip. The line pressure was 80 psi, whereas the pressure at the spray gun was 10-12 psi. The temperature and relative humidity in the booth were 92 °F and 13%, respectively, yet the artisans began spraying instead of waiting for the temperature to decrease and the humidity to increase. Figure 142 shows an artisan spraying the medium gray 1K polysiloxane topcoat on the right side tail boom, whereas figure 143 shows the topcoat being applied on the right side fuselage and nacelle. The majority of the aircraft, except for the rotor housing, horizontal stabilizers, top of tail boom, and nose, was painted with the medium gray 1K topcoat. The majority of the aircraft was painted with the medium gray 1K topcoat within 45 minutes and consumed about 2.5 gallons of topcoat. Two gallons of the blue gray 1K polysiloxane topcoat (NCP Batch #19-118-3, DoM 11/2018) were agitated, poured into gravity feed cups, attached to the spray guns, then applied on the remaining areas of the aircraft. This application required 35 minutes and consumed about 1.25 gallons of topcoat. The booth conditions were 85 °F and 12% relative humidity when painting ceased, then the topcoat was allowed to cure overnight. Figure 144 shows a photo of the aircraft after the topcoats had cured overnight.

The following day, the majority of the aircraft was stenciled using small quantities of the medium gray and blue gray 1K polysiloxane topcoats. The medium gray topcoat on the sides of the tail boom was marginally soft due to the low humidity in the booth both during and post application cure, so the artisans waited another day to apply the vinyl stencils to that area. Upon removing the stencils there were no signs of topcoat delamination. The aircraft was provided to the squadron 1-2 weeks after all work was complete and the aircraft was fully assembled (figure 145).

Figure 139 — Prepared surface of BUNO 168416.

Figure 140 —MIL-PRF-85582, Type II primer after spray-applied on BUNO 168416.

Figure 141 — Gallon cans of medium gray and blue gray 1K polysiloxane topcoat for painting BUNO 168416.

Figure 142 — Spray application of medium gray 1K polysiloxane topcoat on tail boom of BUNO 168416.

Figure 143 — Spray application of medium gray 1K polysiloxane topcoat on fuselage and nacelles of BUNO 168416.

Figure 144 — Medium gray and blue gray 1K polysiloxane topcoats on BUNO 168416 the day after application.

Figure 145 —BUNO 168416 with 1K polysiloxane topcoats after delivered to squadron.

7.3.1.2 Volume of Topcoats Utilized and Emitted VOCs

The painting of UH-1Y BUNO 168416 required 2.5 gallon of medium gray and 1.25 gallons of blue gray 1K polysiloxane topcoat for a total of 3.75 gallons. This does not include the minor amount of topcoat that was used for stenciling. For comparison, artisans typically use a total of 5.0-5.5 gallons (i.e., 3.0-3.5 gallons of medium gray and 2 gallons of blue gray) of a MIL-PRF-85285 2K camouflage gray polyurethane topcoat to paint the exterior of a UH-1Y Venom. At 286 g/l (2.38 lb/gal) VOC content the 1K polysiloxane topcoats emitted 8.92 pounds of volatiles, whereas a 2K polyurethane, which has a VOC content of 420 g/l (3.50 lb/gal), emits 17.5-19.25 pounds of volatiles for the same application. Thus, not only was less paint consumed by painting the aircraft with the 1K polysiloxane topcoats, but a reduction of 8.6-10.3 pounds in VOCs were achieved in comparison to a typical polyurethane topcoat application.

7.3.1.3 Collection of Initial Metrics on BUNO 168416

Gloss and color measurements of the polysiloxane topcoats were recorded the day following the application of the medium gray and blue gray topcoats. Typically, topcoats are allowed to cure for a minimal of 14 days before initial metrics are collected, but due to time limitations it was determined that metrics be collected as soon as possible so the aircraft could be stenciled and returned to the squadron. Gloss units at 60 and 85 degree angles were recorded with a Byk-Gardner micro-TRI gloss meter, and color values in CIELAB (L*, a*, b*) color space coordinates were recorded with a Hunter Lab Mini-scan D65/10° spherical meter. As shown in Figure 146, color and gloss values were collected from the pilot's door, pilot's side cargo door, left side of tail boom, left horizontal stabilizer, top of tail boom, and nose, in addition to the co-pilot's door, co-pilot's side cargo door, right side of tail boom, and right horizontal stabilizer. Three to five measurements were collected from each location, followed by averaging the results. DFT values were not collected during the initial inspection.

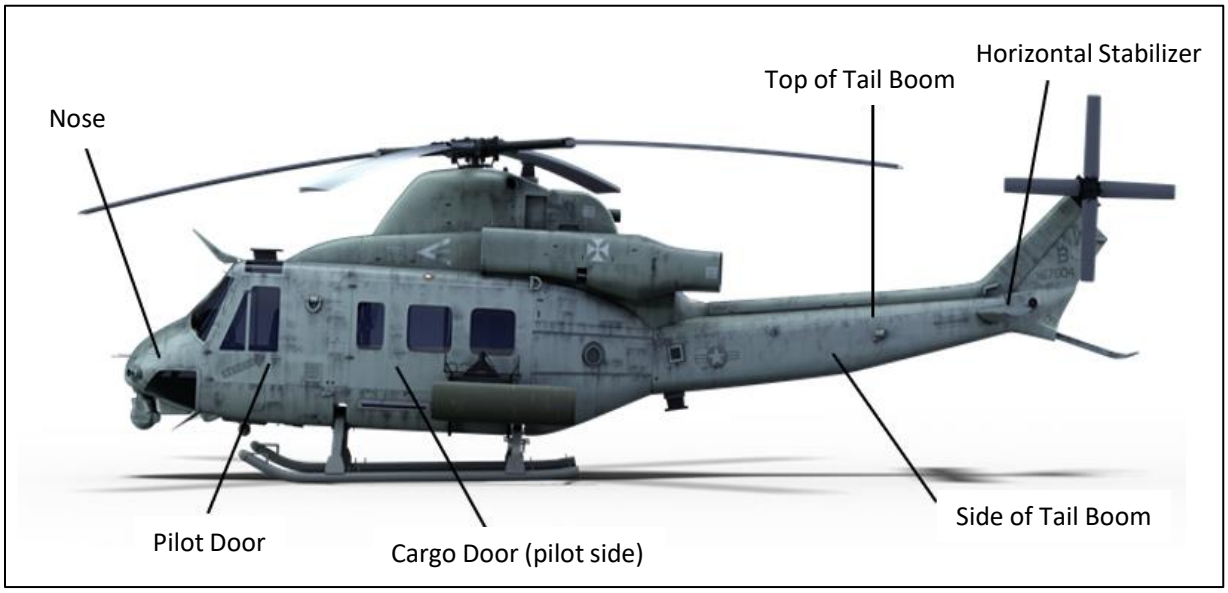


Figure 146 —BUNO 168416 with 1K polysiloxane topcoats after delivered to squadron.

The initial color values for the medium gray and blue gray colored 1K polysiloxane topcoats on BUNO 168416 are shown in Tables 115 and 116. These topcoats visually matched 2K polyurethanes with #36375 and #35237 colors, and the applicators stated that the polysiloxane topcoats blended well at transition points with no signs of delamination or peeling between colors. The colors also appeared homogenous across all areas of the aircraft, as shown in Figures 144 and 145, and there were zero sags, runs, or other unsightly blemishes.

Table 115 — Initial average color values of medium gray 1K polysiloxane topcoat on BUNO 168416.

Location	**Left side, color coordinates**			**Right side, color coordinates**		
	L	**a**	**b**	**L**	**a**	**b**
Pilot Door	65.38	-2.15	-4.31	N/A	N/A	N/A
Co-Pilot Door	N/A	N/A	N/A	64.05	-2.09	-4.48
Cargo Door (pilot side)	65.87	-2.19	-4.28	N/A	N/A	N/A
Cargo Door (co-pilot side)	N/A	N/A	N/A	65.45	-2.12	-4.44
Side of Tail Boom	65.88	-2.18	-4.33	66.26	-2.19	-4.33
Nose	64.71	-2.19	-4.34	64.60	-2.35	-4.31
AVG.	**65.46**	**-2.18**	**-4.32**	**65.09**	**-2.19**	**-4.39**

Table 116 — Initial average color values of blue gray 1K polysiloxane topcoat on BUNO 168416.

Location	Left side, color coordinates			Right side, color coordinates		
	L	**a**	**b**	**L**	**a**	**b**
Top of tail boom	57.13	-4.09	-4.29	56.16	-4.04	-4.43
Horizontal stabilizer	N/A	N/A	N/A	N/A	N/A	N/A
AVG.	**57.13**	**-4.09**	**-4.29**	**56.16**	**-4.04**	**-4.43**

The initial gloss values of the medium gray and blue gray 1K polysiloxane topcoats are provided in Tables 117 and 118. Similar to the color, the gloss values were recorded the day following the topcoat applications and while the topcoat was marginally soft. The gloss of the 1K polysiloxane topcoats decrease as they react with atmospheric moisture, thus the gloss values were expected to decrease in subsequent days or weeks. The target gloss for MIL-PRF-85285 aircraft topcoats is ≤5 GU at 60 degrees and ≤10 GU at 85 degrees. For the medium gray 1K polysiloxane topcoat, on both sides of the aircraft, the average recorded values at 60 degrees were slightly greater than specified, although the average values on the pilot's door were 3.70 GU and within range. The average gloss on the pilot's side cargo door was 5.20 GU and barely exceeded the range. All 60 and 85 degree gloss values for the blue gray 1K polysiloxane topcoat were within the specified range. Visually, both topcoats had a flat appearance across the aircraft.

Table 117 — Initial average gloss values of medium gray 1K polysiloxane topcoat on BUNO 168416.

Location	Left side, gloss units (GU)		Right side, gloss units (GU)	
	60°	**85°**	**60°**	**85°**
Pilot Door	8.10	9.70	N/A	N/A
Co-Pilot Door	N/A	N/A	3.70	3.40
Cargo Door (pilot side)	5.20	4.90	N/A	N/A
Cargo Door (co-pilot side)	N/A	N/A	5.90	6.30
Side of Tail Boom	7.10	7.80	11.3	13.9
AVG.	**6.80**	**7.47**	**6.97**	**7.87**

Table 118 — Initial average gloss values of blue gray 1K polysiloxane topcoat on BUNO 168416.

Location	Left side, gloss units (GU)		Right side, gloss units (GU)	
	60°	**85°**	**60°**	**85°**
Top of tail boom	5.20	5.00	N/A	N/A
Horizontal stabilizer	4.20	3.80	4.10	3.60
AVG.	**4.70**	**4.40**	**4.10**	**3.60**

7.3.2 UH-1Y BUNO 167807 – August 2019

7.3.2.1 Preparation and Painting of BUNO 167807

Similar to BUNO 168416, this aircraft was prepared for painting by first removing the aged polyurethane topcoat and anti-corrosive epoxy primer from the aluminum alloy skin and composite materials. This was accomplished using plastic media blast and hand sanding according to NAVAIR established procedures. Once the coatings were removed the aluminum alloy skin was treated with an Alodine 1200 marker, followed by a MIL-PRF-81706 chromate conversion solution. This was followed by spray-application of PPG/Deft 44GN008A, which is a MIL-PRF-85582, Type II, Class 1 hexavalent chromium based waterborne epoxy primer with low infrared reflective pigments. The primer was applied by artisans to achieve an average DFT of 0.57 mils (figure 147).

The following day, artisans agitated gallon cans of the medium gray 1K polysiloxane topcoat (NCP Batch #20-37-1, DoM 07/2019) for several minutes each using a paint shaker, then opened the cans and poured the liquid coating into 3M PPS™ gravity feed cups. The cups were attached to Binks Mach 1 HVLP spray guns with a 1.8 mm fluid tip, which was larger than the 1.2 mm tip used during the prior application on a UH-1Y aircraft (see Section 7.3.1.1). The line pressure was 80 psi and the pressure at the spray gun was approximately 18 psi. The temperature inside the spray booth was 71.7-89.0 °F and the RH was 61.9-83.1%. The latter was substantially greater than the relative humidity during the prior application on a UH-1Y aircraft (see section 7.3.1.1). Figure 148 shows an artisan spraying the medium gray 1K polysiloxane topcoat on the co-pilot's door, and the majority of the aircraft, except for the rotor housing, horizontal stabilizers, top of tail boom, and nose, was painted with this color. Three passes were applied on each side of the aircraft. After 85 minutes the artisans had painted the majority of the aircraft with the medium gray 1K topcoat, which consumed 3.25-3.50 gallons of the latter. Two gallons of the blue gray 1K polysiloxane topcoat (NCP Batch #20-37-2, DoM 07/2019) were then agitated and sprayed on the remaining areas of the aircraft using the same 3M PPS™ cups and Binks Mach 1 HVLP spray guns. This application required 70 minutes and included 8-10 passes on the nose, which is unusually high for a small area. About 1.25 gallons of the blue gray 1K topcoat was consumed. The artisans were pleased with the way the topcoats flowed-out and covered the primer. Additionally, the artisans stated this batch of topcoats was easier to spray than those in February of 2019, although the spray guns possessed a larger fluid tip for this application, which allowed for a greater volume of topcoat to be applied with minimal dry spray.

The following day, the 1K polysiloxane topcoats were hard due to the increased humidity in the paint booth, as opposed to when UH-1Y BUNO 168416 was painted. The topcoats were also visually low in gloss (figure 149). The majority of the aircraft was then stenciled using small quantities of the medium gray and blue gray 1K polysiloxane topcoats. Upon removing the stencils there were no signs of topcoat marring or

delamination (figures 150 and 151). The aircraft was provided to the squadron 1-2 weeks after all work was complete and the aircraft was fully assembled.

Figure 147 —MIL-PRF-85582, Type II primer after spray-applied on BUNO 167807.

Figure 148 — Spray application of medium gray 1K polysiloxane topcoat on co-pilot's door of BUNO 167807.

Figure 149 — Appearance of 1K polysiloxane topcoats on BUNO 167807 the day following application.

Figure 150 — Removal of stencil from tail boom of BUNO 167807 after painted with 1K polysiloxane topcoat.

Figure 151 — BUNO 167807 after majority of stencils were applied.

7.3.2.2 Collection of Initial Metrics on BUNO 167807

Dry film thickness, gloss, and color measurements of the polysiloxane topcoats were recorded the day following the application of the medium gray and blue gray 1K topcoats. Typically, topcoats are allowed to cure for a minimal of 14 days before initial metrics are collected, but due to time limitations it was determined that metrics be collected as soon as possible so the aircraft could be stenciled and returned to the squadron. DFT values were recorded in mils (1 mil = 25.4 microns) with a DeFelsko PosiTest coating thickness gauge for non-ferrous metals. Gloss units at 60 and 85 degree angles were recorded with a Byk-Gardner micro-TRI gloss meter, and color values in CIELAB (L*, a*, b*) color space coordinates were recorded with a Hunter Lab Mini-scan D65/10° spherical meter. DFT, color, and gloss values were collected from the pilot's door, pilot's side cargo door, left side of tail boom, left horizontal stabilizer, top of tail boom, and nose, in addition to the co-pilot's door, co-pilot's side cargo door, right side of tail boom, and right horizontal stabilizer. Three to five measurements were collected from each location, followed by averaging the results.

Initial DFT values were collected from the pilot's door, co-pilot's door, and both left and right sides of the tail boom (table 119). The average of all values was 3.44 mils, which equates to an average DFT of 2.87 mils for the medium gray topcoat after subtracting an average of 0.57 mils for the anti-corrosive epoxy primer. The average thickness on the nose was 8.6 mils as a result of applying 8-10 coats of the blue gray topcoat application (table 120), which equates to an average topcoat thickness of 8.03 mils after subtracting an average of 0.57 mils for the primer. This value was substantially above the NAVAIR recommended thickness of 1.7-2.3 mils for an aircraft topcoat.

Table 119 — Initial average DFT values of medium gray 1K polysiloxane topcoat on BUNO 167807 after overnight cure.

Location	Left side, DFT (mils)	Right side, DFT (mils)
Pilot Door	3.27	N/A
Co-Pilot Door	N/A	3.07
Side of Tail Boom	4.21	3.22
AVG.	**3.74**	**3.15**

Table 120 — Initial average DFT values of blue gray 1K polysiloxane topcoat on BUNO 167807 after overnight cure.

Location	Left side, DFT (mils)	Right side, DFT (mils)
Nose	8.6	8.6
AVG.	**8.6**	**8.6**

The initial color values for the medium gray and blue gray colored 1K polysiloxane topcoats on BUNO 168416 are shown in Tables 121 and 122. These topcoats visually matched 2K polyurethane topcoats in #36375 and #35237 colors, and the applicators stated that the polysiloxane topcoats blended well at transition points with no signs of delamination or peeling. The colors also appeared homogenous across all areas of the aircraft as shown in Figure 151, and there were zero sags or other unsightly blemishes.

Table 121 — Initial average color values of medium gray 1K polysiloxane topcoat on BUNO 167807.

Location	Left side, color coordinates			Right side, color coordinates		
	L	**a**	**b**	**L**	**a**	**b**
Pilot Door	65.97	-2.36	-3.76	N/A	N/A	N/A
Co-Pilot Door	N/A	N/A	N/A	66.24	-2.35	-3.74
Cargo Door (pilot side)	65.79	-2.27	-3.70	N/A	N/A	N/A
Cargo Door (co-pilot side)	N/A	N/A	N/A	65.71	-2.25	-3.75
Side of Tail Boom	65.99	-2.34	-3.71	66.27	-2.35	-3.74
Nose	65.66	-2.44	-3.74	N/A	N/A	N/A
AVG.	**65.85**	**-2.35**	**-3.73**	**66.07**	**-2.32**	**-3.74**

Table 122 — Initial average color values of blue gray 1K polysiloxane topcoat on BUNO 167807.

Location	Left side, color coordinates			Right side, color coordinates		
	L	**a**	**b**	**L**	**a**	**b**
Top of tail boom	56.16	-4.2	-4.1	55.89	-4.19	-4.13
Horizontal stabilizer	56.72	-4.21	-4.15	57.18	-4.15	-4.01
Nose	56.63	-4.26	-4.1	N/A	N/A	N/A
AVG.	**56.50**	**-4.22**	**-4.12**	**56.54**	**-4.17**	**-4.07**

The initial gloss values of the medium gray and blue gray 1K polysiloxane topcoats are provided in Tables 123 and 124. Similar to the color, the gloss values were recorded the day following the topcoat applications. The gloss of the 1K polysiloxane topcoats was expected to decrease slightly in subsequent days or weeks as the topcoats cured. The target gloss for MIL-PRF-85285 aircraft topcoats is ≤5 GU at 60 degrees and ≤10 GU at 85 degrees. For the medium gray 1K polysiloxane topcoat, on both sides of the aircraft, the average recorded values at 60 degrees were slightly greater than specified, although the average values on the co-pilot's side cargo door was 4.83 GU and within range. The average gloss on the pilot's side cargo door was 5.17 GU and barely exceeded the range. All 60 and 85 degree gloss values for the blue gray 1K polysiloxane topcoat were within the specified range. Visually, both topcoats had a low gloss appearance across the aircraft.

Table 123 — Initial average gloss values of medium gray 1K polysiloxane topcoat on BUNO 167807.

Location	Left side, gloss units (GU)		Right side, gloss units (GU)	
	60°	**85°**	**60°**	**85°**
Pilot Door	7.93	10	N/A	N/A
Co-Pilot Door	N/A	N/A	4.4	3.97
Cargo Door (pilot side)	5.17	5.93	N/A	N/A
Cargo Door (co-pilot side)	N/A	N/A	4.83	4.47
Side of Tail Boom	5.53	6.2	5.87	6.87
AVG.	**6.21**	**7.38**	**5.03**	**5.10**

Table 124 — Initial average gloss values of blue gray 1K polysiloxane topcoat on BUNO 167807.

Location	Left side, gloss units (GU)		Right side, gloss units (GU)	
	60°	85°	60°	85°
Top of tail boom	4.03	3.67	3.67	3.43
Horizontal stabilizer	3.83	3.33	3.47	3.27
Nose	3.97	4.5	N/A	N/A
AVG.	**3.94**	**3.83**	**3.57**	**3.35**

7.3.3 In-service inspections of 1K polysiloxane topcoats on UH-1Y Venoms

7.3.3.1 Inspection of UH-1Y BUNO 168416 after 12 Months of Service – February 2020

The 1K polysiloxane topcoats on BUNO 168416 were inspected in February of 2020 after 12 months of active service at MCAS New River (figures 152-154). In general, the topcoats were in good condition with minimal mechanical damage (e.g., scratches) on doors, fasteners, and protrusions due to normal operations. There was a large dent in the co-pilot's door near the handle. The 1K topcoats showed no signs of blistering, cracking, delamination, damage due to heat or fluids, or facial corrosion. However, the aircraft was contaminated with soot, and there were long black marks on the left fuselage (figure 155). The aircraft was not washed prior to inspection and attempts to remove the dark contamination marks with water and rags were unsuccessful.

Figure 152 — 1K polysiloxane topcoats on BUNO 168416 after 12 months of service.

Figure 153 — Medium gray 1K polysiloxane topcoat on BUNO 168416 after 12 months of service.

Figure 154 —1K polysiloxane topcoats on tail boom and vertical stabilizer of BUNO 168416 after 12 months of service.

Figure 155 — Black marks on medium gray 1K polysiloxane topcoat on fuselage of BUNO 168416 after 12 months of service.

The color and gloss values of the 1K polysiloxane topcoats were recorded using the same instruments that were used to determine the initial values. Measurements were collected on the pilot's door, co-pilot's door, cargo doors, tail boom, nose, and top of tail boom. The horizontal stabilizers were removed during the inspection, thus measurements were not collected from those components. After 12 months of service, the color for the medium gray and blue gray 1K topcoats was yellower compared to the initial values, whereas the lightness/darkness values were similar (tables 125 and 126). The largest change was observed on the right side of the tail boom and right top of tail boom. The yellowing is potentially the result of degradation on the coating's surface due to exposure to sunlight, although it's unclear why the changes in the "b" value on the right side of tail boom and right top of tail boom were significantly greater than those in other areas. It is also unclear if contaminants on the surface affected the values, as the aircraft was not washed prior to inspection. The average color change for the medium gray and blue gray 1K polysiloxane topcoats after 12 months of service was 2.48 and 2.63, respectively. According to maintainers in the squadron they did not observe a visual difference in color between the 1K polysiloxane topcoats and aircraft painted with MIL-PRF-85285 2K polyurethane topcoats.

Table 125 — Average color values of medium gray 1K polysiloxane topcoat on BUNO 168416 after 12 months of service.

Location	Left side, color coordinates			Right side, color coordinates		
	L	**a**	**b**	**L**	**a**	**b**
Pilot Door	65.25	-1.97	-2.84	N/A	N/A	N/A
Co-Pilot Door	N/A	N/A	N/A	64.54	-1.98	-2.66
Cargo Door (pilot side)	64.57	-1.90	-2.25	N/A	N/A	N/A
Cargo Door (co-pilot side)	N/A	N/A	N/A	64.69	-1.96	-2.39
Side of Tail Boom	64.18	-1.85	-1.97	63.94	-1.71	-0.52
Nose	63.22	-1.77	-2.05	N/A	N/A	N/A
AVG.	**64.31**	**-1.87**	**-2.28**	**64.39**	**-1.88**	**-1.86**

Table 126 — Average color values of blue gray 1K polysiloxane topcoat on BUNO 168416 after 12 months of service.

Location	Left side, color coordinates			Right side, color coordinates		
	L	**a**	**b**	**L**	**a**	**b**
Top of tail boom	56.66	-3.41	-2.19	56.7	-3.31	-1.46
Horizontal stabilizer	N/A	N/A	N/A	N/A	N/A	N/A
AVG.	**56.66**	**-3.41**	**-2.19**	**56.7**	**-3.31**	**-1.46**

The average gloss values for the medium gray and blue gray 1K topcoats showed minor changes after 12 months of service (tables 127 and 128). The average 60 degree value for the medium gray topcoat was 6.38 GU, which was slightly greater than the NAVAIR required value of ≤5 GU at 60 degrees, whereas the average at 85 degrees was 6.97 GU, which was far below the requirement of ≤10 GU at 85 degrees. As shown in Table 127, the gloss on the sides of the tail boom was greater than those on all four doors. This may have resulted from the gloss meter not being flush with the surface, thereby allowing external light to enter the meter and provide inaccurate values. The average 60 degree and 85 degree values for the blue gray topcoat were 4.30 GU and 4.31 GU, respectively, which were below the required gloss values.

Table 127 — Average gloss values of medium gray 1K polysiloxane topcoat on BUNO 168416 after 12 months of service.

Location	**Left side, gloss units (GU)**		**Right side, gloss units (GU)**	
	60°	**85°**	**60°**	**85°**
Pilot Door	4.50	5.13	N/A	N/A
Co-Pilot Door	N/A	N/A	6.43	6.60
Cargo Door (pilot side)	5.83	7.10	N/A	N/A
Cargo Door (co-pilot side)	N/A	N/A	4.83	5.63
Side of Tail Boom	8.50	8.17	8.20	9.20
AVG.	**6.28**	**6.80**	**6.49**	**7.14**

Table 128 — Average gloss values of blue gray 1K polysiloxane topcoat on BUNO 168416 after 12 months of service.

Location	**Left side, gloss units (GU)**		**Right side, gloss units (GU)**	
	60°	**85°**	**60°**	**85°**
Top of tail boom	4.93	4.23	3.7	4.4
Horizontal stabilizer	N/A	N/A	N/A	N/A
AVG.	**4.93**	**4.23**	**3.7**	**4.4**

7.3.3.2 Inspection of UH-1Y BUNO 168416 after 21 Months of Service – November 2020

The 1K polysiloxane topcoats on BUNO 168416 were inspected in November of 2020 after 21 months of active service at MCAS New River (figures 156-160). In general, the topcoats were in good condition with minimal mechanical damage (e.g., scratches) on the doors, nose, and fasteners due to normal operations. The 1K topcoats showed no signs of blistering, cracking, delamination, or facial corrosion, although minor staining was observed above a cargo door and on the tail boom (figure 160). There was minor delamination around a few of the window frames, but maintainers stated this is common for topcoats on these aircraft.

The aircraft had a visible build-up of soot on horizontal areas, such as the horizontal stabilizers and top of tail boom, and maintainers could not recall the last time it was washed. Attempts to remove the soot with water and rags was unsuccessful. Plexus®, a plastic cleaner for aircraft windshields,[61] was applied on several areas of the topcoats in effort to remove the soot. Unfortunately, a faint yellow color on the topcoat resulted in areas where the cleaner was applied (figure 160).

Figure 156 — 1K polysiloxane topcoats on front, left side of BUNO 168416 after 21 months of service.

Figure 157 — 1K polysiloxane topcoats on front, right side of BUNO 168416 after 21 months of service.

Figure 158 — 1K polysiloxane topcoats on nose of BUNO 168416 after 21 months of service.

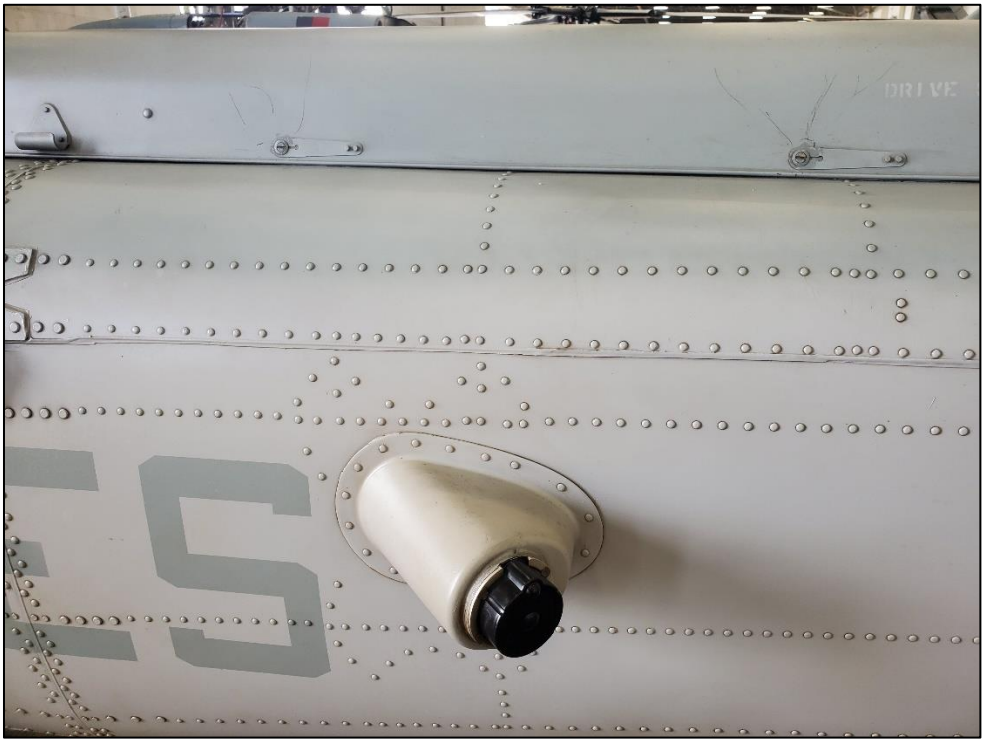


Figure 159 — 1K polysiloxane topcoats on left side of tail boom of BUNO 168416 after 21 months of service.

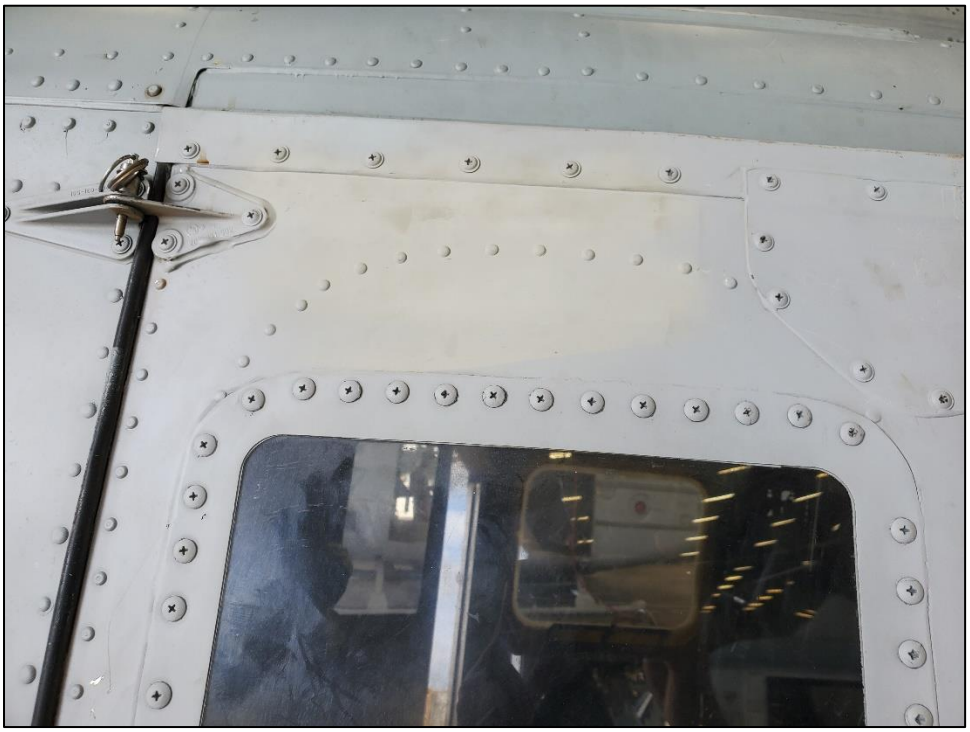


Figure 160 — Stained 1K polysiloxane topcoat above cargo door on BUNO 168416 after 21 months of service.

Figure 161 — Removal of soot from 1K polysiloxane topcoat on horizontal stabilizer of BUNO 168416 using Plexus® cleaner.

The color and gloss values of the 1K polysiloxane topcoats were determined using the same instruments that were used to collect the initial and 12-month inspection values. Measurements were collected on the pilot's door, co-pilot's door, cargo doors, tail boom, nose, top of tail boom, and horizontal stabilizers. After 21 months of service, the medium gray and blue gray 1K topcoats were slightly darker and significantly more yellow than the initial values (tables 129 and 130). The largest changes were on the tail boom, top of the tail boom, and horizontal stabilizer, which are all located behind the engine and receive both heat and soot from the exhaust. These were also areas with significant soot build-up compared to vertical areas (e.g., doors). Furthermore, all color values were collected in areas that were cleaned with the Plexus® plastic cleaner, which already possessed a yellowish color due to the cleaner. As a result, the calculated color change for the medium gray and blue gray 1K polysiloxane topcoats after 21 months of service was 4.56 and 6.62, respectively, which is 1.8 times the color change for the medium gray topcoat at 12 months and 2.5 times the color change for the blue gray topcoat at 12 months.

Table 129 — Average color values of medium gray 1K polysiloxane topcoat on BUNO 168416 after 21 months of service.

Location	**Left side, color coordinates**			**Right side, color coordinates**		
	L	**a**	**b**	**L**	**a**	**b**
Pilot Door	62.42	-2.00	-2.24	N/A	N/A	N/A
Co-Pilot Door	N/A	N/A	N/A	63.79	-2.04	-2.20
Cargo Door (pilot side)	61.76	-1.90	-1.46	N/A	N/A	N/A
Cargo Door (co-pilot side)	N/A	N/A	N/A	63.27	-1.98	-1.86
Side of Tail Boom	61.49	-1.70	0.95	62.75	-0.81	1.36
Nose	61.90	-1.92	0.80	N/A	N/A	N/A
AVG.	**61.89**	**-1.88**	**-0.49**	**63.27**	**-1.61**	**-0.90**

Table 130 — Average color values of blue gray 1K polysiloxane topcoat on BUNO 168416 after 21 months of service.

Location	**Left side, color coordinates**			**Right side, color coordinates**		
	L	**a**	**b**	**L**	**a**	**b**
Top of tail boom	53.62	-2.84	0.37	54.40	-2.22	1.13
Horizontal stabilizer	51.19	-2.75	0.41	52.75	-2.01	1.80
AVG.	**52.41**	**-2.80**	**0.39**	**53.58**	**-2.12**	**1.47**

The average gloss values for the medium gray 1K topcoats showed an increase for both the 60 and 85 degree angle measurements (table 131), although the majority of the change can be attributed to the sides of the tail boom, which had values above 10 GU at both angles. The tail boom is a highly curved surface,

thus it is likely the meter was not flush with the surface when the gloss was collected, thereby allowing external light to enter the meter and provide inaccurate values. The average 60 degree gloss values for the blue gray 1K topcoat remained below 5 GU, whereas the average 85 degree gloss values remained below 10 GU (table 132). Visually, the gloss on all areas of the aircraft had a flat appearance and resembled other aircraft in the hanger that were painted with 2K camouflage gray polyurethane topcoats.

Table 131 — Average gloss values of medium gray 1K polysiloxane topcoat on BUNO 168416 after 21 months of service.

Location	**Left side, gloss units (GU)**		**Right side, gloss units (GU)**	
	60°	**85°**	**60°**	**85°**
Pilot Door	5.10	7.03	N/A	N/A
Co-Pilot Door	N/A	N/A	8.13	10.37
Cargo Door (pilot side)	6.97	8.60	N/A	N/A
Cargo Door (co-pilot side)	N/A	N/A	6.37	7.03
Side of Tail Boom	12.23	17.33	15.37	16.93
AVG.	**8.10**	**10.99**	**9.96**	**11.44**

Table 132 — Average gloss values of blue gray 1K polysiloxane topcoat on BUNO 168416 after 21 months of service.

Location	**Left side, gloss units (GU)**		**Right side, gloss units (GU)**	
	60°	**85°**	**60°**	**85°**
Top of tail boom	4.17	7.8	4.8	8.3
Horizontal stabilizer	4.53	6.9	5.1	7.9
AVG.	**4.35**	**7.35**	**4.95**	**8.10**

7.3.3.3 Inspection of UH-1Y BUNO 168416 after 27 Months of Service – May 2021

The 1K camouflage gray polysiloxane topcoats on BUNO 168416 were inspected in May of 2021 after 27 months of active service at MCAS New River (figures 162-166). This was the final inspection of the aircraft. In general, the topcoats were in good condition with minimal mechanical damage, such as scratches and chips, on the doors, horizontal stabilizers, around fasteners, and on door handles. The 1K topcoats showed no signs of blistering, cracking, delamination, or facial corrosion. Dark contaminants, likely grease marks, were observed on the cargo doors and fuselage, and soot was found on the tail boom, top of tail boom, and horizontal stabilizers. Furthermore, the squadron repainted the nose, vertical stabilizer, and several stencils with a black topcoat and red/black checkered (figures 167 and 168), although

we were not informed as to why this action was performed. The aircraft was not washed prior to the final inspection, although permission was given to use rags and isopropanol to clean various areas of the topcoats. Figure 169 shows an area of the medium gray 1K topcoat on the tail boom after being cleaned with rags and IPA.

Figure 162 — Medium gray 1K polysiloxane topcoats on left side of BUNO 168416 after 27 months of service.

Figure 163 — Medium gray 1K polysiloxane topcoat on right side of BUNO 168416 after 27 months of service.

Figure 164 — Medium gray 1K polysiloxane topcoat on right, rear fuselage area of BUNO 168416 after 27 months of service.

Figure 165 — 1K polysiloxane topcoats on right side of tail boom on BUNO 168416 after 27 months of service.

Figure 166 — 1K polysiloxane topcoats on rear, right side of BUNO 168416 after 27 months of service.

Figure 167 — Repainted nose of BUNO 168416 after 27 months of service.

Figure 168 — Repainted vertical stabilizer of BUNO 168416 after 27 months of service.

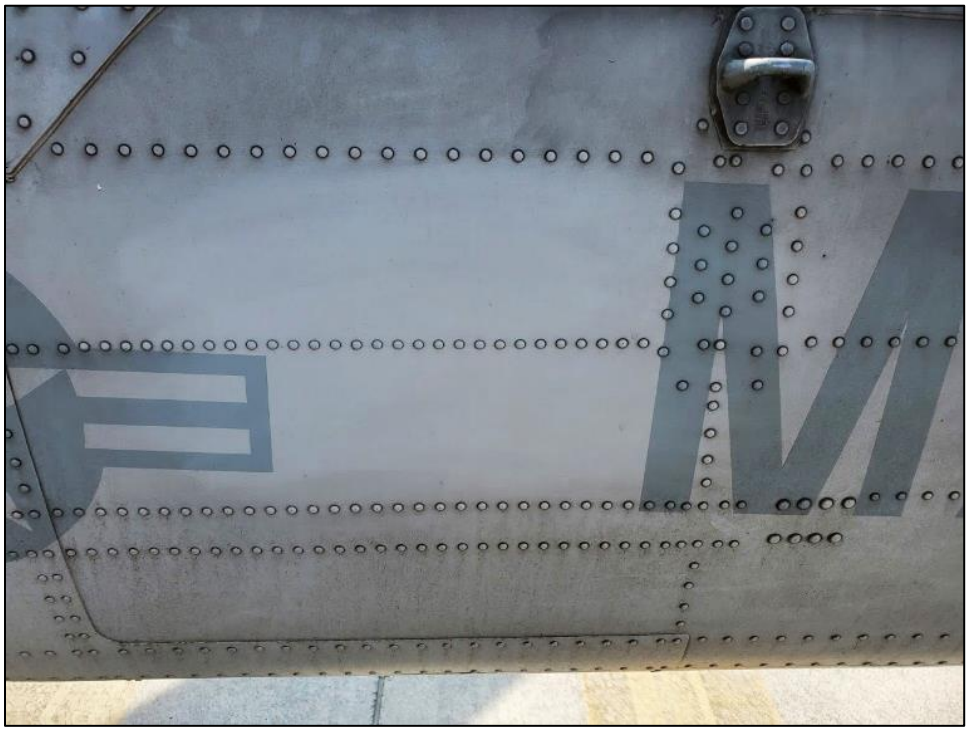


Figure 169 — Removal of dark contaminants from tail boom of BUNO 168416 using rags and IPA.

DFT values were recorded with a DeFelsko PosiTest coating thickness gauge for non-ferrous metals, even though values were not collected during the initial, 12-month, and 21-month inspections. Values were collected from the pilot's door, co-pilot's door, the cargo doors, and both sides of the tail boom (table 133). The average DFT was 2.49 mils, which equates to an average thickness of 1.88 mils for the topcoat once the average primer thickness was subtracted. This value was within the recommended thickness range of 1.7-2.3 mils for an aircraft topcoat. However, an average DFT value of 1.54 mils was measured on the horizontal stabilizer, which showed that the topcoat was applied thin (<1.0 mils) on the components (table 134).

Table 133 — Average DFT values of medium gray 1K polysiloxane topcoat on BUNO 168416 after 27 months of service.

Location	Left side, DFT (mils)	Right side, DFT (mils)
Pilot Door	2.34	N/A
Co-Pilot Door	N/A	1.99
Cargo Door (pilot side)	2.52	N/A
Cargo Door (co-pilot side)	N/A	3.13
Side of Tail Boom	2.29	2.71
AVG.	**2.38**	**2.61**

Table 134 — Average DFT values of blue gray 1K polysiloxane topcoat on BUNO 168416 after 27 months of service.

Location	Left side, DFT (mils)	Right side, DFT (mils)
Horizontal Stabilizer	1.65	1.44
AVG.	**1.65**	**1.44**

The color and gloss values of the 1K polysiloxane topcoats were determined using the same instruments that were used to collect the initial, 12-month, and 21-month inspection values. Measurements were recorded on the pilot's door, co-pilot's door, cargo doors, tail boom, nose, top of tail boom, and horizontal stabilizers. After 27 months of service, the medium gray and blue gray 1K topcoats were slightly darker and significantly more yellow than when initially applied, although not as yellow as during the 21-month inspection (tables 135 and 136). The largest changes were on the sides of the tail boom, top of the tail boom, and horizontal stabilizer, which are all located behind the engines and receive both heat and soot from the exhaust. These areas were also the most contaminated. The average color change for the medium gray and blue gray 1K polysiloxane topcoats after 27 months of service was 2.82 and 4.87, respectively (table 137), which were less than the color changes during the 21-month inspection. The use of rags and IPA appeared to remove the majority of dark contaminants from the surface, although it is unclear if the change in yellowness was due to heat damage and/or degradation of the blue pigment and polymers at the surface as a result of exposure to sunlight.

Table 135 — Average color values of medium gray 1K polysiloxane topcoat on BUNO 168416 after 27 months of service.

Location	Left side, color coordinates			Right side, color coordinates		
	L	**a**	**b**	**L**	**a**	**b**
Pilot Door	64.68	-1.94	-2.45	N/A	N/A	N/A
Co-Pilot Door	N/A	N/A	N/A	65.07	-2.02	-2.38
Cargo Door (pilot side)	63.58	-2.17	-2.06	N/A	N/A	N/A
Cargo Door (co-pilot side)	N/A	N/A	N/A	64.12	-2.03	-2.36
Side of Tail Boom	64.79	-1.79	-1.51	64.99	-0.89	0.87
Nose	N/A	N/A	N/A	N/A	N/A	N/A
AVG.	**64.35**	**-1.97**	**-2.01**	**64.73**	**-1.65**	**-1.29**

Table 136 — Average color values of blue gray 1K polysiloxane topcoat on BUNO 168416 after 27 months of service.

Location	Left side, color coordinates			Right side, color coordinates		
	L	a	b	L	a	b
Top of tail boom	57.45	-2.73	-0.53	56.52	-2.40	0.26
Horizontal stabilizer	51.41	-1.82	0.32	59.44	-2.16	0.55
AVG.	**54.43**	**-2.28**	**-0.11**	**57.98**	**-2.28**	**0.41**

Table 137 — Color change of medium gray (#36375) and blue gray (#35237) 1K polysiloxane topcoats on UH-1Y BUNO 168416 after 27 months of service.

BUNO	1K Polysiloxane Color	February 2019			May 2021			ΔE
		L*	a*	b*	L*	a*	b*	
168416	Medium Gray	65.27	-2.18	-4.35	64.54	-1.79	-1.65	**2.82**
	Blue Gray	56.64	-4.06	-4.36	56.20	-2.28	0.15	**4.87**

The average gloss for the medium gray 1K topcoat was 5.38 GU at 60 degrees and 8.73 GU at 85 degrees, (table 138). The former was slightly above the NAVAIR required value of ≤5 GU, whereas the latter was below the required value of ≤10 GU. The averages at both angles decreased compared to the 21-month inspection. The average gloss for the blue gray 1K topcoat was 3.93 GU at 60 degrees and 4.89 GU at 85 degrees, which were below the NAVAIR required values (table 139). Visually, the gloss on all areas of the aircraft had a flat appearance and resembled other aircraft on the flight line that possessed MIL-PRF-85285 qualified 2K camouflage gray polyurethane topcoats.

Table 138 — Average gloss values of medium gray 1K polysiloxane topcoat on BUNO 168416 after 27 months of service.

Location	Left side, gloss units (GU)		Right side, gloss units (GU)	
	60°	85°	60°	85°
Pilot Door	4.70	5.80	N/A	N/A
Co-Pilot Door	N/A	N/A	7.20	13.3
Cargo Door (pilot side)	2.30	3.80	N/A	N/A
Cargo Door (co-pilot side)	N/A	N/A	4.00	6.50
Side of Tail Boom	6.80	9.60	7.20	13.3
AVG.	**4.60**	**6.43**	**6.17**	**11.04**

Table 139 — Average gloss values of blue gray 1K polysiloxane topcoat on BUNO 168416 after 27 months of service.

Location	**Left side, gloss units (GU)**		**Right side, gloss units (GU)**	
	60°	**85°**	**60°**	**85°**
Top of tail boom	5.70	5.80	5.30	6.60
Horizontal stabilizer	2.40	3.70	2.40	3.50
AVG.	**4.05**	**4.75**	**3.82**	**5.03**

7.3.3.4 Inspection of UH-1Y BUNO 167807 after 6 Months of Service – February 2020

The 1K camouflage gray polysiloxane topcoats on BUNO 167807 were inspected in February of 2020 after 6 months of active service at MCAS New River (figures 170-173). The aircraft was on the flight line and it was raining, thus DFT, color, and gloss values could not be collected. However, photographs were taken to show how dirty / contaminated the aircraft was after 6 months of service. The dark color, likely soot, was especially noticeable on the tail boom, vertical stabilizer, and horizontal stabilizers, which are all located behind the engines. In general, the topcoats were in good condition with minimal mechanical damage (e.g., scratches) on doors and around fasteners. The 1K topcoats also showed no signs of blistering, cracking, delamination, or facial corrosion.

Figure 170 — Dark contaminants on tail boom of BUNO 167807 after 6 months of service.

Figure 171 — Dark contaminants on horizontal and vertical stabilizers of BUNO 167807 after 6 months of service.

Figure 172 — 1K polysiloxane topcoats on co-pilot's door and nose of BUNO 167807 after 6 months of service.

Figure 173 — 1K polysiloxane topcoat on right side of BUNO 167807 after 6 months of service.

7.3.3.5 Inspection of UH-1Y BUNO 167807 after 22 Months of Service – May 2021

The 1K polysiloxane topcoats on BUNO 167807 were inspected in May of 2021 after 22 months of active service at MCAS New River (figures 174-177). This was the final inspection of the aircraft. In general, the topcoats were in good condition with minimal mechanical damage on the doors, around fasteners, and on door handles. However, the leading edge of the left horizontal stabilizer was repainted with a golden-colored paint, although it is unclear if the blue gray 1K topcoat was removed due to erosion (during normal operations) or damage during maintenance activities (figure 178). Aside from the damage on the leading edge the 1K polysiloxane topcoats showed no signs of blistering, cracking, delamination, or facial corrosion. Dark contaminants, likely soot and grease, were observed on the majority of the aircraft, especially on areas located behind the engines. The aircraft was not washed prior to the final inspection, although permission was granted to use rags and isopropanol in effort to remove contaminants from the topcoats.

Figure 174 — 1K polysiloxane topcoat on co-pilot's door and nose of BUNO 167807 after 22 months of service.

Figure 175 — 1K polysiloxane topcoats on nose of BUNO 167807 after 22 months of service.

Figure 176 — 1K polysiloxane topcoat on right side of fuselage of BUNO 167807 after 22 months of service.

Figure 177 — 1K polysiloxane topcoats on tail boom and right horizontal stabilizer of BUNO 167807 after 22 months of service.

Figure 178 — Repainted leading edge of left horizontal stabilizer of BUNO 167807 after 22 months of service.

DFT values were collected from the pilot's door, co-pilot's door, the cargo doors, and both sides of the tail boom. The average DFT for the medium gray 1K topcoat was 3.68 mils, which equates to an average topcoat thickness of 3.11 mils upon subtraction of the primer thickness, whereas the average DFT for the blue gray 1K topcoat was 2.39 mils, which equates to 1.82 mils upon subtraction of the primer (tables 140 and 141). The medium gray topcoat exceeded the recommended thickness range of 1.7-2.3 mils for an aircraft topcoat, although the blue gray topcoat was within range. The average DFT value on the left horizontal stabilizer was 2.00 mils, which is only 1.43 mils of topcoat upon subtraction of the primer thickness. This low DFT may have resulted in damage at the leading edge after 22 months as shown in Figure 178.

Table 140 — Average DFT values of medium gray 1K polysiloxane topcoat on BUNO 167807 after 22 months of service.

Location	Left side, DFT (mils)	Right side, DFT (mils)
Pilot Door	3.50	N/A
Co-Pilot Door	N/A	4.26
Cargo Door (pilot side)	N/A	N/A
Cargo Door (co-pilot side)	3.20	3.32
Side of Tail Boom	3.55	4.23
AVG.	**3.42**	**3.94**

Table 141 — Average DFT values of blue gray 1K polysiloxane topcoat on BUNO 167807 after 22 months of service.

Location	Left side, DFT (mils)	Right side, DFT (mils)
Horizontal Stabilizer	2.00	2.78
AVG.	**2.00**	**2.78**

The color values of the 1K polysiloxane topcoats were determined using the same instruments that were used to collect the initial inspection values. Measurements were collected on the pilot's door, co-pilot's door, cargo doors, sides of tail boom, nose, top of tail boom, and horizontal stabilizers. After 22 months of service, the medium gray and blue gray 1K topcoats were slightly darker and significantly more yellow than after applied (tables 142 and 143). Similar to BUNO 168416, the largest changes were on the sides of the tail boom, top of the tail boom, and horizontal stabilizer, which are all located behind the engines and receive both heat and soot from the exhaust. These areas were also the most heavily contaminated. Rags and IPA removed some of these contaminants, although it is unclear the extent of contamination that remained on the surface and how it affected the color values. After 22 months of service, the calculated color change for the medium gray and blue gray 1K polysiloxane topcoats was 2.62 and 3.83, respectively (table 144). It is worth mentioning that maintainers were unaware the aircraft was painted with 1K polysiloxane topcoats, yet they did not observe a difference in visual appearance or performance compared to aircraft on the flight line that were painted with MIL-PRF-85285 qualified 2K polyurethane topcoats.

Table 142 — Average color values of medium gray 1K polysiloxane topcoat on BUNO 167807 after 22 months of service.

Location	Left side, color coordinates			Right side, color coordinates		
	L	**a**	**b**	**L**	**a**	**b**
Pilot Door	65.97	-2.19	-2.50	N/A	N/A	N/A
Co-Pilot Door	N/A	N/A	N/A	66.01	-2.16	-2.68
Cargo Door (pilot side)	65.92	-2.12	-1.89	N/A	N/A	N/A
Cargo Door (co-pilot side)	N/A	N/A	N/A	65.09	-2.09	-1.67
Side of Tail Boom	63.72	-1.70	-0.54	64.78	-1.20	1.46
Nose	64.73	-2.01	-1.34	N/A	N/A	N/A
AVG.	**65.09**	**-2.01**	**-1.57**	**65.29**	**-1.82**	**-0.96**

Table 143 — Average color values of blue gray 1K polysiloxane topcoat on BUNO 167807 after 22 months of service.

Location	Left side, color coordinates			Right side, color coordinates		
	L	a	b	L	a	b
Top of tail boom	54.31	-3.06	-0.97	55.06	-2.67	-0.57
Horizontal stabilizer	54.81	-2.41	-0.27	55.95	-2.76	-0.57
Nose	56.35	-3.36	-1.35	N/A	N/A	N/A
AVG.	**55.16**	**-2.94**	**-0.86**	**55.51**	**-2.72**	**-0.57**

Table 144 — Color change of medium gray (#36375) and blue gray (#35237) 1K polysiloxane topcoats on UH-1Y BUNO 167807 after 22 months of service.

BUNO	1K Polysiloxane Color	August 2019			May 2021			ΔE
		L*	a*	b*	L*	a*	b*	
168416	Medium Gray	65.96	-2.33	-3.73	65.19	-1.91	-1.26	**2.62**
	Blue Gray	56.52	-4.19	-4.09	55.33	-2.83	-0.71	**3.83**

The average gloss for the medium gray 1K topcoat was 5.72 GU at 60 degrees and 8.48 GU at 85 degrees, (table 145). The former was slightly above the NAVAIR required value of ≤5 GU, whereas the latter was below the required value of ≤10 GU. The average gloss for the blue gray 1K topcoat was 3.84 GU at 60 degrees and 6.65 GU at 85 degrees, which were below the NAVAIR required values (table 146). Visually, the gloss on all areas of the aircraft had a flat appearance and resembled other aircraft on the flight line that were painted with qualified 2K polyurethane topcoats.

Table 145 — Average gloss values of medium gray 1K polysiloxane topcoat on BUNO 167807 after 22 months of service.

Location	**Left side, gloss units (GU)**		**Right side, gloss units (GU)**	
	60°	**85°**	**60°**	**85°**
Pilot Door	5.30	5.60	N/A	N/A
Co-Pilot Door	N/A	N/A	7.10	11.6
Cargo Door (pilot side)	5.10	5.80	N/A	N/A
Cargo Door (co-pilot side)	N/A	N/A	4.20	5.40
Side of Tail Boom	5.50	10.70	7.10	11.6
AVG.	**5.29**	**7.40**	**6.16**	**9.57**

Table 146 — Average gloss values of blue gray 1K polysiloxane topcoat on BUNO 167807 after 22 months of service.

Location	**Left side, gloss units (GU)**		**Right side, gloss units (GU)**	
	60°	**85°**	**60°**	**85°**
Top of tail boom	4.4	7.00	4.70	6.30
Horizontal stabilizer	3.70	9.30	3.10	7.00
Nose	3.20	3.70	N/A	N/A
AVG.	**3.77**	**6.66**	**3.92**	**6.65**

7.3.3.6 Discussion

The entire exterior of two UH-1Y Venom aircraft (BUNOs 168416 and 167807) at Marine Corps Air Base New River were painted with the NCP Coatings produced 1K camouflage gray polysiloxane topcoats in FED-STD-595 #36375 medium gray and #35237 blue gray colors. These applications occurred in February and August of 2019. Because of its single-component nature the artisans were not required to meter and mix components, which saved 10-15 minutes of preparation time and met the success criteria for ease-of-use as shown in Table 9. The gallon cans of 1K topcoat were agitated for a few minutes on a mechanical shaker, opened, poured into several 3M PPS™ gravity feed cups, then applied with HVLP spray guns. A 1.2 mm fluid tip was used in the spray guns during the application in February of 2019, whereas 1.8 mm fluid tips were used during the August 2019 application. Artisans noted that the 1K polysiloxane topcoats sprayed and covered better with the larger tip size. The 1K polysiloxane topcoats were applied using same equipment that is used to apply MIL-PRF-85285 qualified 2K polyurethane topcoats, which met the success criteria for equipment and method of application as shown in Table 9.

Artisans did not experience issues with sagging of the 1K topcoats during spray application, nor did they experience adhesion issues when colors were blended at transition points. After the applications, the medium gray and blue gray 1K polysiloxane topcoats were visually homogenous across both UH-1Y Venom aircraft, which met the success criteria for appearance as shown in Table 9. Unused topcoats were not recovered from the gravity feed cups and used for stenciling, thus we were unable to determine if the topcoats met the success criteria for reduction of hazardous paint waste as shown in Table 10.

The 1K polysiloxane topcoats on BUNO 168416, especially the blue gray color, was marginally soft the day following the application in February of 2019 due to <15% relative humidity in the spray booth, which starved the topcoat of moisture that is required for curing/cross-linking. However, the 1K topcoats were hard the day following the application on BUNO 167807 in August of 2019 because the relative humidity in the booth was >60%. Nevertheless, with less than 24 hours of curing, and under both conditions, none of the 1K topcoats demonstrated marring or lost adhesion to the primer upon removal (via peeling) of the vinyl stencils.

During each UH-1Y paint application the artisans utilized approximately 3 gallons of the medium gray 1K topcoat and 1.25 gallons of the blue gray 1K polysiloxane topcoat to cover the entire exterior, which equates to a total of 4.25 gallons, not including the minor amounts used for stenciling. At a VOC of 286 g/l (2.38 lb/gal) the 1K polysiloxane topcoats emitted 10.11 pounds of VOCs for each aircraft. Based on feedback from the artisans, painting the same aircraft with 2K polyurethane topcoats typically requires about 3.5 gallons of the medium gray color and 2 gallons of blue gray color, which equates to 6.5 gallons, not including the minor amounts used for stenciling. At a VOC of 420 g/l (3.5 lb/gal) the 2K polyurethane topcoats emit 22.75 pounds of VOCs. Thus, a VOC difference of 12.64 pounds, or less than half the VOCs, were emitted into the air during each application of the 1K camouflage gray polysiloxane topcoats. This reduction met the success criteria as shown in Table 10.

Overall, the medium gray and blue gray 1K polysiloxane topcoats performed well on the two UH-1Y helicopters after approximately 2 years of active field service at MCAB New River. During the inspections, the topcoats showed minor mechanical damage (i.e., scrapes, chips) on the doors, nose, areas around fasteners, and door handles, although the majority, if not all, of this damage was due to maintenance on the aircraft. There were no signs of topcoat blistering, cracking, or facial corrosion, thereby meeting the success criteria in Table 9, and the only area of topcoat damage, which was minor, was on the leading edge of the left horizontal stabilizer of BUNO 167807 after 22 months. However, it remains unknown if the damage was due to erosion during operations or during maintenance activities. Both aircraft were contaminated with soot and grease in numerous areas during the inspections, especially in areas that are located behind the engines (e.g., top of tail boom, horizontal stabilizers). These aircraft were not washed prior to any of the inspections, thus hampering the ability to obtain accurate color and gloss values for the topcoats. Attempts to remove the contaminants with water and rags were unsuccessful, although moderate removal was accomplished using rags and isopropanol. It is also worth restating that several areas of 1K topcoats on BUNO 168416 at 21 months were cleaned with a commercial plastic cleaner, which resulted in a yellowish tint on the surface due to the wax-like components in the cleaning product.

After approximately 2 years, the UH-1Ys that were painted with the 1K camouflage gray polysiloxane topcoats were visually similar to aircraft on the flight line that were painted with MIL-PRF-85285 qualified 2K camouflage gray polyurethane topcoats, which met the success criteria for visual in-service weatherability as shown in Table 9. Furthermore, aircraft maintainers in the squadron stated they did not notice a difference in appearance or performance between the 1K polysiloxane topcoats and the legacy 2K polyurethane topcoats.

The medium gray 1K polysiloxane topcoat on BUNOs 167807 and 168416 demonstrated an average color change of 2.62 and 2.82 after 22 and 27 months of service, respectively, whereas the blue gray 1K

polysiloxane topcoat on these aircraft demonstrated an average color change of 3.83 and 4.87, respectively, during the same periods (figure 179). Elevated color change values on BUNO 168416 were calculated during the 21-month inspection, although it was determined these increased values resulted from the thin yellowish film generated by the commercial plastic cleaner. However, the film did not appear to be present on the topcoats during the 27-month inspection. Both 1K topcoats demonstrated an average ΔE of ≥2.0 around the 2-year period, although both aircraft were highly contaminated with soot and grease, and neither aircraft were washed prior to the final inspection. Attempts were made to remove the contaminants, although the extent of removal could not be quantified and the topcoats remained contaminated and darker in color than when initially applied. Thus, the true color of the 1K topcoats was unknown. As a result, per Table 10, the 1K polysiloxane topcoats did not meet the quantitative success criteria for in-service weathering (i.e., ΔE ≤2.0) after 1-2 years of service. However, the 1K polysiloxane topcoats were visually similar in color to UH-1Ys on the fight line that were painted with 2K polyurethane topcoats, and as mentioned above, the maintainers could not visually discern between the aircraft with different topcoat technologies.

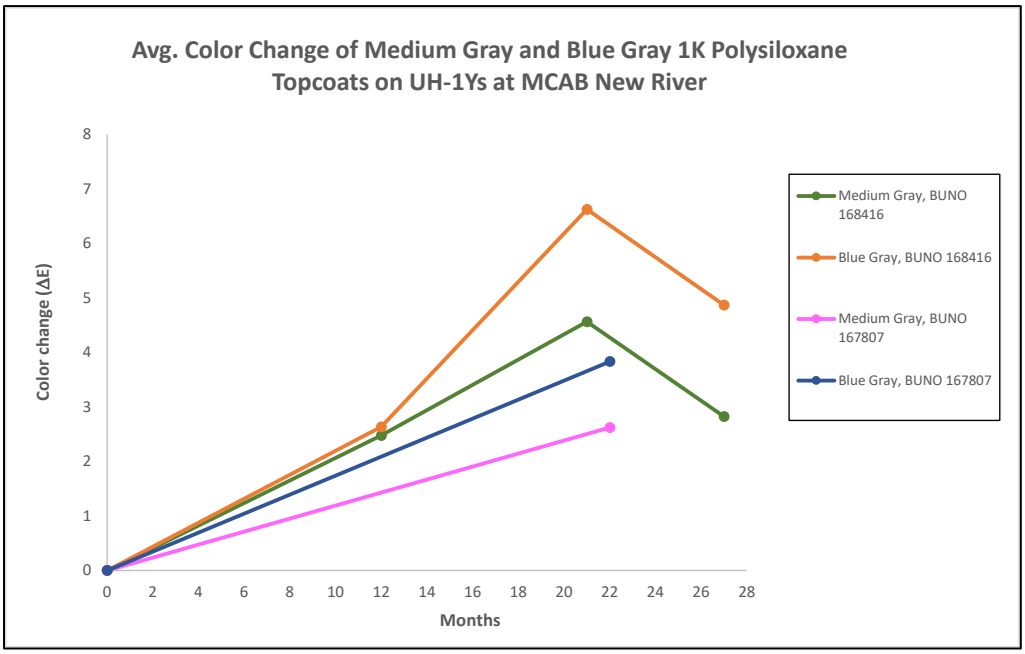


Figure 179 — Average color change of 1K polysiloxane topcoats after 22-27 months of service on UH-1Ys.

The average gloss values of the medium gray and blue gray 1K polysiloxane topcoats were relatively consistent between the initial and final inspections, whereas periodic inspections on BUNO 168416 demonstrated both increases and decreases in values. The variability during inspections was most likely due to the meter not being flush with the surface, especially when collecting gloss values on areas with substantial curvature (e.g., top of tail boom), thereby allowing external light to enter the meter and provide elevated values. After 22 months, the 60 degree gloss for the medium gray topcoat on BUNO 167807 was an average of 5.72 GU, which was slightly above the NAVAIR requirement of ≤5 GU, although the averages on the pilot's and co-pilot's door were 5.1 GU and 5.3 GU, respectively, whereas the cargo door on the co-pilot's side was an average of 4.2 GU. However, the 85 degree value for the medium gray 1K topcoat on BUNO 167807 after 22 months was ≤10 GU, and both the 60 and 85 degree values for the blue gray 1K topcoat were ≤5 GU and ≤10 GU, respectively, after 22 months (figure 180).

After 27 months of service, the 60 degree gloss for the medium gray topcoat on BUNO 168416 was an average of 5.38 GU, which was slightly above the NAVAIR requirement of ≤5 GU, although the averages on the pilot's door and pilot's cargo door were 4.7 GU and 2.3 GU, respectively, whereas the cargo door on the co-pilot's side was an average of 4.0 GU. However, the 85 degree value for the medium gray 1K topcoat on BUNO 167807 after 22 months was ≤10 GU, and both the 60 and 85 degree values for the blue gray 1K topcoat were ≤5 GU and ≤10 GU, respectively, after 22 months (figure 181). This demonstrated that the 1K camouflage gray polysiloxane topcoats can retain their gloss and meet the NAVAIR requirement of ≤5 GU at 60 degrees and ≤10 GU at 85 degrees after 1-2 years of service, which satisfied the success criteria in Table 10. Furthermore, as stated previously, the gloss on both aircraft had a flat appearance and were visually similar to other UH-1Y aircraft on the flight line that were painted with MIL-PRF-85285 qualified 2K camouflage gray polyurethane topcoats.

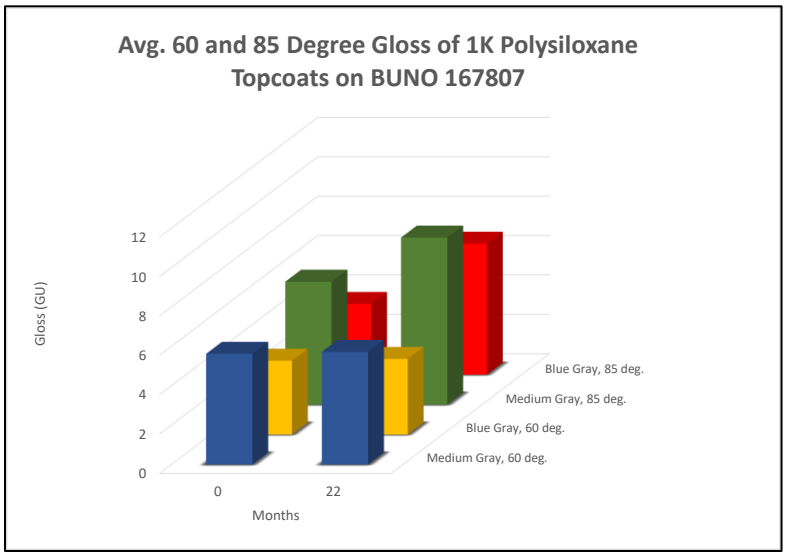


Figure 180 — Average gloss of 1K polysiloxane topcoats after 22 months of service on UH-1Y BUNO 167807.

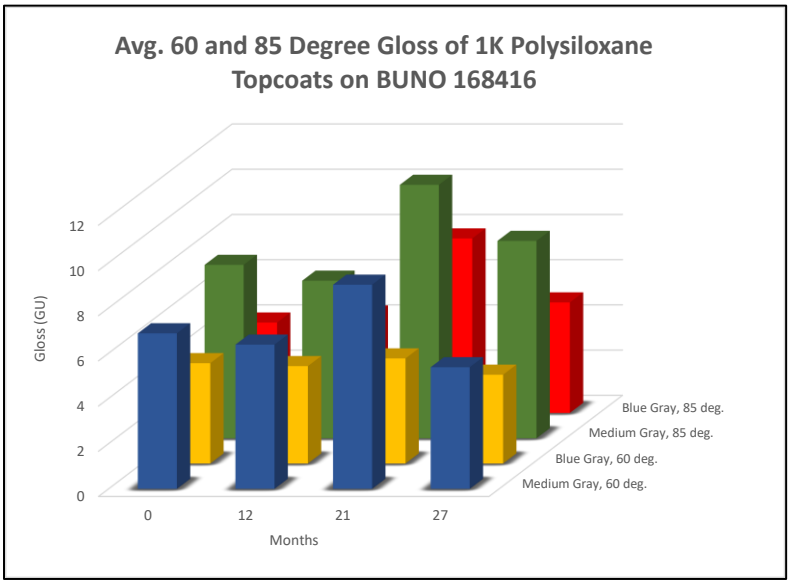


Figure 181 — Average gloss of 1K polysiloxane topcoats after 27 months of service on UH-1Y BUNO 168416.

7.4 Demonstration of 1K Camouflage Gray Polysiloxane Touch-Up Topcoats on Aircraft

In 2018, NCP Coatings produced over 60 Smart Touch® kits of the single-component camouflage gray polysiloxane touch-up topcoat, in FED-STD-595 #36375 medium gray color, for shipment by NAWC-AD to naval air stations around the globe. Several of these kits were sent to squadrons at NAS Oceana and NAS Whidbey to repair damaged areas of a polyurethane topcoat on F/A-18s, EA-18s, UH-1Ys, and other tactical aircraft. Surveys regarding the touch-up kits were provided to the squadrons by NAWC-AD.

7.4.1 F/A-18E Super Hornet – August 2018

7.4.1.1 Preparation and Painting of F/A-18E at NAS Oceana

Personnel from Strike Fighter Squadron 105 (VFA-105) at NAS Oceana, Virginia used the NCP Smart Touch® kit to repair two small areas on an F/A-18E Super Hornet. The areas in need of repair were hand-sanded, treated with an Alodine 1200 pen, primed with a chromate-containing epoxy primer, then painted with the 1K polysiloxane touch-up topcoat via brush and spray methods. Figures 182 and 183 show the sanded and primed areas of the F/A-18E, whereas figure 184 shows the applications of the 1K topcoat on those areas.

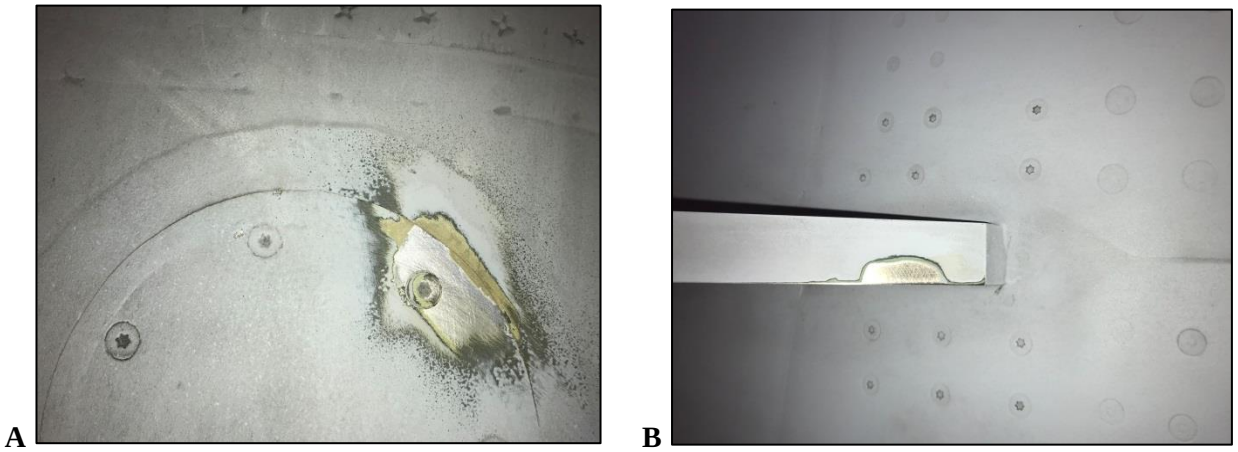


Figure 182 — Areas of an F/A-18 sanded by VFA-105 personnel at NAS Oceana.

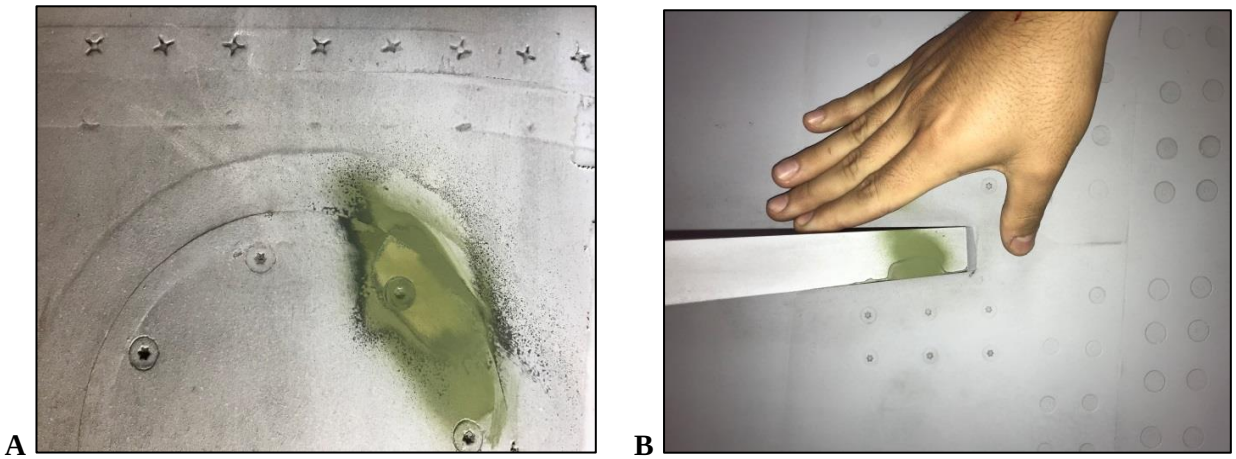


Figure 183 — Areas of an F/A-18E primed by VFA-105 personnel at NAS Oceana.

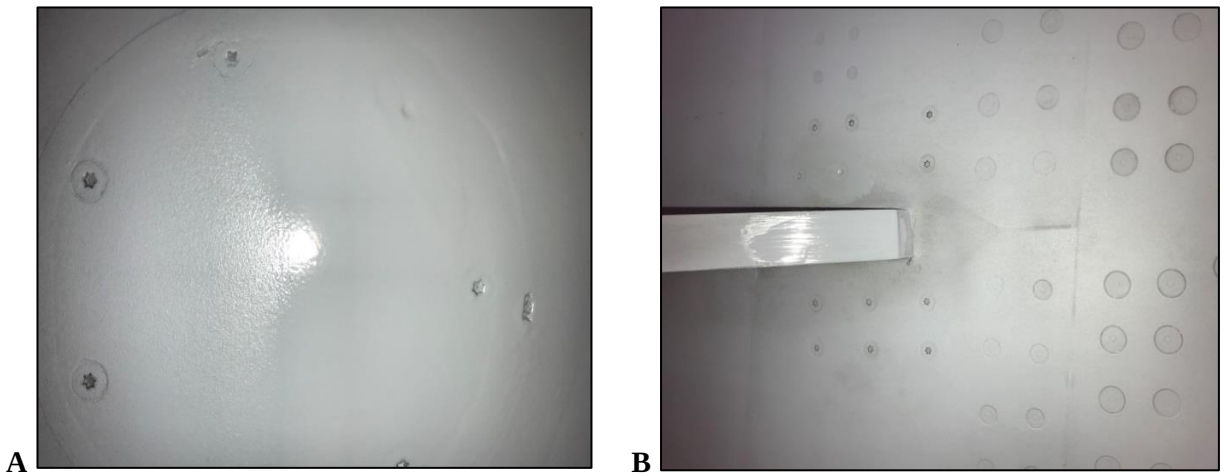


Figure 184 — Application of 1K polysiloxane touch-up topcoat on F/A-18E via a) Preval® spray gun and b) brush.

The painter from the squadron stated it was simple to mix the 1K polysiloxane topcoat and methyl acetate reducer in a 1:1 ratio (by volume) and apply with the Preval® spray gun. The paint sprayed and flowed out smoothly in one coat, then blended well with the surrounding polyurethane topcoat as it dried. A photo of the cured 1K polysiloxane topcoat after curing for 24 hours is shown in figure 185a. The consistency of the 1K topcoat enabled an easy application with the brush as well, although without the need for solvent reduction. However, the brush left minor strokes in the paint, even though the paint flowed-out and blended well. The brush application after curing for 24 hours is shown in figure 185b. Additionally, the painter stated that it required two coats via brushing to fully cover the primer, and he recommended waiting five minutes between each coat.

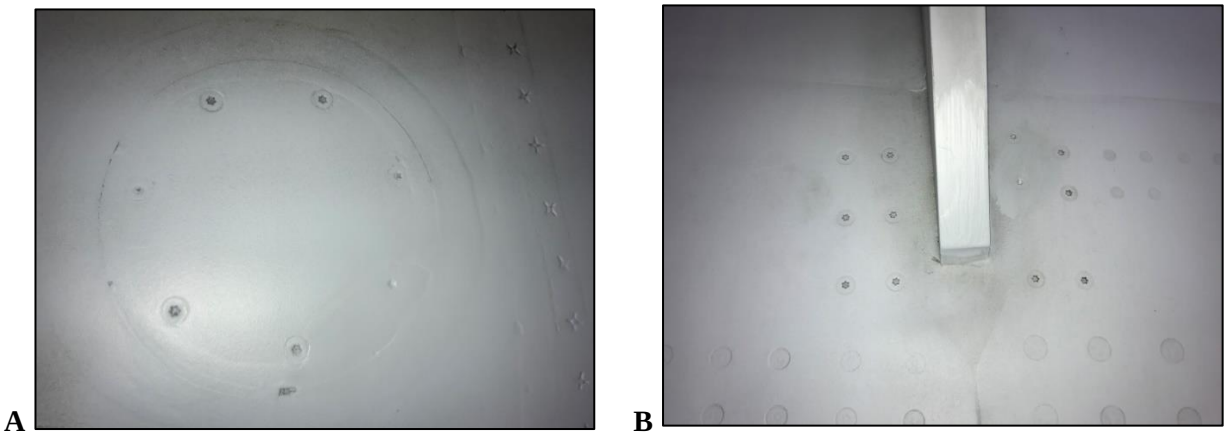


Figure 185 — Appearance of 24-hour cured 1K polysiloxane touch-up topcoat on F/A-18E resulting from a) Preval® spray gun application and b) brush application.

The 1K polysiloxane touch-up topcoat was deemed easy-to-use and required no training, which met the success criteria shown in Table 9. The time from opening the kit until spraying was only a few minutes, as opposed to metering an mixing a kit of 2K polyurethane topcoat, which can require up to 30 minutes. The 1K topcoat also blended well with the 2K polyurethane topcoat on the aircraft, which met the appearance criteria in Table 9. Furthermore the applicator stated that the 1K polysiloxane touch-up topcoat possessed

a more pleasant smell than the 2K polyurethane topcoats currently used by the squadron for touch-up / repair of aircraft.

7.4.1.2 Inspection of Touch-Up Topcoat

The F/A-18E with VFA-105 was used under normal operating conditions after the 1K polysiloxane touch-up topcoat was cured for over 24 hours. Periodic inspections of the topcoat did not occur and the squadron did not report any issues, such as delamination, of the repaired areas.

7.5 Demonstration of 1K Semi-Gloss Gray Polysiloxane Topcoat on B4 Maintenance Stands

In 2019, NCP Coatings manufactured 12 gallons of a single-component semi-gloss gray polysiloxane topcoat (product code BM1947), in FED-STD-595 #26173 dark gray, for shipment to MacDill Air Force Base, Tampa, Florida and Joint Base Andrews, Maryland for application on AGE. The 1K topcoat at MacDill AFB was applied on two B4 maintenance stands, whereas the application at Joint Base Andrews never occurred.

7.5.1 B4 Maintenance Stands – March/April 2019

7.5.1.1 Preparation and Painting of B401 and B407 Maintenance Stands

B401 and B407 maintenance stands were painted by personnel at MacDill AFB in March and April of 2019, respectively. The stands were prepared for painting by first removing the old coatings from the steel via abrasive blast media, followed cleaning, application of PreKote pretreatment, and spray application of a MIL-PRF-23377, Type I chromate-containing epoxy primer.

The 1K semi-gloss gray polysiloxane topcoat was applied on the stands via HVLP spray equipment, although the brand of equipment, spray gun settings, and fluid tip size used for the application were not provided to NRL. Per the applicator, the 1K topcoat sprayed well on B401 and flowed-out evenly. The topcoat cured overnight and had a better appearance (e.g., less orange peel) than the MIL-PRF-85285, Type I qualified 2K semi-gloss gray polyurethane topcoats that are typically applied. The following day, touch-up to minor areas of the stand was performed using a brush and the 1K semi-gloss topcoat, which smoothed out and blended well with sprayed areas. Painting of the B401 stand consumed 1-1.25 gallons of the 1K topcoat, versus 1.5-2 gallons when applying a 2K polyurethane topcoat. Photos of the B401 maintenance stand after several days of curing are shown in figures 186 and 187. The B407 stand was painted in a similar fashion the following month.

7.5.1.2 Collection of Initial Metrics on B401 and B407

Initial DFT, color, and gloss values on the maintenance stands were not collected because a representative from NRL or AFRL were not present for the application.

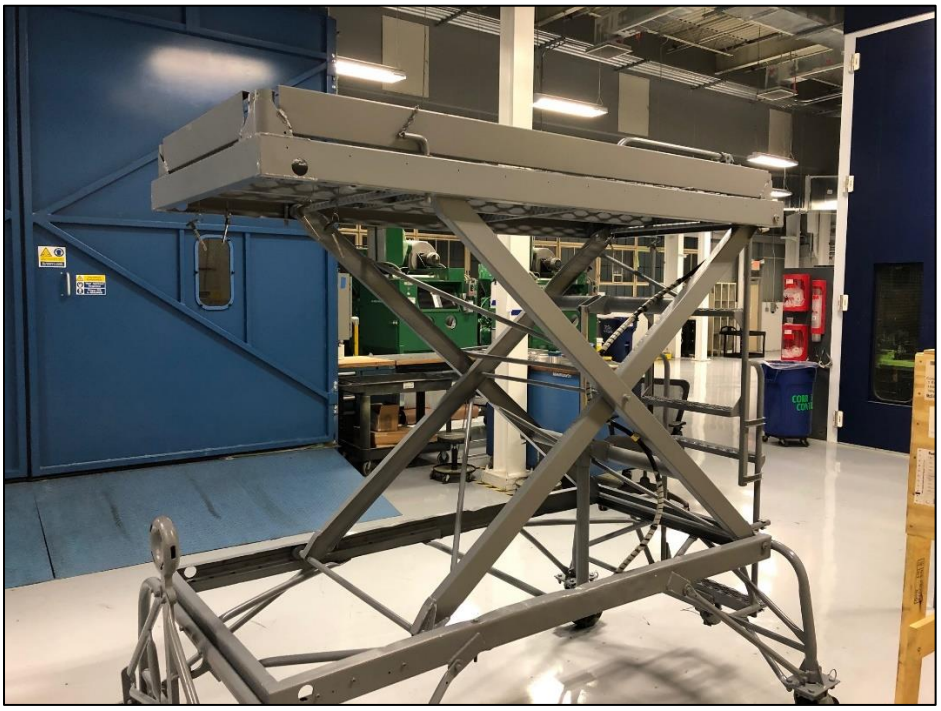


Figure 186 — 1K semi-gloss gray polysiloxane topcoat on B401 maintenance stand after curing for several days.

Figure 187 — 1K semi-gloss gray polysiloxane topcoat on bottom section of B401 maintenance stand after curing for several days.

7.5.1.3 Volume of Topcoats Utilized and Emitted VOCs

Painting of the B401 stand utilized 1-1.25 gallons of the 1K semi-gloss gray polysiloxane topcoat. At 96 g/l (0.82 lb/gal) VOCs this equates to 0.82-1.02 pounds (0.92 pound average) of VOCs released during the application. On the contrary, painting of a B4 stand typically requires 1.5-2 gallons of a 2K semi-gloss gray polyurethane topcoat, which has a VOC content of 420 g/l (3.50 lb/gal), and equates to 5.25-7 pounds (6.12 pound average) of emitted VOCs. Thus, not only was less paint consumed by applying the 1K polysiloxane topcoat on the B4 stand, but approximately 5.2 pounds less VOCs were emitted into the air in comparison to a typical 2K polyurethane topcoat application.

7.5.1.4 Inspection of B401 and B407after 3-4 Months of Service – July 2019

The 1K semi-gloss gray polysiloxane topcoat on B401 and B407 stands were inspected after 3-4 months of use in the field. The topcoats were in excellent condition with only minor damage due to mechanical abrasion. Additionally, the topcoats showed no signs of blistering, cracking, delamination, damage due to heat, damage due to fluids, or facial corrosion, as well as no signs of color fading or loss of gloss. Figures 188-190 show the 1K topcoat on stands B401 and B407 after 4 and 3 months of service, respectively.

Figure 188 — 1K semi-gloss gray polysiloxane topcoat on B401 maintenance stand after 4 months of service.

Figure 189 — Close-up of 1K semi-gloss gray polysiloxane topcoat (product code BM1947) on B401 maintenance stand after 4 months of service.

Figure 190 — 1K semi-gloss gray polysiloxane topcoat on B407 maintenance stand after 3 months of service.

7.5.1.5 Inspection of B401 and B407after 14-15 Months of Service – June 2020

The 1K semi-gloss gray polysiloxane topcoat on B401 and B407 stands were inspected after 14-15 months of service in the field, which was the final inspection of the stands. In general, the topcoats remained in good condition after greater than 1 year of field service. Corrosion was showing in typical areas of both stands due to metal on metal contact, in addition to running rust in several areas on B401 where the coating system was damaged. However, running rust was not observed in damaged areas on B407. The topcoats showed no signs of blistering, cracking, flaking, delamination, damage due to heat, or damage due to fluids, as well as no signs of color fading or loss of gloss. Figures 191-193 show the 1K topcoat on stands B401 and B407 after 15 and 14 months of service, respectively.

Figure 191 — 1K semi-gloss gray polysiloxane topcoat on B401 maintenance stand after 15 months of service.

Figure 192 — 1K semi-gloss gray polysiloxane topcoat on B407 maintenance stand after 14 months of service with side showing corrosion due to mechanical damage.

Figure 193 — 1K semi-gloss gray polysiloxane topcoat on B407 maintenance stand after 14 months of service with non-damaged side showing.

7.5.1.6 Discussion

The exterior of two Air Force B4 maintenance stands at MacDill AFB were painted with the NCP Coatings' single-component semi-gloss gray polysiloxane topcoat in FED-STD-595 #26173 dark gray color. These applications occurred in March and April of 2019. The 1K topcoat was easy-to-use and advantageous for applicators because it did not require the metering and mixing of components, which met the criteria for topcoat ease-of-use as shown in Table 9. The 1K topcoat was applied on the majority of the stands using HVLP spray equipment, then touched-up in several areas the following day via brush application. As a result, the 1K topcoat met the success criteria for equipment and method of application as shown in Table 9. The applicator also stated that the 1K polysiloxane topcoat sprayed, covered, and flowed-out well on the stands.

The painters used 1-1.25 gallons of the 1K semi-gloss gray polysiloxane topcoat to paint each B4 stand, which equates to an average VOC emission of 0.92 pounds per application. This was a reduction of 5.2 pounds of VOCs per stand by using the 1K topcoat, which met the criteria for VOC reduction as shown in Table 10.

During the 14-15 months in-service inspection the stand showed corrosion in areas where the coating system was damaged. However, the topcoats showed no signs of blistering, cracking, flaking, delamination, damage due to heat, or damage due to fluids, which met the success criteria in Table 9. Following the final inspection a service member stated the adhesion and color stability of the 1K polysiloxane topcoat was superior to the MIL-PRF-85285, Type I qualified 2K semi-gloss gray polyurethane topcoat that is typically applied on AGE, which met the visual in-service weatherability criteria shown in Table 9. The enhanced performance of the 1K polysiloxane topcoat may increase the service life of B4 stands and reduce paint intervals, thereby reducing maintenance costs for the Air Force. A reduction in paint consumption and VOC emissions will also reduce maintenance costs and the impact on the environment, respectively.

7.6 Demonstration of 2K Gloss White Polysiloxane Topcoat on ATT

In October of 2018, NCP Coatings produced gallon kits of the 2K gloss white polysiloxane topcoat (Batch 20-29, DoM 07/2018), in FED-STD-595 #17925 color, for application on an aircraft towing tractor (ATT) (a.k.a. spotting dolly) at FRC Aviation Support Center, Solomon's Island, Maryland. After 5 months of remaining at the facility the spotting dolly was deployed for use on the flight deck of the USS Nimitz (CVN-68) for a period of 25 months.

7.6.1 Application of topcoat on ATT – October 2018

The frame and components of the spotting dolly were prepared by removing the old coatings via abrasive blast media and subsequent cleaning (figure 194), followed by HVLP spray application of a buff-colored MIL-DTL-53022, Type II epoxy primer (figure 195). Once the primer had dried for about 2 hours the 2K gloss white polysiloxane topcoat was applied using a Binks Mach 1 HVLP spray gun with a 1.7 mm fluid tip (figure 196). The spray booth conditions were 82.5-86.3 °F ambient temperature and 68.2-82.4% relative humidity. Two successive coats were applied, which required a total of about 40 minutes and consumed more than 1 gallon of paint. No sags, drips, or runs were observed during the application, and one of the painters stated "it was the best paint he has ever sprayed". In some areas, the painters tried to deliberately create runs by applying excess coating, but were unsuccessful. Figure 197 show the 2K topcoat immediately after the spray application.

Figure 194 — Preparation of spotting dolly frame via abrasive blast media and cleaning.

Figure 195 — Application of MIL-DTL-53022, Type II epoxy primer on frame of spotting dolly.

Figure 196 — Spray application of 2K gloss white polysiloxane topcoat on frame of spotting dolly.

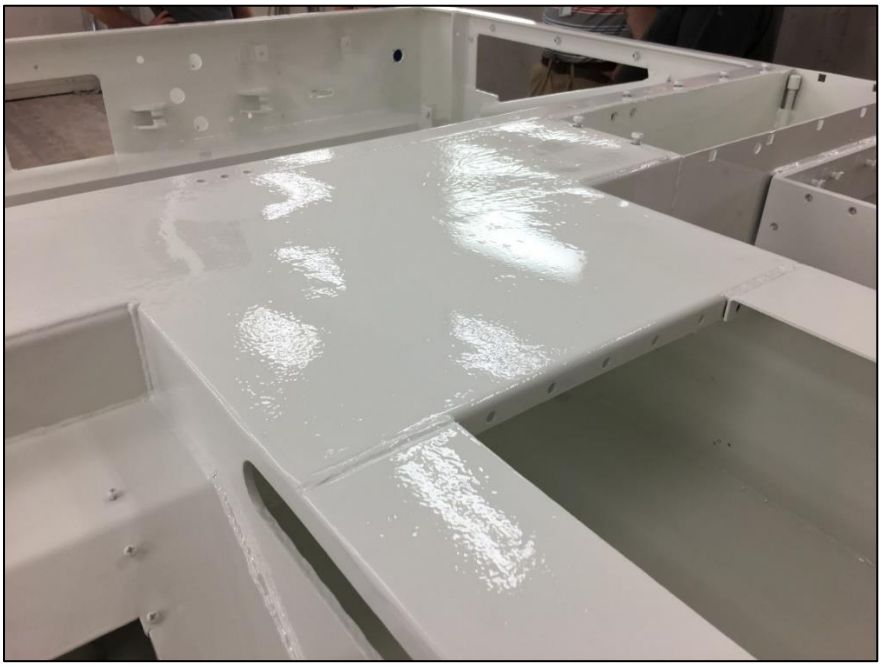


Figure 197 — 2K gloss white polysiloxane topcoat on frame of spotting dolly immediately after application.

The 2K gloss white polysiloxane topcoat was inspected the day following the spray application. The topcoat was visually high in gloss with a bright white color as shown in figures 198-201. No runs or sags were observed, and the topcoat covered well on sharp edges.

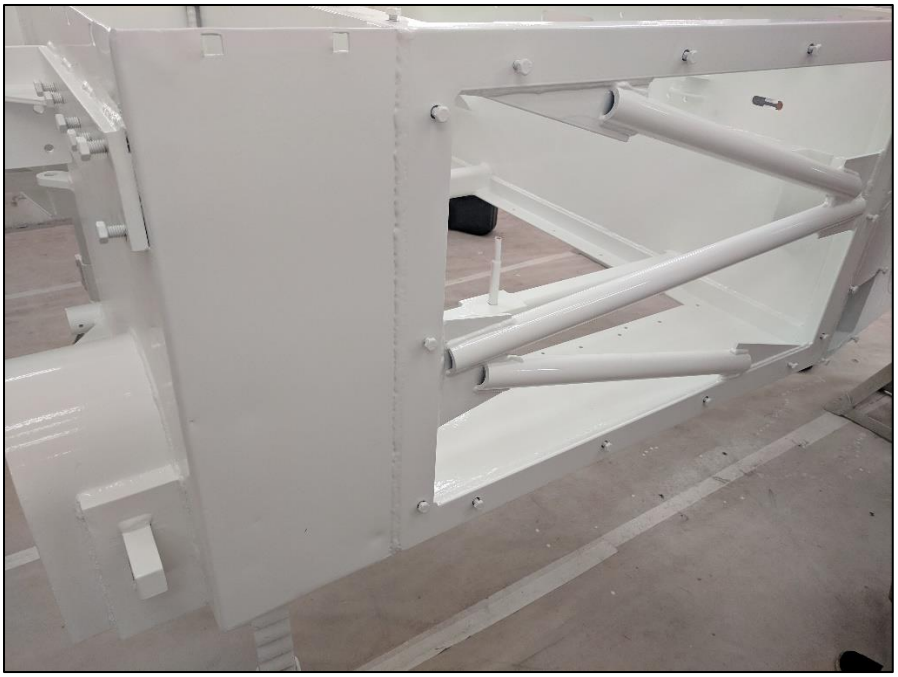


Figure 198 — 2K gloss white polysiloxane topcoat on flat and rounded areas of spotting dolly frame the day after application.

Figure 199 — 2K gloss white polysiloxane topcoat on angular and rounded areas of spotting dolly frame the day after application.

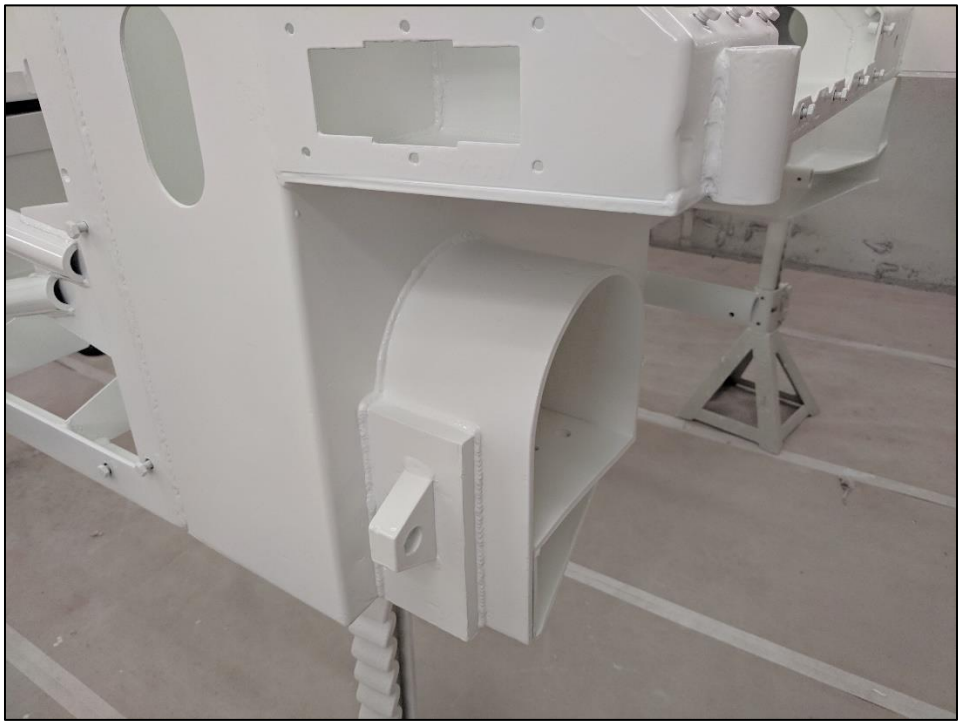


Figure 200 — 2K gloss white polysiloxane topcoat on angular and flat areas of spotting dolly frame the day after application.

Figure 201 — 2K gloss white polysiloxane topcoat on side of spotting dolly frame showing lines from primer profile.

The appearance of the topcoat varied depending on the surface profile of the frame and primer. For example, the topcoat on several of the flat areas was orange peeled due to the undulating profile of the blasted frame, whereas several areas on the sides of the frame appeared as parallel lines due to the underlying primer.

DFT values were collected with a PosiTector gauge. The average value on the frame was 3.78 mils, whereas the average on the components was 3.60 mils. The DFT of the epoxy primer was an average of 1.28 mils, thus the topcoat thickness on the frame and components was 2.5 mils and 2.3 mils, respectively.

Color and gloss values were determined with an X-Rite SP62 spectrophotometer and Elcometer 407 statistical gloss meter, respectively. Table 147 shows the initial color and gloss of the 2K polysiloxane topcoat that were collected from the frame of the ATT.

Table 147 — Initial color and gloss values of 2K gloss white polysiloxane topcoat on the ATT frame.

	Color			**Gloss (60° angle)**
Measurement #	**L**	**a**	**b**	**Gloss Unit (GU)**
1	92.73	-1.87	6.87	88.8
2	92.41	-1.84	6.68	88.6
3	92.50	-1.87	6.63	81.8
4	93.40	-1.77	5.96	86.5
Avg.	**92.76**	**-1.84**	**6.53**	**86.4**

This spotting dolly remained at FRC Solomon's until deployment to the USS Nimitz (CNV-68) in March of 2019. For use as a control, a spotting dolly was painted with a MIL-PRF-85285, Type II qualified 2K gloss white polyurethane topcoat in October of 2018 and deployed to the USS Nimitz in December of 2018 for comparative performance to the polysiloxane topcoat during operations on the flight deck.

7.6.2 In-service inspections of topcoat on ATT

7.6.2.1 Inspection of ATT after 2 Months on USS Nimitz – May 2019

The spotting dolly with the 2K gloss white polysiloxane topcoat, S/N QCF011, was visually inspected and photographed by Ship's Force after 2 months of service aboard the USS Nimitz. During this period, the topcoat showed no signs of blistering, cracking, chipping, delamination, or damage due to heat or fluids, including no facial corrosion (figure 202). DFT, gloss, and color values were not determined because the asset was deployed at sea and a NRL or NAWC-AD representative could not be present to collect metrics. Figure 203 shows the 2K gloss white polyurethane topcoat (control) on a similar spotting dolly, S/N QCF073, during the same period.

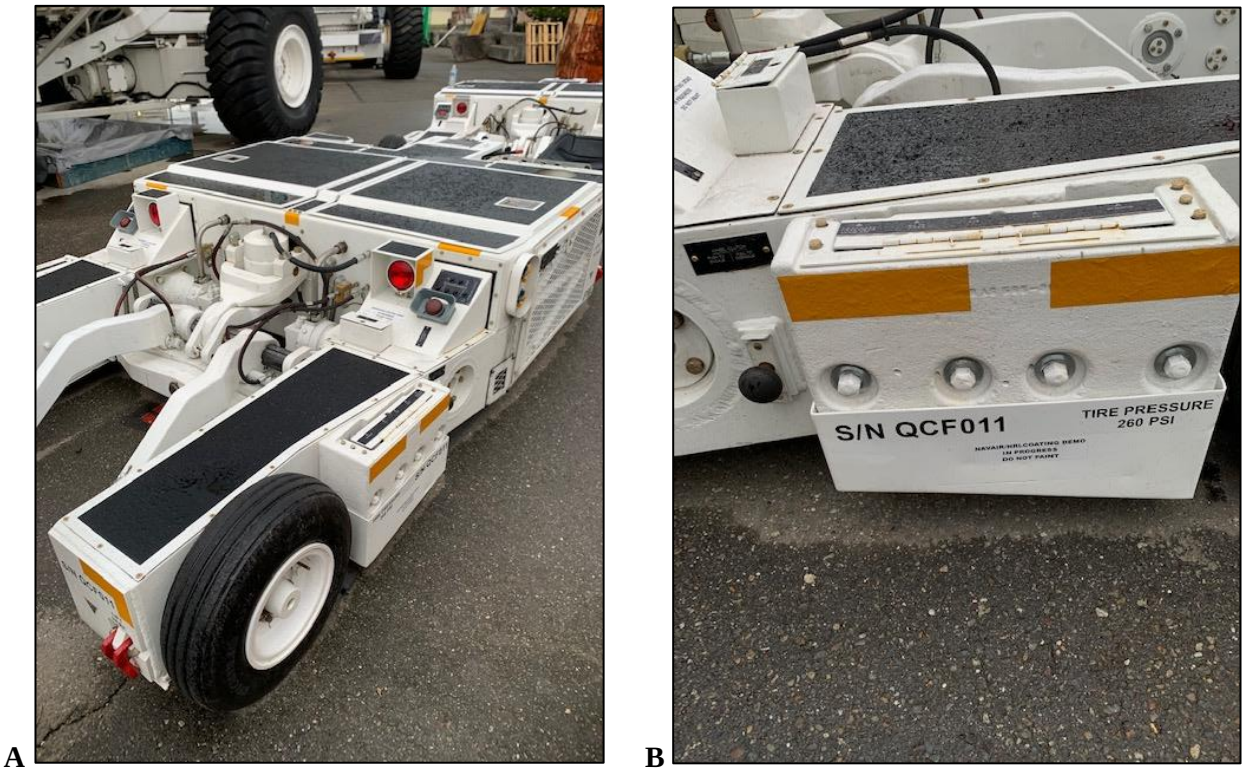


Figure 202 — 2K gloss white polysiloxane topcoat on a) front and b) side of spotting dolly after 2 months on the USS Nimitz.

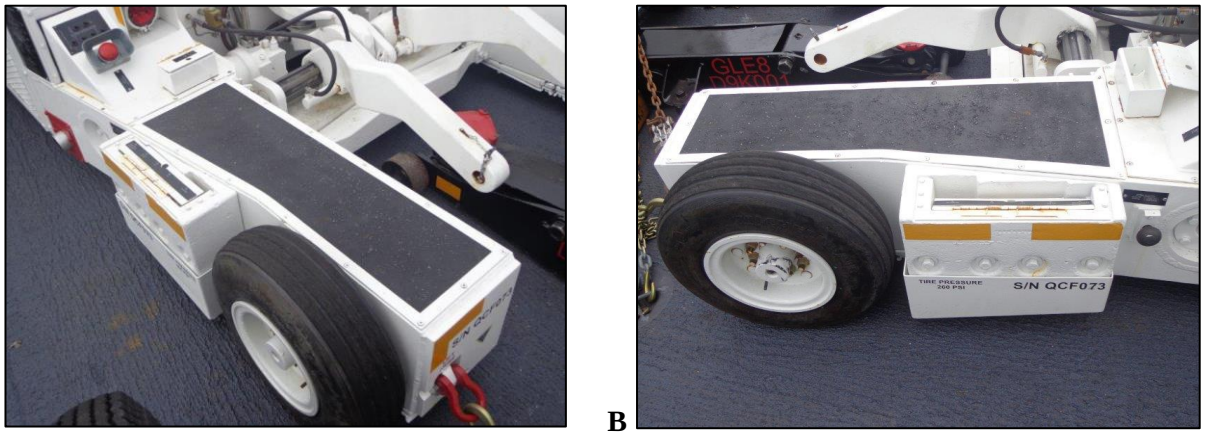


Figure 203 — 2K gloss white polyurethane topcoat (control) on a) front and b) side of a spotting dolly aboard USS Nimitz.

7.6.2.2 Inspection of ATT after 18 Months on USS Nimitz – September 2020

Photographs of the 2K gloss white polysiloxane topcoat on the spotting dolly were provided by Ship's Force after 18 months aboard the USS Nimitz. As is shown in figure 204, the topcoat showed no signs of blisters, delamination, cracking, peeling, damage due to sunlight, or damage due to fluids. In addition, the topcoat showed no facial corrosion, although there was some corrosion on edges and around screws. The spotting dolly painted with the MIL-PRF-85285, Type II qualified 2K gloss white polyurethane topcoat (control) demonstrated similar performance after 21 months on the USS Nimitz as shown in figure 205.

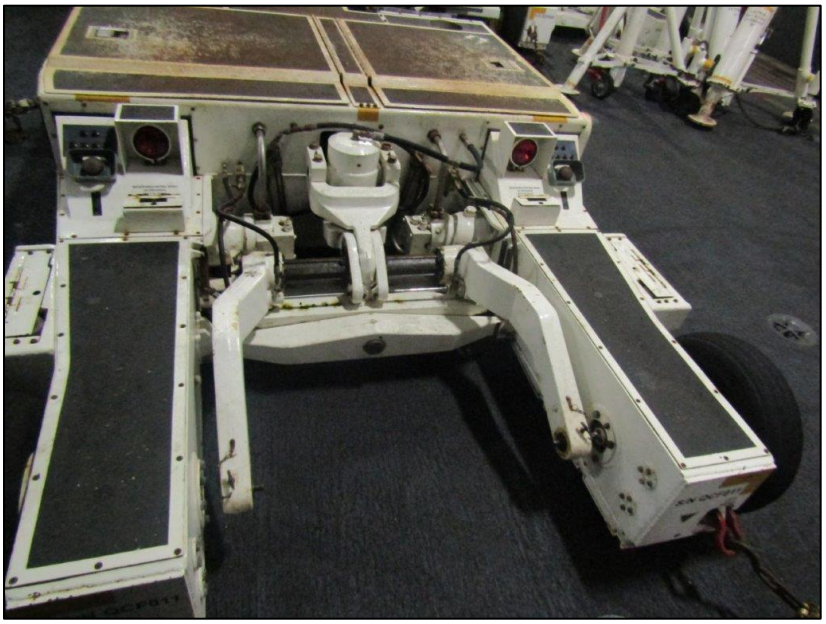


Figure 204 — 2K gloss white polysiloxane topcoat on spotting dolly after 18 months on the USS Nimitz.

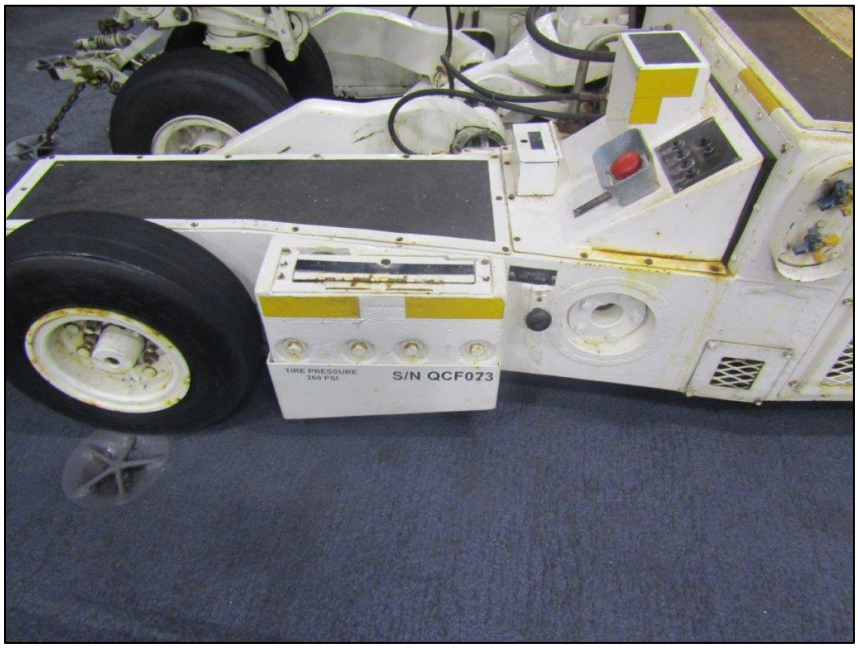


Figure 205 — 2K gloss white polyurethane topcoat on spotting dolly after 21 months on the USS Nimitz.

7.6.2.3 Inspection of ATT after 25 Months of Service on USS Nimitz – April 2021

On April, 22, 2021, the 2K gloss white polysiloxane topcoat on spotting dolly S/N QCF011 was inspected at Naval Station Everett, Washington after logging over 393 hours (based on asset time meter) of service on the flight deck of the USS Nimitz. The coating was in moderate-to-good condition with no signs of blistering, cracking, damage due to fluids, or damage due to heat. However, there was moderate mechanical damage to the topcoat, especially on the top hatches of the asset (figure 206). NRL and NAWC-AD were informed the mechanical damage was due to having chains dropped on and/or dragged across the spotting dolly during deployment, which is a common practice when moving and anchoring aircraft on a flight deck. The chains also removed the majority of the dark-colored nonskid coating on the hatches as shown in figure 207. This damage resulted in corrosion to several areas of the spotting dolly, especially on edges where the primer and topcoat there applied thin and could be easily removed via abrasion (figure 208). In addition, corrosion was observed on welds and facial corrosion was observed on flat surface due to running rust. Most of the screws and bolts were also corroded around the edges, although these items were not painted prior or after installation (figure 209-211). The spotting dolly was not cleaned prior to inspection.

The 2K gloss white polyurethane topcoat (control) on spotting dolly S/N QCF073, which had been utilized for a total of 334 hours, or about 18% less time than S/N QCF011 with the 2K gloss white polysiloxane topcoat, was inspected and showed the same mechanical damage and corrosion as the latter (figures 212-215). Ship's Force stated there was no particular reason why S/N QCF011 was used more than S/N QCF073, although one would expect to observe increased damage and corrosion to a spotting dolly that was used on the flight deck for a longer period of time.

Figure 206 — 2K gloss white polysiloxane topcoat on spotting dolly after 393 hours of service on the USS Nimitz.

Figure 207 — Mechanical damage to top hatches of spotting dolly painted with 2K gloss white polysiloxane topcoat.

Figure 208 — Loss of 2K gloss white polysiloxane topcoat on edges and resulting corrosion.

Figure 209 — 2K gloss white polysiloxane topcoat on vertical surface with minor corrosion on edges.

Figure 210 — 2K gloss white polysiloxane topcoat on vertical surface with corrosion on bolts.

Figure 211 — 2K gloss white polysiloxane topcoat on horizontal and vertical surfaces with corrosion on bolts.

Figure 212 — Type II 2K gloss white polyurethane topcoat (control) on spotting dolly after 334 hours of service on the USS Nimitz.

Figure 213 — Type II 2K gloss white polyurethane topcoat (control) on spotting dolly after 334 hours of service on the USS Nimitz.

Figure 214 — Type II 2K gloss white polyurethane topcoat (control) on horizontal and vertical surfaces with corrosion on bolts.

Figure 215 — Loss of Type II 2K gloss white polyurethane topcoat (control) on edges and resulting corrosion.

DFT values were collected with the same instrument as used during the initial inspection. The 2K gloss white polysiloxane topcoat on spotting dolly S/N QCF011 had an average DFT of 3.97 mils, which equates to 2.69 mils of topcoat once the primer thickness is subtracted. The average DFT for the Type II 2K gloss white polyurethane topcoat (control) on S/N QCF073 was 7.35 mils, which equates to 6.07 mils of topcoat assuming the primer was applied at the same thickness. Thus, even at half the thickness the 2K polysiloxane topcoat performed similarly to the 2K polyurethane topcoat, although the latter should have yielded better corrosion resistance, especially on edges.

Color and gloss values were collected with the same instruments as used during the initial inspection (table 148). Compared to the initial values, the 2K gloss white polysiloxane topcoat after 25 months was slightly more red and yellow in color, which is likely due to the presence of rust staining and minor surface degradation due to exposure in sunlight. However, these changes resulted in an overall color change of only 0.87 for the 2K polysiloxane topcoat as shown in Table 149. The average gloss of the 2K polysiloxane topcoat after 25 months was 66.0 GU at 60 degrees compared to the initial average of 86.4 GU at 60 degrees, which is a decrease of 23.6%.

Table 148 — Average color and gloss values of 2K gloss white polysiloxane topcoat on ATT after 25 months of service.

	Color			**Gloss (60° angle)**
Measurement #	**L**	**a**	**b**	**Gloss Unit (GU)**
1	91.98	-1.24	7.36	55.2
2	91.99	-1.57	8.55	67.6
3	93.14	-1.35	6.49	74.2
4	92.35	-1.30	6.15	66.9
Avg.	**92.36**	**-1.36**	**7.14**	**66.0**

Table 149 — Average color change of 2K gloss white polysiloxane topcoat on ATT after 25 months of service.

March 2019			**April 2021**			**ΔE**
L*	**a***	**b***	**L***	**a***	**b***	
92.76	**-1.84**	**6.53**	**92.36**	**-1.36**	**7.14**	**0.87**

Color and gloss values for the MIL-PRF-85285, Type II qualified 2K gloss white polyurethane topcoat (control) on S/N QCF073 were collected for comparison to the 2K gloss white polysiloxane topcoat, even though initial values for the control were not collected. Nevertheless, both topcoats had a color difference of <1.0 from the FED-STD-595 #17925 color chip after applied, and were visually similar before deployment. As shown in Table 150, the color values for the Type II 2K polyurethane topcoat after deployment for 28 months were darker and redder in color compared to the 2K polysiloxane, although can be attributed to rust staining and contaminants on the asset. Furthermore, the average gloss for the Type II 2K polyurethane topcoat after deployment was 67.5 GU, which was nearly identical to the gloss of the 2K polysiloxane topcoat after deployment.

Table 150 — Average color and gloss values of MIL-PRF-85285, Type II qualified 2K gloss white polyurethane topcoat (control) on ATT after 28 months of service.

	Color			**Gloss (60° angle)**
Measurement #	**L**	**a**	**b**	**Gloss Unit (GU)**
1	93.95	-0.48	7.45	59.7
2	93.87	-0.62	8.29	65.7
3	94.65	-0.78	5.63	74.6
4	94.54	-0.64	6.35	70.0
Avg.	**94.25**	**-0.63**	**6.93**	**67.5**

7.6.2.4 Discussion

The 2K gloss white polysiloxane topcoat is isocyanate-free, HAP-free, and possesses only 65 g/l (0.54 lb/gal) VOCs. Approximately two gallons of the topcoat were used to paint the frame and all components of ATT S/N QCF011, which equates to 1.08 pounds of VOCs released into the air. The MIL-PRF-85285, Type II qualified 2K gloss white polyurethane topcoat (control) used on ATT S/N QCF073 possessed 336 g/l (2.8 lb/gal) VOCs, and assuming 2 gallons were used this equates to 5.6 pounds of VOC emitted. This was a reduction of 4.52 pounds VOCs by applying the 2K polysiloxane topcoat, which met the success criteria in Table 10.

After 393 hours of service, the 2K gloss white polysiloxane topcoat was in moderate-to-good condition with no signs of blistering, cracking, damage due to fluids, or damage due to heat. However, there was moderate mechanical damage to the topcoat due to chains being dropped on and dragged across the asset, thereby chipping and abrading the polysiloxane topcoat in several areas, such as on the top hatches and surrounding edges. Running rust and corresponding staining were also observed on the topcoat due to thinly coated edges and non-painted bolts that were used to connect components. Consequently, the ATT that was painted with the qualified 2K gloss white polyurethane topcoat, which was twice the thickness of the 2K polysiloxane topcoat and operated for only 334 hours, showed similar mechanical damage on the hatches and surrounding edges, in addition to running rust and staining on flat surfaces. This shows that the 2K polysiloxane topcoat can provide similar visual and corrosion performance in the field compared to a MIL-PRF-85285, Type II qualified 2K polyurethane topcoat, which met the success criteria in Table 9.

The ATTs were not cleaned prior to inspection, thereby leaving contaminants, such as rust staining, on the surface of the topcoats. After 393 hours of service the 2K gloss white polysiloxane topcoat had an average color change of 0.87 and a gloss retention of 76.4%. Rust staining and surface degradation were minor contributors to the color change. However, the color values for the Type II 2K polyurethane topcoat after deployment were similar, and it is known that both topcoats were color matched to a difference of <1.0 compared to the FED-STD-595 #17925 color chip, thus the color change for the 2K polysiloxane after deployment was likely similar to the polyurethane. The average gloss for the Type II 2K polyurethane topcoat was also similar to the 2K polysiloxane topcoat after deployment. This validated that the 2K polysiloxane topcoat can provide similar visual and in-service weatherability as a MIL-PRF-85285E, Type II qualified 2K gloss white polyurethane topcoat, which met the success criteria shown in Tables 9 and 10, respectively.

7.7 Demonstration of 2K Gloss White Polysiloxane Topcoat on Mobile Facility

In September of 2019, NCP Coatings produced gallon kits of the 2K gloss white polysiloxane topcoat, in FED-STD-595 #17925 color, for application on a Mobile Facility at Marine Depot Maintenance Command (MDMC) Albany, Georgia. The unit then remained outside at the depot for a period of 1 year until being deployed overseas.

7.7.1 Application of topcoat on Mobile Facility – September 2019

Mobile facility JCM-302, which is constructed of a lightweight, aluminum composite material, was prepared for painting by removing the old coatings via plastic media blasting. This was followed by cleaning and HVLP spray application of a light gray MIL-DTL-53022, Type IV epoxy primer. The 2K gloss white polysiloxane topcoat was mixed in a 4:1 ratio (by volume), stirred by hand for 5 minutes, then spray-applied at 71 °F using an HVLP spray gun with a 1.4 mm fluid tip. An induction time was not required for the polysiloxane topcoat. Two successive coats were applied with about 1.15 hours between each coat (figure 216). Total time for the application was 2.25 hours and consumed 4 gallons of topcoat.

Figure 216 — Spray application of 2K gloss white polyurethane topcoat on mobile facility.

The painters were able to apply 3-4 mils wet film thickness of 2K polysiloxane per coat, which included cross-coating, without observing sags, drips, or runs. This is currently unachievable with the MIL-PRF-85285, Type II qualified 2K gloss white polyurethane topcoat that is commonly used at MDMC Albany because WFTs greater than 2 mils per coat will sag. Furthermore, the painters stated that the 2K gloss white polysiloxane topcoat was "one of the best coatings we have ever sprayed" and "we could have painted the entire mobile facility with just one coat".

7.7.2 Inspections of topcoat on Mobile Facility

7.7.2.1 Inspection After Application

The following day, DFT and gloss values of the topcoat were collected from JCM-302 using a PosiTector gauge and Elcometer 407 statistical gloss meter, respectively. The topcoat DFT was 7.0 mils, which includes the primer thickness, whereas the average gloss was 85.0 GU. Figures 217-220 show photos of the 2K gloss white polysiloxane topcoat once cured and after removed from paint booth. Figure 221 shows the mobile facility with stencils and decals.

Figure 217 — 2K gloss white polyurethane topcoat on side of mobile facility after overnight cure.

Figure 218 — 2K gloss white polyurethane topcoat on door of mobile facility after overnight cure.

Figure 219 — 2K gloss white polyurethane topcoat on side of mobile facility after removed from paint booth.

Figure 220 — Close-up of 2K gloss white polyurethane topcoat on side of mobile facility.

Figure 221 — Mobile facility with 2K gloss white polysiloxane topcoat, stencils, and decals.

For comparison, mobile facility JCM-301, which was painted with a MIL-PRF-85285, Type II qualified 2K gloss white polyurethane topcoat earlier in the morning, required 2.75 hours to complete and consumed 5 gallon of topcoat. The following day the DFT and gloss of the 2K polyurethane topcoat were 5 mils and 75 GU, respectively (figure 222).

Figure 222 — Type II 2K gloss white polyurethane topcoat on side of mobile facility after overnight cure.

7.7.2.2 Inspection After 12 Months at MDMC Albany – September 2020

Mobile facility JCM-302, which possessed the 2K gloss white polysiloxane topcoat, remained outside at MDMC Albany for over a year before being deployed to Marine Aviation Logistics Squadron 36 (MALS-36) in Okinawa, Japan. Photographs of the unit were taken after 1 year as shown in Figure 223, although DFT and gloss values were not recorded by NRL or NAWC-AD personnel due to facility access restrictions as a result of the COVID-19 pandemic.

Figure 223 — Mobile Facility with 2K gloss white polysiloxane topcoat after 1 year outside at MDMC Albany.

7.7.2.3 Discussion

The 2K gloss white polysiloxane topcoat is isocyanate-free, HAP-free, and possesses only 65 g/l (0.54 lb/gal) VOCs. Approximately four gallons of the topcoat were used to paint mobile facility JCM-302, which equates to 2.16 pounds of VOCs released into the air. Five gallons of a MIL-PRF-85285, Type II qualified 2K gloss white polyurethane topcoat, which possessed 336 g/l (2.8 lb/gal) VOCs, were required to paint mobile facility JCM-301. Five gallons of 2K polyurethane equates to 14.0 pounds of emitted VOCs. This was a difference of 11.84 pounds, or about 7.5 times less VOCs, thus the 2K polysiloxane topcoat met the success criteria in Table 10 for VOC reductions.

The 2K gloss white polysiloxane topcoat, which did not require an induction time after mixed by hand for a few minutes, was applied at 3-4 mils WFT per coat via HVLP spray equipment. The topcoat did not sag, run, or drip, even when applied via cross-coating. Painters stated that this cannot be accomplished with a Type II polyurethane topcoat because it can only be applied in 1-2 mils WFT per coat. Furthermore, the polyurethane topcoat required a 30 minute induction time after mixing and before application, which increased the paint preparation time. As a result, the 2K gloss white polysiloxane topcoat met the success criteria for ease-of-use and other performance requirements shown in Table 9. After curing overnight, the 2K gloss white polysiloxane topcoat possessed a DFT of 7 mils (primer included) and an average gloss of 85.0 GU, whereas the Type II 2K gloss white polyurethane topcoat after overnight cure possessed a DFT of 5 mils (primer included) and an average gloss of 75.0 GU, which demonstrated that the former can outperform a qualified Type II polyurethane topcoat and exceed the success criteria for appearance as shown in Table 9. It is worth restating that the painters mentioned the 2K gloss white polysiloxane topcoat was “one of the best coatings we have ever sprayed” and “we could have painted the entire unit with just one coat”.

8. COST ASSESSMENT

8.1 Cost Model and Analysis

The cost model for this project will be SparkLC from Noblis. However, the life cycle analysis (LCA) for this project, which will include the cost analysis, will be conducted at a later date. This information will be provided to ESTCP in a separate addendum to the report.

8.2 Qualitative Cost Savings

There are several cost savings that are expected to result from implementation of the 1K and 2K polysiloxane topcoats within the DoD. For example, the polysiloxane topcoats are free of hazardous isocyanate-functional molecules, thereby eliminating the need for industrial hygiene offices to collect air samples and determine the concentration of airborne HDI and/or oligomers of HDI during spray applications. Elimination of isocyanates will also eliminate health-related medical costs due to worker exposure to isocyanates. The 1K camouflage gray and semi-gloss gray polysiloxane topcoats do not require the metering and mixing of components, thereby reducing preparation and application times for painters, which will subsequently reduce labor costs. The 2K gloss white polysiloxane topcoat, which requires mixing of components in a 4:1 ratio (by volume), does not require an induction time, thereby also reducing the time required for preparation and application when compared to a MIL-PRF-85285, Type II qualified 2K gloss white polyurethane topcoat. Furthermore, unsprayed 1K polysiloxane topcoats can be recovered from pressure pots and cup guns, returned to their original cans, and used for future applications, thereby reducing the generation of hazardous paint waste and associated disposal costs. During the demonstration periods the 1K and 2K polysiloxane topcoats demonstrated equivalent, and in a few instances better, field performance than MIL-PRF-85285 qualified 2K polyurethane topcoats, thus a cost saving may exist by reducing paint intervals and extending the service life of assets. Currently, the cost of the polysiloxane topcoats is $150-175 per gallon (or gallon kit), which is similar to the cost of a MIL-PRF-85285 qualified 2K polyurethane topcoat. However, the price of the polysiloxane topcoats is based on small batch sizes (i.e., approximately 50 gallons) and is likely to decrease once production levels reach several hundred to a thousand gallons annually.

9. SUMMARY AND IMPLEMENTATION

NRL developed and patented two novel and environmentally friendly topcoat technologies: 1) a single-component polysiloxane topcoat, which is an all-in-one can system that does not require the metering and mixing of components, and 2) a two-component polysiloxane topcoat, which requires metering and mixing of components. These polysiloxane topcoats are free of hazardous isocyanates, free of HAPs, and lower in VOCs than MIL-PRF-85285 qualified 2K polyurethane topcoats. The technologies were licensed to NCP Coatings, LLC for optimization and commercialization, and multi-gallon quantities of camouflage gray, semi-gloss gray, and gloss white topcoats were produced for testing to MIL-PRF-85285, MIL-PRF-32239, MIL-PRF-81352, and extended laboratory performance requirements, including application on scrap aircraft components and the entire OML of active DoD assets. These assets were then utilized in the field under normal operating conditions for a period of 1-2 years, and assets painted with a MIL-PRF-85285 qualified 2K polyurethane topcoat were used for comparative purposes. During all demonstrations, polysiloxane topcoats demonstrated equivalent, and in a few instances better, field performance (e.g., corrosion resistance, weatherability) compared to the qualified polyurethane topcoat. Use of the polysiloxane topcoats on assets also resulted in reduced VOC emissions, reduced preparation and application times, and a reduction in the generation of hazardous paint waste. These results validated that the polysiloxane topcoats can be an environmentally friendly drop-in replacement for MIL-PRF-85285 qualified 2K polyurethane topcoats without sacrificing performance.

The organosilane polymer used as a binder in the single-component camouflage gray and semi-gloss gray polysiloxane topcoats is currently registered for commercial use under the EPA's TSCA chemical substance inventory. The polymers used as binders in the two-component gloss white polysiloxane topcoat are also TSCA-registered. Furthermore, all other raw materials (e.g., solvents, pigments, additives) are commercially used in these topcoats are available in large quantities from several manufacturers. Although production batches during this project were slightly greater than 50 gallons the topcoats can be produced by NCP Coatings on a larger scale (i.e., several hundred gallons per batch). NCP Coatings, who is currently a producer of coatings for the Navy and Marine Corps, will be responsive for all technical data sheets, conformance testing, and safety data sheets related to the 1K and 2K polysiloxane topcoats. Currently, the cost of the polysiloxane topcoats is similar to MIL-PRF-85285, Type IV polyurethane topcoats.

For decades, MIL-PRF-85285 performance specification pertained strictly to polyurethane topcoats and had not been revised since January 12, 2012.[1a] However, NAVAIR approved MIL-PRF-85285 Revision F on May 16, 2022, which included isocyanate-free, high-solids topcoats per Class NH, in addition to single-component topcoats per Form S.[1b] As a result, on August 19, 2022, the 1K camouflage gray polysiloxane topcoat, formally named N85 1K SiloxoShield by NCP Coatings, was approved by NAVAIR and listed on the qualified products database (QPD) as a MIL-PRF-85285F, Type I/IV, Class NH, Form S, Grade N product. The same day, the 2K gloss white polysiloxane topcoat, formally named N85 2K SiloxoShield by NCP Coatings, was also approved by NAVAIR and listed on the QPD as a MIL-PRF-85285F, Type II, Class NH, Form M, Grade N product. Local process instructions at depots, including NAVAIR's cleaning and corrosion control technical manual, are currently being revised to include these topcoats.[62] NAVAIR also plans to update the aircraft touch-up topcoat specification, MIL-PRF-81352, by adding an addition "Type" for polysiloxane topcoats.

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11. APPENDICIES

11.1 Appendix I – Points of Contact

Point of Contact	Organization	Phone and Email Address	Role in Project
Dr. Erick Iezzi	Naval Research Laboratory	(202) 404-2889 erick.iezzi@nrl.navy.mil	Principal Investigator
Dr. Mike Brindza	Naval Air Warfare Center – Aircraft Division	(412) 425-6282 michael.brindza@navy.mil	NAVAIR Stakeholder
Dr. Jessica Rex	Naval Air Warfare Center – Aircraft Division	jessica.m.rex2.civ@us.navy.mil	NAVAIR Stakeholder
John Benfer	NAVAIR FRC-Southeast	(904) 790-6405 john.benfer@navy.mil	NAVAIR Stakeholder
Christopher Gladson	NAVAIR FRC-East	(252) 464-8241 christopher.gladson@navy.mil	NAVAIR Stakeholder
Luc Doan	NAVAIR FRC-Southwest	(619) 545-9756 luc.doan@navy.mil	NAVAIR Stakeholder
Atish Gupta	NAVAIR Lakehurst	(732) 323-7550 atish.gupta@navy.mil	NAVAIR Stakeholder
Diane Buhrmaster	Air Force Research Laboratory	(937) 656-9549 diane.buhrmaster.1@us.af.mil	Air Force Stakeholder
Glenn Arent	NCP Coatings, LLC	(574) 315-4167 glenn@ncpcoatings.com	Polysiloxane Topcoat Manufacturer
Rob Holzapfel	NCP Coatings, LLC	(800) 627-1948, Ext. 240 rob@ncpcoatings.com	Polysiloxane Topcoat Manufacturer

11.2 Appendix II – Safety Data Sheet for Hexamethylene Diisocyanate

Sigma-Aldrich.

www.sigmaaldrich.com

SAFETY DATA SHEET

Version 6.2
Revision Date 11/15/2019
Print Date 11/20/2020

SECTION 1: Identification of the substance/mixture and of the company/undertaking

1.1 Product identifiers

Product name : Hexamethylene diisocyanate

Product Number : 52650
Brand : Sigma-Aldrich
Index-No. : 615-011-00-1
CAS-No. : 822-06-0

1.2 Relevant identified uses of the substance or mixture and uses advised against

Identified uses : Laboratory chemicals, Synthesis of substances

1.3 Details of the supplier of the safety data sheet

Company : Sigma-Aldrich Inc.
3050 Spruce Street
ST. LOUIS MO 63103
UNITED STATES

Telephone : +1 314 771-5765
Fax : +1 800 325-5052

1.4 Emergency telephone number

Emergency Phone # : 800-424-9300 CHEMTREC (USA) +1-703-527-3887 CHEMTREC (International) 24 Hours/day; 7 Days/week

SECTION 2: Hazards identification

2.1 Classification of the substance or mixture

GHS Classification in accordance with 29 CFR 1910 (OSHA HCS)

Acute toxicity, Oral (Category 4), H302
Acute toxicity, Inhalation (Category 1), H330
Skin corrosion (Category 1B), H314
Serious eye damage (Category 1), H318
Respiratory sensitisation (Category 1), H334
Specific target organ toxicity - single exposure (Category 3), Respiratory system, H335
Short-term (acute) aquatic hazard (Category 3), H402

For the full text of the H-Statements mentioned in this Section, see Section 16.

2.2 GHS Label elements, including precautionary statements

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operates as MilliporeSigma in the US and Canada

Pictogram	
Signal word	Danger
Hazard statement(s)	
H302	Harmful if swallowed.
H314	Causes severe skin burns and eye damage.
H330	Fatal if inhaled.
H334	May cause allergy or asthma symptoms or breathing difficulties if inhaled.
H335	May cause respiratory irritation.
H402	Harmful to aquatic life.
Precautionary statement(s)	
P260	Do not breathe dust/ fume/ gas/ mist/ vapours/ spray.
P264	Wash skin thoroughly after handling.
P270	Do not eat, drink or smoke when using this product.
P271	Use only outdoors or in a well-ventilated area.
P273	Avoid release to the environment.
P280	Wear protective gloves/ protective clothing/ eye protection/ face protection.
P284	Wear respiratory protection.
P301 + P312 + P330	IF SWALLOWED: Call a POISON CENTER/doctor if you feel unwell. Rinse mouth.
P301 + P330 + P331	IF SWALLOWED: Rinse mouth. Do NOT induce vomiting.
P303 + P361 + P353	IF ON SKIN (or hair): Take off immediately all contaminated clothing. Rinse skin with water/shower.
P304 + P340 + P310	IF INHALED: Remove person to fresh air and keep comfortable for breathing. Immediately call a POISON CENTER/doctor.
P305 + P351 + P338 + P310	IF IN EYES: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing. Immediately call a POISON CENTER/doctor.
P342 + P311	If experiencing respiratory symptoms: Call a POISON CENTER/doctor.
P363	Wash contaminated clothing before reuse.
P403 + P233	Store in a well-ventilated place. Keep container tightly closed.
P405	Store locked up.
P501	Dispose of contents/ container to an approved waste disposal plant.

2.3 Hazards not otherwise classified (HNOC) or not covered by GHS

Lachrymator., Rapidly absorbed through skin.

SECTION 3: Composition/information on ingredients

3.1 Substances

Synonyms	:	1,6-Diisocyanatohexane
Formula	:	$C_8H_{12}N_2O_2$
Molecular weight	:	168.19 g/mol
CAS-No.	:	822-06-0
EC-No.	:	212-485-8
Index-No.	:	615-011-00-1

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Component	Classification	Concentration
Hexamethylene diisocyanate		
	Acute Tox. 4; Acute Tox. 1; Skin Corr. 1B; Eye Dam. 1; Resp. Sens. 1; STOT SE 3; Aquatic Acute 3; H302, H330, H314, H318, H334, H335, H402	<= 100 %

For the full text of the H-Statements mentioned in this Section, see Section 16.

SECTION 4: First aid measures

4.1 Description of first aid measures

General advice
Consult a physician. Show this safety data sheet to the doctor in attendance.Move out of dangerous area.

If inhaled
If breathed in, move person into fresh air. If not breathing, give artificial respiration. Consult a physician.

In case of skin contact
Take off contaminated clothing and shoes immediately. Wash off with soap and plenty of water. Take victim immediately to hospital. Consult a physician.

In case of eye contact
Rinse thoroughly with plenty of water for at least 15 minutes and consult a physician.Continue rinsing eyes during transport to hospital.

If swallowed
Do NOT induce vomiting. Never give anything by mouth to an unconscious person. Rinse mouth with water. Consult a physician.

4.2 Most important symptoms and effects, both acute and delayed
The most important known symptoms and effects are described in the labelling (see section 2.2) and/or in section 11

4.3 Indication of any immediate medical attention and special treatment needed
No data available

SECTION 5: Firefighting measures

5.1 Extinguishing media

Suitable extinguishing media
Use water spray, alcohol-resistant foam, dry chemical or carbon dioxide.

Unsuitable extinguishing media
For this substance/mixture no limitations of extinguishing agents are given.

5.2 Special hazards arising from the substance or mixture
Carbon oxides, Nitrogen oxides (NOx)
Combustible liquid.

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5.3 Advice for firefighters
Wear self-contained breathing apparatus for firefighting if necessary.

5.4 Further information
No data available

SECTION 6: Accidental release measures

6.1 Personal precautions, protective equipment and emergency procedures
Wear respiratory protection. Avoid breathing vapours, mist or gas. Ensure adequate ventilation. Evacuate personnel to safe areas.
For personal protection see section 8.

6.2 Environmental precautions
Prevent further leakage or spillage if safe to do so. Do not let product enter drains. Discharge into the environment must be avoided.

6.3 Methods and materials for containment and cleaning up
Soak up with inert absorbent material and dispose of as hazardous waste. Keep in suitable, closed containers for disposal.

6.4 Reference to other sections
For disposal see section 13.

SECTION 7: Handling and storage

7.1 Precautions for safe handling
Avoid contact with skin and eyes. Avoid inhalation of vapour or mist.
For precautions see section 2.2.

7.2 Conditions for safe storage, including any incompatibilities
Keep container tightly closed in a dry and well-ventilated place. Containers which are opened must be carefully resealed and kept upright to prevent leakage.

Store under inert gas. Moisture sensitive.
Storage class (TRGS 510): 6.1A: Combustible, acute toxic Cat. 1 and 2 / very toxic hazardous materials

7.3 Specific end use(s)
Apart from the uses mentioned in section 1.2 no other specific uses are stipulated

SECTION 8: Exposure controls/personal protection

8.1 Control parameters

Components with workplace control parameters

Component	CAS-No.	Value	Control parameters	Basis
Hexamethylene diisocyanate	822-06-0	TWA	0.0050 ppm	USA. ACGIH Threshold Limit Values (TLV)
	Remarks	Upper Respiratory Tract irritation Respiratory sensitization		

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		TWA	0.0050 ppm 0.035 mg/m3	USA. NIOSH Recommended Exposure Limits
		10 minute ceiling value		
		C	0.02 ppm 0.14 mg/m3	USA. NIOSH Recommended Exposure Limits
		10 minute ceiling value		

Biological occupational exposure limits

Component	CAS-No.	Parameters	Value	Biological specimen	Basis
Hexamethylene diisocyanate	822-06-0	1,6-Hexamethylene diamine	15µg/g creatinine	Urine	ACGIH - Biological Exposure Indices (BEI)
	Remarks	End of shift			

8.2 Exposure controls

Appropriate engineering controls
Avoid contact with skin, eyes and clothing. Wash hands before breaks and immediately after handling the product.

Personal protective equipment

Eye/face protection
Tightly fitting safety goggles. Faceshield (8-inch minimum). Use equipment for eye protection tested and approved under appropriate government standards such as NIOSH (US) or EN 166(EU).

Skin protection
Handle with gloves. Gloves must be inspected prior to use. Use proper glove removal technique (without touching glove's outer surface) to avoid skin contact with this product. Dispose of contaminated gloves after use in accordance with applicable laws and good laboratory practices. Wash and dry hands.

Splash contact
Material: Nitrile rubber
Minimum layer thickness: 0.4 mm
Break through time: 60 min
Material tested:Camatril® (KCL 730 / Aldrich Z677442, Size M)

data source: KCL GmbH, D-36124 Eichenzell, phone +49 (0)6659 87300, e-mail sales@kcl.de, test method: EN374
If used in solution, or mixed with other substances, and under conditions which differ from EN 374, contact the supplier of the CE approved gloves. This recommendation is advisory only and must be evaluated by an industrial hygienist and safety officer familiar with the specific situation of anticipated use by our customers. It should not be construed as offering an approval for any specific use scenario.

Body Protection
Complete suit protecting against chemicals, The type of protective equipment must be selected according to the concentration and amount of the dangerous substance at the specific workplace.

Respiratory protection
Where risk assessment shows air-purifying respirators are appropriate use a full-face respirator with multi-purpose combination (US) or type ABEK (EN 14387) respirator cartridges as a backup to engineering controls. If the respirator is the sole

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means of protection, use a full-face supplied air respirator. Use respirators and components tested and approved under appropriate government standards such as NIOSH (US) or CEN (EU).

Control of environmental exposure
Prevent further leakage or spillage if safe to do so. Do not let product enter drains. Discharge into the environment must be avoided.

SECTION 9: Physical and chemical properties

9.1 Information on basic physical and chemical properties

a)	Appearance	Form: liquid Colour: clear, colourless
b)	Odour	pungent
c)	Odour Threshold	No data available
d)	pH	No data available
e)	Melting point/freezing point	Melting point/freezing point: ca.-67 °C (ca.-89 °F) - (ECHA)
f)	Initial boiling point and boiling range	82 - 85 °C 180 - 185 °F at 0.1 hPa
g)	Flash point	130 °C (266 °F) - closed cup - DIN 51755 Part 1
h)	Evaporation rate	No data available
i)	Flammability (solid, gas)	No data available
j)	Upper/lower flammability or explosive limits	Upper explosion limit: 9.5 %(V) Lower explosion limit: 0.9 %(V)
k)	Vapour pressure	< 0.01 hPa at 20 °C (68 °F)
l)	Vapour density	5.81 - (Air = 1.0)
m)	Relative density	1.047 g/mL at 20 °C (68 °F)
n)	Water solubility	Hydrolysis
o)	Partition coefficient: n-octanol/water	log Pow: 3.2 at 25 °C (77 °F) - Bioaccumulation is not expected.
p)	Auto-ignition temperature	454 °C (849 °F) at 1,013 hPa
q)	Decomposition temperature	No data available
r)	Viscosity	1.68 mm2/s at 40 °C (104 °F) - OECD Test Guideline 114 -
s)	Explosive properties	No data available
t)	Oxidizing properties	No data available

9.2 Other safety information

Relative vapour density	5.81 - (Air = 1.0)

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SECTION 10: Stability and reactivity

10.1 Reactivity
No data available

10.2 Chemical stability
Stable under recommended storage conditions.

10.3 Possibility of hazardous reactions
No data available

10.4 Conditions to avoid
Heat Avoid moisture.

10.5 Incompatible materials
Alcohols, Strong bases, Amines, Strong oxidizing agents, Water

10.6 Hazardous decomposition products
Hazardous decomposition products formed under fire conditions. - Carbon oxides, Nitrogen oxides (NOx)
Other decomposition products - No data available
In the event of fire: see section 5

SECTION 11: Toxicological information

11.1 Information on toxicological effects

Acute toxicity
LD50 Oral - Rat - male - 746 mg/kg
(OECD Test Guideline 401)
LC50 Inhalation - Rat - male and female - 4 h - 0.124 mg/l
(OECD Test Guideline 403)
LD50 Dermal - Rat - male and female - > 7,000 mg/kg
(OECD Test Guideline 402)
No data available

Skin corrosion/irritation
Skin - Rabbit
Result: Corrosive - 4 h
(OECD Test Guideline 404)

Serious eye damage/eye irritation
Eyes - Rabbit
Result: Causes serious eye damage.
(OECD Test Guideline 405)

Respiratory or skin sensitisation
Maximisation Test - Guinea pig
Result: positive
(OECD Test Guideline 406)

Germ cell mutagenicity
Ames test
Salmonella typhimurium
Result: negative
(ECHA)
In vitro mammalian cell gene mutation test

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Chinese hamster ovary cells
Result: negative
(ECHA)
OECD Test Guideline 474
Mouse - male and female - Bone marrow
Result: negative

Carcinogenicity

IARC: No component of this product present at levels greater than or equal to 0.1% is identified as probable, possible or confirmed human carcinogen by IARC.

NTP: No component of this product present at levels greater than or equal to 0.1% is identified as a known or anticipated carcinogen by NTP.

OSHA: No component of this product present at levels greater than or equal to 0.1% is on OSHA's list of regulated carcinogens.

Reproductive toxicity
No data available

Specific target organ toxicity - single exposure
May cause respiratory irritation. - Respiratory system

Specific target organ toxicity - repeated exposure
No data available

Aspiration hazard
No data available

Additional Information
RTECS: MO1740000

burning sensation, Cough, wheezing, laryngitis, Shortness of breath, spasm, inflammation and edema of the larynx, spasm, inflammation and edema of the bronchi, pneumonitis, pulmonary edema, Material is extremely destructive to tissue of the mucous membranes and upper respiratory tract, eyes, and skin., To the best of our knowledge, the chemical, physical, and toxicological properties have not been thoroughly investigated.

SECTION 12: Ecological information

12.1 Toxicity

No data available

Toxicity to daphnia and other aquatic invertebrates	Remarks: No data available(Hexamethylene diisocyanate)
Toxicity to algae	static test ErC50 - Desmodesmus subspicatus (green algae) - > 77.4 mg/l - 72 h (OECD Test Guideline 201)
	static test NOEC - Desmodesmus subspicatus (green algae) - 11.7 mg/l - 72 h (OECD Test Guideline 201)
Toxicity to bacteria	Remarks: (IUCLID)(Hexamethylene diisocyanate)

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12.2 Persistence and degradability

Biodegradability aerobic - Exposure time 28 d
Result: 42 % - Not readily biodegradable.
(OECD Test Guideline 301F)

12.3 Bioaccumulative potential

No data available

12.4 Mobility in soil

No data available

12.5 Results of PBT and vPvB assessment

PBT/vPvB assessment not available as chemical safety assessment not required/not conducted

12.6 Other adverse effects

An environmental hazard cannot be excluded in the event of unprofessional handling or disposal.
Harmful to aquatic life.
No data available

Stability in water - 5 - 10 min at 20 °C
Remarks: Hydrolyses on contact with water.

SECTION 13: Disposal considerations

13.1 Waste treatment methods

Product

Offer surplus and non-recyclable solutions to a licensed disposal company. Contact a licensed professional waste disposal service to dispose of this material. Dissolve or mix the material with a combustible solvent and burn in a chemical incinerator equipped with an afterburner and scrubber.

Contaminated packaging

Dispose of as unused product.

SECTION 14: Transport information

DOT (US)

UN number: 2281 Class: 6.1 Packing group: II
Proper shipping name: Hexamethylene diisocyanate
Reportable Quantity (RQ): 100 lbs
Poison Inhalation Hazard: No

IMDG

UN number: 2281 Class: 6.1 Packing group: II EMS-No: F-A, S-A
Proper shipping name: HEXAMETHYLENE DIISOCYANATE

IATA

UN number: 2281 Class: 6.1 Packing group: II
Proper shipping name: Hexamethylene diisocyanate

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SECTION 15: Regulatory information

SARA 302 Components
No chemicals in this material are subject to the reporting requirements of SARA Title III, Section 302.

SARA 313 Components
The following components are subject to reporting levels established by SARA Title III, Section 313:

	CAS-No.	Revision Date
Hexamethylene diisocyanate	822-06-0	1993-02-16

SARA 311/312 Hazards
Acute Health Hazard

Massachusetts Right To Know Components
No components are subject to the Massachusetts Right to Know Act.

Pennsylvania Right To Know Components

	CAS-No.	Revision Date
Hexamethylene diisocyanate	822-06-0	1993-02-16

SECTION 16: Other information

Further information
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The above information is believed to be correct but does not purport to be all inclusive and shall be used only as a guide. The information in this document is based on the present state of our knowledge and is applicable to the product with regard to appropriate safety precautions. It does not represent any guarantee of the properties of the product. Sigma-Aldrich Corporation and its Affiliates shall not be held liable for any damage resulting from handling or from contact with the above product. See www.sigma-aldrich.com and/or the reverse side of invoice or packing slip for additional terms and conditions of sale.

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Version: 6.2 Revision Date: 11/15/2019 Print Date: 11/20/2020

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11.3 Appendix III – Safety Data Sheet for Homopolymer of Hexamethylene Diisocyanate

Sigma-Aldrich. www.sigmaaldrich.com

SAFETY DATA SHEET

Version 6.2
Revision Date 01/10/2020
Print Date 11/20/2020

SECTION 1: Identification of the substance/mixture and of the company/undertaking

1.1 Product identifiers

Product name : Poly(hexamethylene diisocyanate)

Product Number : 418005
Brand : Aldrich
CAS-No. : 28182-81-2

1.2 Relevant identified uses of the substance or mixture and uses advised against

Identified uses : Laboratory chemicals, Synthesis of substances

1.3 Details of the supplier of the safety data sheet

Company : Sigma-Aldrich Inc.
3050 Spruce Street
ST. LOUIS MO 63103
UNITED STATES

Telephone : +1 314 771-5765
Fax : +1 800 325-5052

1.4 Emergency telephone number

Emergency Phone # : 800-424-9300 CHEMTREC (USA) +1-703-527-3887 CHEMTREC (International) 24 Hours/day; 7 Days/week

SECTION 2: Hazards identification

2.1 Classification of the substance or mixture

GHS Classification in accordance with 29 CFR 1910 (OSHA HCS)

Acute toxicity, Inhalation (Category 3), H331
Respiratory sensitisation (Category 1), H334
Skin sensitisation (Category 1), H317
Specific target organ toxicity - single exposure (Category 3), Respiratory system, H335

For the full text of the H-Statements mentioned in this Section, see Section 16.

2.2 GHS Label elements, including precautionary statements

Pictogram

Signal word Danger

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Hazard statement(s)	
H317	May cause an allergic skin reaction.
H331	Toxic if inhaled.
H334	May cause allergy or asthma symptoms or breathing difficulties if inhaled.
H335	May cause respiratory irritation.

Precautionary statement(s)	
P261	Avoid breathing dust/ fume/ gas/ mist/ vapours/ spray.
P271	Use only outdoors or in a well-ventilated area.
P272	Contaminated work clothing must not be allowed out of the workplace.
P280	Wear protective gloves.
P285	In case of inadequate ventilation wear respiratory protection.
P302 + P352	IF ON SKIN: Wash with plenty of soap and water.
P304 + P340 + P311	IF INHALED: Remove person to fresh air and keep comfortable for breathing. Call a POISON CENTER/doctor.
P333 + P313	If skin irritation or rash occurs: Get medical advice/ attention.
P342 + P311	If experiencing respiratory symptoms: Call a POISON CENTER/doctor.
P363	Wash contaminated clothing before reuse.
P403 + P233	Store in a well-ventilated place. Keep container tightly closed.
P405	Store locked up.
P501	Dispose of contents/ container to an approved waste disposal plant.

2.3 Hazards not otherwise classified (HNOC) or not covered by GHS - none

SECTION 3: Composition/information on ingredients

3.1 Substances

CAS-No. : 28182-81-2

Component	Classification	Concentration
Hexane, 1,6-diisocyanato-, homopolymer		
	Acute Tox. 4; Skin Sens. 1; STOT SE 3; H332, H317, H335	<= 100 %

Hexamethylene diisocyanate		
	Acute Tox. 4; Acute Tox. 1; Skin Corr. 1B; Eye Dam. 1; Resp. Sens. 1; STOT SE 3; Aquatic Acute 3; H302, H330, H314, H318, H334, H335, H402	>= 0.1 - < 1 %

For the full text of the H-Statements mentioned in this Section, see Section 16.

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SECTION 4: First aid measures

4.1 Description of first aid measures

General advice
Consult a physician. Show this safety data sheet to the doctor in attendance.Move out of dangerous area.

If inhaled
If breathed in, move person into fresh air. If not breathing, give artificial respiration. Consult a physician.

In case of skin contact
Wash off with soap and plenty of water. Take victim immediately to hospital. Consult a physician.

In case of eye contact
Flush eyes with water as a precaution.

If swallowed
Never give anything by mouth to an unconscious person. Rinse mouth with water. Consult a physician.

4.2 Most important symptoms and effects, both acute and delayed
The most important known symptoms and effects are described in the labelling (see section 2.2) and/or in section 11

4.3 Indication of any immediate medical attention and special treatment needed
No data available

SECTION 5: Firefighting measures

5.1 Extinguishing media

Suitable extinguishing media
Use water spray, alcohol-resistant foam, dry chemical or carbon dioxide.

5.2 Special hazards arising from the substance or mixture
Nature of decomposition products not known.

5.3 Advice for firefighters
Wear self-contained breathing apparatus for firefighting if necessary.

5.4 Further information
No data available

SECTION 6: Accidental release measures

6.1 Personal precautions, protective equipment and emergency procedures
Wear respiratory protection. Avoid breathing vapours, mist or gas. Ensure adequate ventilation. Evacuate personnel to safe areas.
For personal protection see section 8.

6.2 Environmental precautions
Prevent further leakage or spillage if safe to do so. Do not let product enter drains.

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6.3 Methods and materials for containment and cleaning up
Soak up with inert absorbent material and dispose of as hazardous waste. Keep in suitable, closed containers for disposal.

6.4 Reference to other sections
For disposal see section 13.

SECTION 7: Handling and storage

7.1 Precautions for safe handling
Avoid contact with skin and eyes. Avoid inhalation of vapour or mist.
For precautions see section 2.2.

7.2 Conditions for safe storage, including any incompatibilities
Keep container tightly closed in a dry and well-ventilated place. Containers which are opened must be carefully resealed and kept upright to prevent leakage.

Moisture sensitive.
Storage class (TRGS 510): 6.1C: Combustible, acute toxic Cat.3 / toxic compounds or compounds which causing chronic effects

7.3 Specific end use(s)
Apart from the uses mentioned in section 1.2 no other specific uses are stipulated

SECTION 8: Exposure controls/personal protection

8.1 Control parameters

Components with workplace control parameters

Component	CAS-No.	Value	Control parameters	Basis
Hexamethylene diisocyanate	822-06-0	TWA	0.0050 ppm	USA. ACGIH Threshold Limit Values (TLV)
	Remarks	Upper Respiratory Tract irritation Respiratory sensitization		
		TWA	0.0050 ppm 0.035 mg/m3	USA. NIOSH Recommended Exposure Limits
		10 minute ceiling value		
		C	0.02 ppm 0.14 mg/m3	USA. NIOSH Recommended Exposure Limits
		10 minute ceiling value		

Biological occupational exposure limits

Component	CAS-No.	Parameters	Value	Biological specimen	Basis
Hexamethylene diisocyanate	822-06-0	1,6-Hexamethylene diamine	15µg/g creatinine	Urine	ACGIH - Biological Exposure Indices (BEI)
	Remarks	End of shift			

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8.2 Exposure controls

Appropriate engineering controls
Avoid contact with skin, eyes and clothing. Wash hands before breaks and immediately after handling the product.

Personal protective equipment

Eye/face protection
Face shield and safety glasses Use equipment for eye protection tested and approved under appropriate government standards such as NIOSH (US) or EN 166(EU).

Skin protection
Handle with gloves. Gloves must be inspected prior to use. Use proper glove removal technique (without touching glove's outer surface) to avoid skin contact with this product. Dispose of contaminated gloves after use in accordance with applicable laws and good laboratory practices. Wash and dry hands.

Body Protection
Complete suit protecting against chemicals, The type of protective equipment must be selected according to the concentration and amount of the dangerous substance at the specific workplace.

Respiratory protection
Where risk assessment shows air-purifying respirators are appropriate use a full-face respirator with multi-purpose combination (US) or type ABEK (EN 14387) respirator cartridges as a backup to engineering controls. If the respirator is the sole means of protection, use a full-face supplied air respirator. Use respirators and components tested and approved under appropriate government standards such as NIOSH (US) or CEN (EU).

Control of environmental exposure
Prevent further leakage or spillage if safe to do so. Do not let product enter drains.

SECTION 9: Physical and chemical properties

9.1 Information on basic physical and chemical properties

a)	Appearance	Form: liquid Colour: light yellow
b)	Odour	odourless
c)	Odour Threshold	No data available
d)	pH	No data available
e)	Melting point/freezing point	Melting point: < 0 °C (< 32 °F) - OECD Test Guideline 102
f)	Initial boiling point and boiling range	- OECD Test Guideline 103decomposition below boiling point
g)	Flash point	170 °C (338 °F)
h)	Evaporation rate	No data available
i)	Flammability (solid, gas)	No data available
j)	Upper/lower flammability or	No data available

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	explosive limits	
k)	Vapour pressure	< 0.001 hPa at 20 °C (68 °F)
l)	Vapour density	No data available
m)	Relative density	1.130 g/cm3 at 20 °C (68 °F)
n)	Water solubility	insoluble
o)	Partition coefficient: n-octanol/water	No data available
p)	Auto-ignition temperature	No data available
q)	Decomposition temperature	250 °C (482 °F) -
r)	Viscosity	No data available
s)	Explosive properties	No data available
t)	Oxidizing properties	No data available

9.2 Other safety information
No data available

SECTION 10: Stability and reactivity

10.1 Reactivity
No data available

10.2 Chemical stability
Stable under recommended storage conditions.

10.3 Possibility of hazardous reactions
No data available

10.4 Conditions to avoid
No data available

10.5 Incompatible materials
Water, Strong bases, Strong oxidizing agents, Metals, Amines, Alcohols, Surface active materials

10.6 Hazardous decomposition products
Hazardous decomposition products formed under fire conditions. - Nature of decomposition products not known.
Other decomposition products - No data available
In the event of fire: see section 5

SECTION 11: Toxicological information

11.1 Information on toxicological effects

Acute toxicity
No data available

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LD50 Oral - Rat - > 5,000 mg/kg
(OECD Test Guideline 423)
Inhalation: No data available

Acute toxicity estimate Inhalation - Rat - 1.51 mg/l
(Expert judgement)
Dermal: No data available

LD50 Dermal - Rat - male and female - > 2,000 mg/kg
(OECD Test Guideline 402)
No data available

Skin corrosion/irritation
No data available

Skin - Rabbit
Result: slight irritation - 4 h
(OECD Test Guideline 404)

Serious eye damage/eye irritation
No data available
Eyes - Rabbit
Result: slight irritation
(OECD Test Guideline 405)

Respiratory or skin sensitisation
No data available
Sensitisation test (Magnusson and Kligman): - Guinea pig
Result: positive
(OECD Test Guideline 406)
Local lymph node assay (LLNA) - Mouse
Result: positive
(OECD Test Guideline 429)

Germ cell mutagenicity
No data available
Mutagenicity (mammal cell test): chromosome aberration.
Chinese hamster lung cells
Result: negative
In vitro mammalian cell gene mutation test
Chinese hamster ovary cells
Result: negative
Ames test
Escherichia coli/Salmonella typhimurium
Result: negative

Carcinogenicity

IARC:	No component of this product present at levels greater than or equal to 0.1% is identified as probable, possible or confirmed human carcinogen by IARC.
NTP:	No component of this product present at levels greater than or equal to 0.1% is identified as a known or anticipated carcinogen by NTP.
OSHA:	No component of this product present at levels greater than or equal to 0.1% is on OSHA's list of regulated carcinogens.

Reproductive toxicity
No data available

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Specific target organ toxicity - single exposure
No data available

Specific target organ toxicity - repeated exposure
No data available

Aspiration hazard
No data available

Additional Information
RTECS: Not available

To the best of our knowledge, the chemical, physical, and toxicological properties have not been thoroughly investigated.

To the best of our knowledge, the chemical, physical, and toxicological properties have not been thoroughly investigated.

Stomach - Irregularities - Based on Human Evidence
Stomach - Irregularities - Based on Human Evidence

SECTION 12: Ecological information

12.1 Toxicity
No data available

Toxicity to fish	static test LC0 - Danio rerio (zebra fish) - >= 100 mg/l - 96 h Remarks: (ECHA)
Toxicity to daphnia and other aquatic invertebrates	EC0 - Daphnia magna (Water flea) - >= 100 mg/l - 48 h (OECD Test Guideline 202)
Toxicity to algae	static test EC50 - Desmodesmus subspicatus (green algae) - > 1,000 mg/l - 72 h (OECD Test Guideline 201)
Toxicity to bacteria	static test EC50 - activated sludge - 3,828 mg/l - 3 h (OECD Test Guideline 209)

12.2 Persistence and degradability
No data available

12.3 Bioaccumulative potential
No data available

12.4 Mobility in soil
No data available

12.5 Results of PBT and vPvB assessment
PBT/vPvB assessment not available as chemical safety assessment not required/not conducted

12.6 Other adverse effects
No data available

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SECTION 13: Disposal considerations

13.1 Waste treatment methods

Product
Offer surplus and non-recyclable solutions to a licensed disposal company. Contact a licensed professional waste disposal service to dispose of this material.

Contaminated packaging
Dispose of as unused product.

SECTION 14: Transport information

DOT (US)
UN number: 2810 Class: 6.1 Packing group: III
Proper shipping name: Toxic, liquids, organic, n.o.s. (Hexane, 1,6-diisocyanato-, homopolymer)
Reportable Quantity (RQ):
Poison Inhalation Hazard: No

IMDG
UN number: 2810 Class: 6.1 Packing group: III EMS-No: F-A, S-A
Proper shipping name: TOXIC LIQUID, ORGANIC, N.O.S. (Hexane, 1,6-diisocyanato-, homopolymer)

IATA
UN number: 2810 Class: 6.1 Packing group: III
Proper shipping name: Toxic liquid, organic, n.o.s. (Hexane, 1,6-diisocyanato-, homopolymer)

SECTION 15: Regulatory information

SARA 302 Components
No chemicals in this material are subject to the reporting requirements of SARA Title III, Section 302.

SARA 313 Components
This material does not contain any chemical components with known CAS numbers that exceed the threshold (De Minimis) reporting levels established by SARA Title III, Section 313.

SARA 311/312 Hazards
Acute Health Hazard, Chronic Health Hazard

Massachusetts Right To Know Components
No components are subject to the Massachusetts Right to Know Act.

Pennsylvania Right To Know Components

	CAS-No.	Revision Date
Hexane, 1,6-diisocyanato-, homopolymer	28182-81-2	2007-03-01

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SECTION 16: Other information

Further information

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The above information is believed to be correct but does not purport to be all inclusive and shall be used only as a guide. The information in this document is based on the present state of our knowledge and is applicable to the product with regard to appropriate safety precautions. It does not represent any guarantee of the properties of the product. Sigma-Aldrich Corporation and its Affiliates shall not be held liable for any damage resulting from handling or from contact with the above product. See www.sigma-aldrich.com and/or the reverse side of invoice or packing slip for additional terms and conditions of sale.

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Version: 6.2 Revision Date: 01/10/2020 Print Date: 11/20/2020

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11.4 Appendix IV – Paint Scheme for UH-1Y Venom

MIL-STD-2161C(AS)

APPENDIX D

1. MARKING	2. LOCATION	3. SIZE	4. COLOR NO/CODE
A. MARINES	R.H. and L.H. Tail Boom	10"	35237, Figure A-15
B. Model Designation, Acft BUNO	R.H. and L.H. Vertical Tail	2" 6"	35237
C. National Star	R.H. and L.H. Aft Fuselage Bottom Fuselage	15" 15"	35237 35237, Figure A-1
D. Walkway	Top Fuselage	Per drawing	35237
E. Call Numbers	R.H. and L.H. Tail Boom	12"	35237
F. Intake Warning	R.H. and L.H. Intake	15"	36375/35237
G. Beware of Blast	R.H. and L.H. Engine Exhaust	5"	36375/35237
H. Tail Rotor Warning	R.H. and L.H. Tail Boom	22"	35237
I. Unit Identifier	R.H. and L.H. Vertical Tail	10"	35237
J. Rescue Arrow	R.H. and L.H. Fwd. Cockpit Doors	24"	35237
K. MODEX	R.H. and L.H. Lower Side Doors or Aft of cockpit & Nose	10"	35247

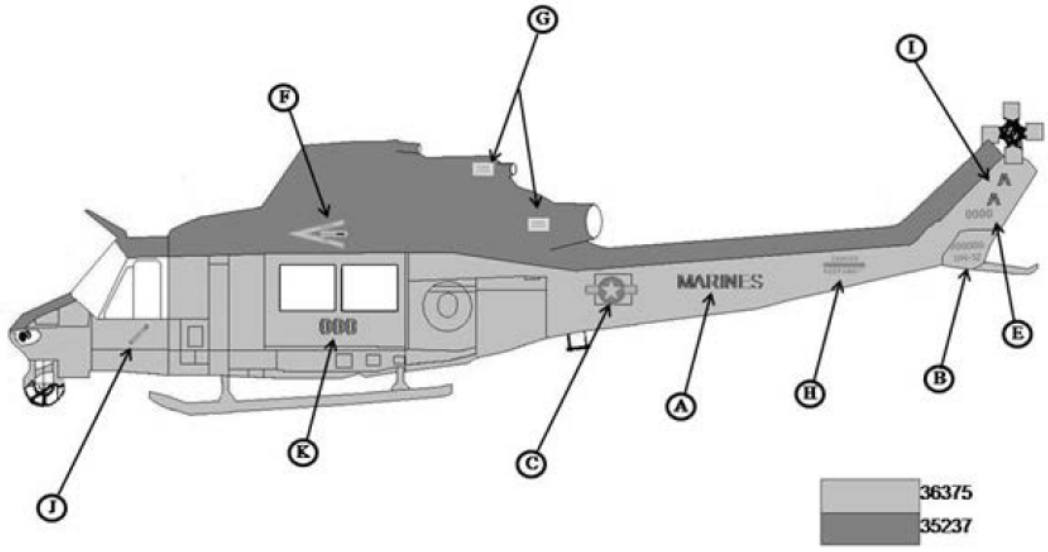

FIGURE D-4. UH-1Y.

MIL-STD-2161C(AS)

APPENDIX D

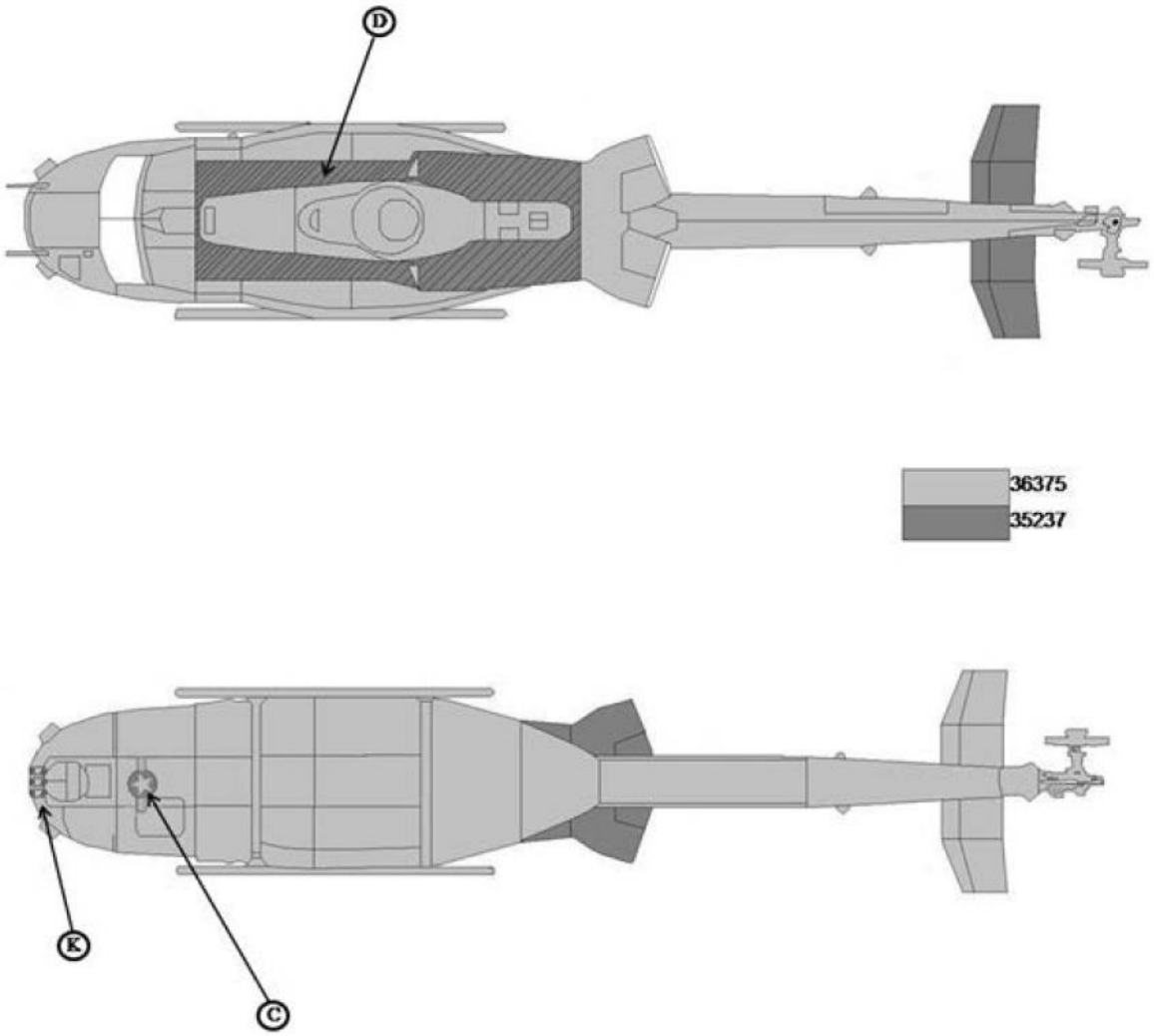

FIGURE D-4. UH-1Y – Continued.

11.5 Appendix V – Paint Scheme for AH-1Z Viper

MIL-STD-2161C(AS)

APPENDIX D

1. MARKING	2. LOCATION	3. SIZE	4. COLOR NO/CODE
A. MARINES	R.H. and L.H. of Tail Boom	10"	35237
B. Model Designation & Acft BUNO	R.H. and L.H. Vertical Tail	2" 6"	35237
C. National Star	R.H. and L.H. Side Body	15"	35237
D. Intake Warning	R.H. and L.H. Fwd. of Intakes	15"	35237
E. Beware of Blast	R.H. and L.H. Sides Fwd of Engine Exhaust	5"	35237
F. Tail Rotor Warning	R.H. and L.H. Tail Boom	22"	35237
G. Walkway Coating	Top of Winglets Top of fuselage	24" X 60" Per drawing	35237
H. Rescue Arrow	R.H. and L.H. Side Lower Canopy	6.5"	35237
I. Unit Aircraft Numbers	R.H. and L.H. of Nose Section	10"	35237
J. Unit Identifier	R.H. and L.H. Side Upper Vertical Tail	10"	35237, See Paragraph 5.2.2.7

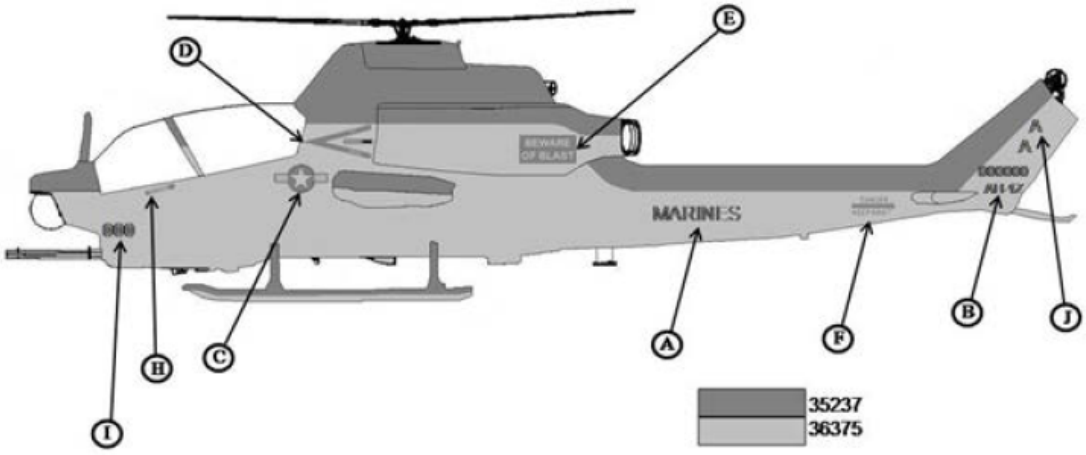

FIGURE D-2. AH-1Z.

MIL-STD-2161C(AS)

APPENDIX D

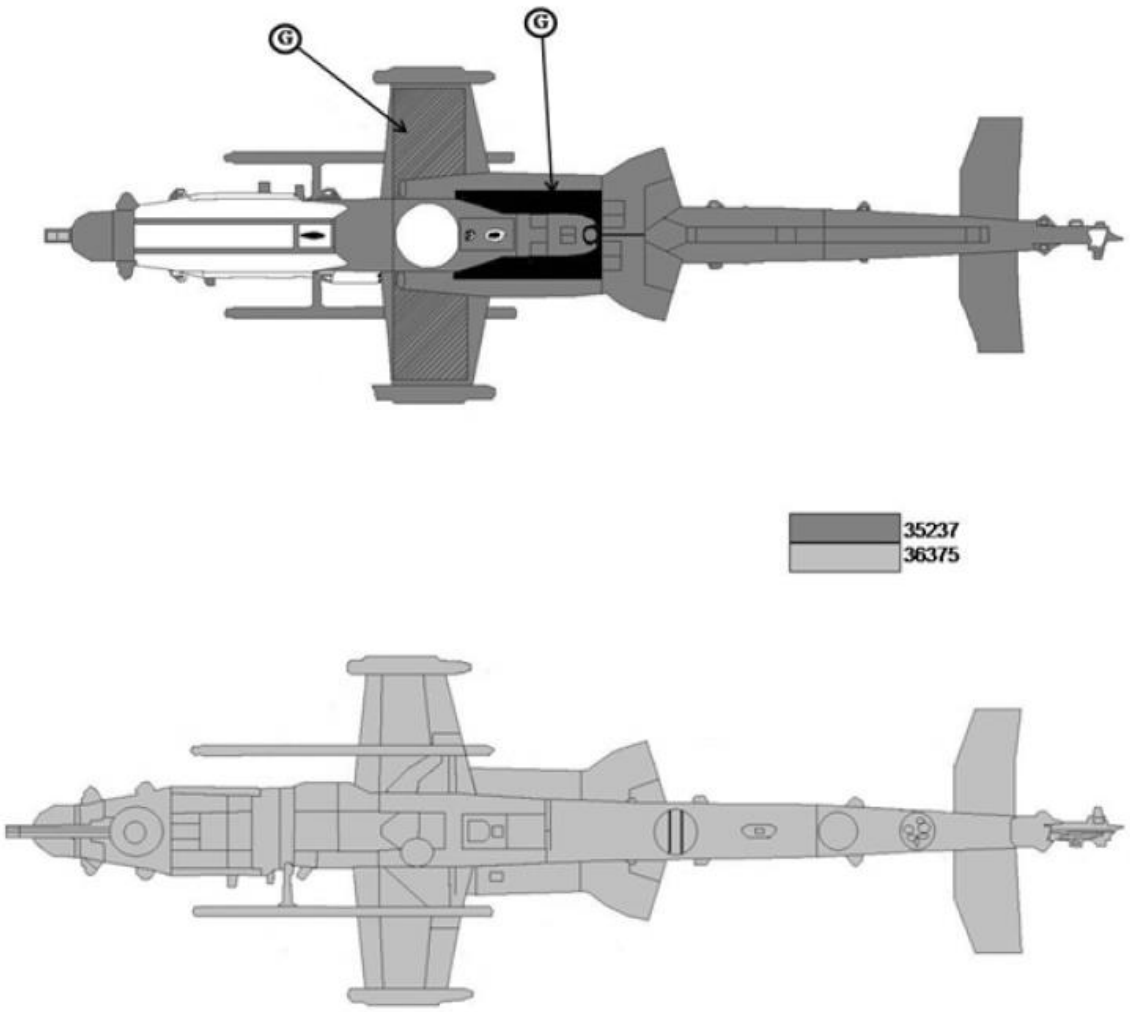

FIGURE D-2. AH-1Z – Continued.

11.6 Appendix VI – Paint Scheme for F/A-18E/F Super Hornet

MIL-STD-2161C(AS)

APPENDIX C

1. MARKING	2. LOCATION	3. SIZE	4. COLOR NO/CODE
A. NAVY/MARINES	L/R Aft Fuselage	10"/12"	35237 (See Figure A-15)
B. Model Designation, Acft BUNO	L/R Aft Fuselage L/R Aft Fuselage	2" 4"	35237 (See Figure A-15) 35237
C. National Star	L/R Fwd Fuselage Lower R/H Wing Upper L/H Wing	15" 15" 15"	35237 (See Figure A-1) 35237 35237
D. Intake Chevron & Warnings	L/R Fwd Engine Intake "Jet" Marking "Danger" Marking "Intake" Marking	3" Stripe 2" 2" 2"	35237 (See Figure A-15) 36375 36375 36375
E. Beware of Blast	L/R Aft Fuselage	1" Letters 4-½" x 8" Block	36375/36320 (See Figure A-8)
F. Arresting Hook Marking	L/R Aft Fuselage	IAW Figure A-14	36375/36320 (See Figure A-14)
G. Ejection Seat Warning	L/R Fwd Fuselage (below canopy)	0.5" W x 1.0" H Letters 8" x 9" Triangle	36320/36375 (See Figure A-16)
H. Unit Aircraft Numbers (MODEX)	L/R Fwd Fuselage L/R T/E Flap L/R Vertical Fin Cap	10" 12" 10"	37038 37038 37038
I. Unit Identifier	O/B Vertical Stabilizers	20"	35237
J. Walkway coating	L/R LEX	N/A	36320
K. Arresting Hook	Aft Lower Fuselage	Per aircraft drawing	Alternating bands of contrasting grays per aircraft drawing

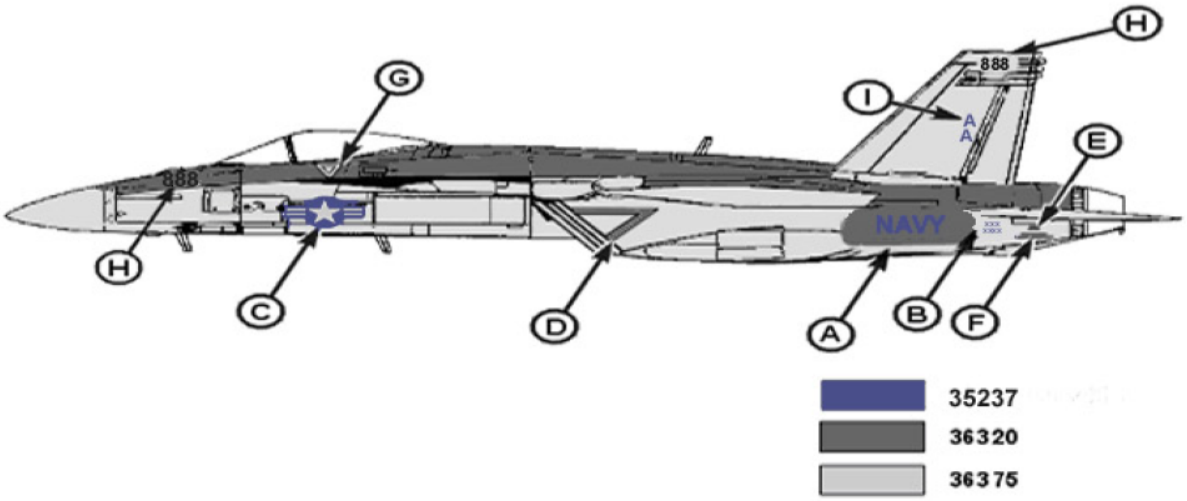

FIGURE C-20. F/A-18E/F and EA-18G tactical.

MIL-STD-2161C(AS)

APPENDIX C

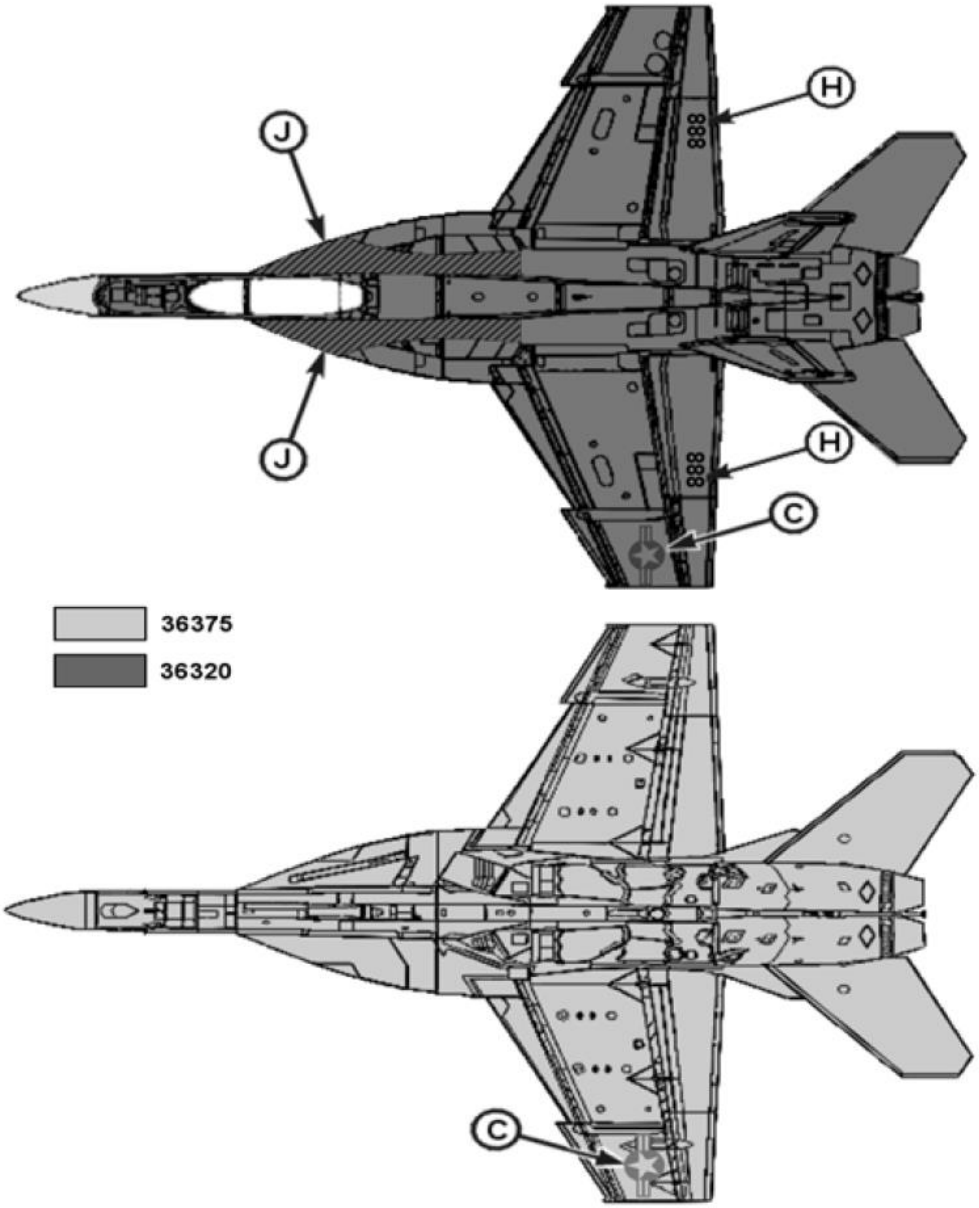

FIGURE C-20. F/A-18E/F and EA-18G tactical – Continued.

11.7 Appendix VII – Paint Scheme for T-45 Goshawk

MIL-STD-2161C(AS)

APPENDIX C

1. MARKING	2. LOCATION	3. SIZE	4. COLOR NO/CODE
A. NAVY	Aft Fuselage Lower L.H. Wing	12"/10" 24"/16"	17038
B. Model Designation, Acft BUNO	Aft Fuselage Aft Fuselage	2" 4"	17038
C. National Star	Fwd. Fuselage Lower R.H. Wing Upper L.H. Wing	20" 30" 30"	17925/11136/15044 17925/11136/15044 17925/11136/15044
D. Call Numbers	Vertical Stabilizer	12"	17038
E. Intake Warning	See Para. 5.2.2.10.1	See Para. 5.2.2.10.1	11136/17925
F. Beware of Blast	Aft Fuselage	See Para. 5.2.2.10.2	17925/11136
G. Arresting Hook Warning	N/A	4" Alternating Stripes	17038/17925
H. Ejection Seat	Below Canopy Rail	See Para. 5.2.2.10.6.11	11136
I. Walkway	Wing Adjacent to Fuselage	N/A	37038
J. Conspicuity Markings	Per Drawing	See Para. 5.1.1.1	12197
K. Anti-Glare	Fwd. of Cockpit	N/A	17038
L. Unit Aircraft Numbers	Fwd. Fuselage Lower L.H. Wing Upper R.H. Wing	12" 16" 16"	17038
M. Unit Identifier	Vertical Stabilizer Lower L.H. Wing Upper R.H. Wing	20" 16"	17038

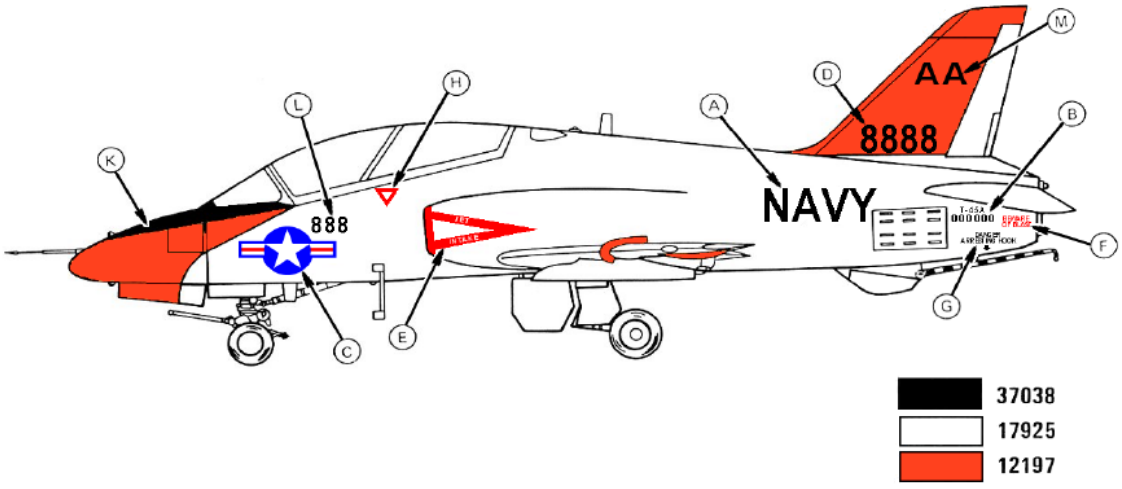

FIGURE C-31. T-45A/C aircraft marking (high visibility).

MIL-STD-2161C(AS)

APPENDIX C

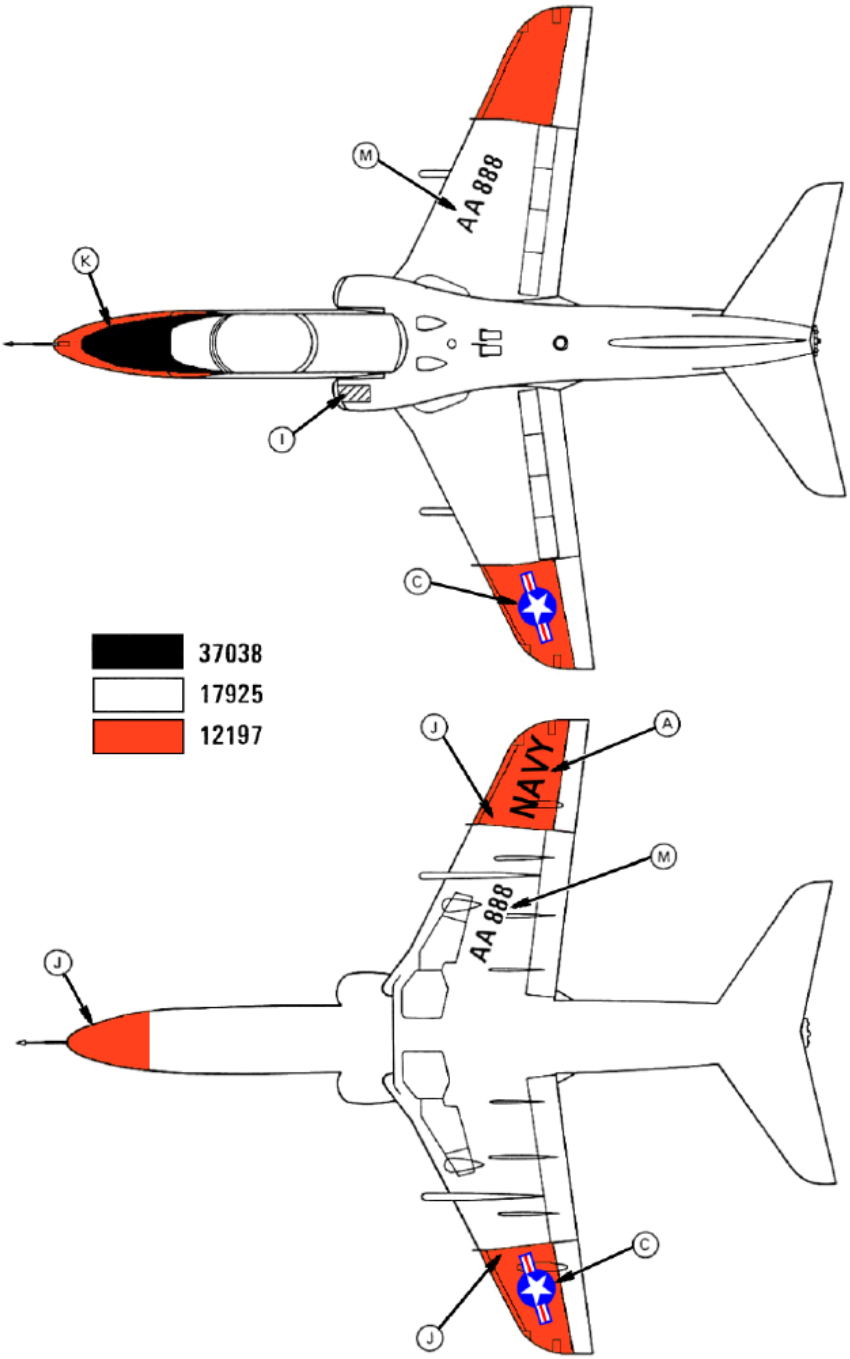

FIGURE C-31. T-45A/C aircraft marking (high visibility) – Continued.

11.8 Appendix VIII – Technical Data Sheet for Single-Component (1K) Polysiloxane Aircraft Topcoat, Camouflage Gray (#36375)

RH-142
Single-Component (1K) Polysiloxane Topcoat
Camouflage Gray #36375

NCP COATINGS

Intended Uses:

The topcoat is a single component (1K) isocyanate-free and HAP's free system designed for the outer mold line (exterior) of the aircraft. The topcoat does not require the addition of components or a catalyst before application, and thus provides a user-friendly system for applicators.

Physical Properties

Color:	Gray Fed. Std.#36375
Gloss:	5.0 max @ 60° 10.0 max @ 85°
Volume Solids:	43.3 % +/- 1%
Weight Solids:	41.4 % +/- 1%
Weight Per Gallon:	9.4 +/- 0.5 lbs/gallon
Theoretical Coverage:	695 sq ft/gal @ 1 mil dft
VOC:	2.4#/gal or 286g/l
Recommended Film Thickness:	1.7-2.3 mils DFT
Viscosity:	25-30 sec Ford#4

Chemical Resistance

MEK, 100 Double Rubs:	Pass after full cure	**10%-Hydrochloric Acid:**	N/A
Lubricating and Cutting Oils:	N/A	**10%-Acetic Acid:**	N/A
Hydraulic Fluids:	N/A	**10%-Sodium Hydroxide:**	N/A
Water Immersion:	N/A	**Gasoline:**	N/A

Application Characteristics

Mixing:	Single Component (1K).			
Induction time:	None. Ready to spray.			
Cleaning Solvent:	T-210 or urethane grade thinner.			
Dry Times: A function of time and temperature	**Dry toTouch:** < 2 hr.	**Dry Hard:** 1-2 hrs	**Handle:** 3 hrs	**Dry Through:** 3-4 hrs
Note: Test Performed @ 72° F 50% Relative Humidity				

Technical Data Sheet

NCP® Coatings, Inc. 225 Fort St. Niles, MI 49120
Phone: 269-683-3377 Fax: 269-683-3305
www.ncpcoatings.com

Rev. 04/29/19

RH-142
Single-Component (1K) Polysiloxane Topcoat
Camouflage Gray #36375

Technical Data Sheet

Recommended Primers

Substrate	Recommended Primer
Aluminum/Galvanized Steel/Stainless Steel:	Approved aircraft primers
Ductile or Grey Iron Castings:	N-1981A/B or N-1088A/B
Plastics:	Due to the wide variety of plastic/fiberglass substrates, system performance should be tested and confirmed on actual substrate.
Previously Painted Surfaces:	Surface should be intact and sound. All loose and flaking material removed and bare spots primed with an appropriate primer. An area should be tested with the coating to assure compatibility.
Steel:	N-5751M2 Zinc Rich Epoxy, N-1088A/B or N-1981A/B Epoxy.
Wood:	Due to the wide variety of wood substrates, system performance should be tested and confirmed on actual substrate.

Application Equipment

Conventional Electrostatic:	**Air Pressure:** N/A	**Fluid Pressure:** N/A	**Cap:** N/A **Tip:**
Conventional Spray:	**Air Pressure:** 10 -50 psi	**Fluid Pressure:** 8 - 40 psi *	**Cap:** **Tip:** 1.7 – 2.0
HVLP Spray:	**Air Pressure:** 10 psi	**Fluid Pressure:** 8 - 40 psi *	**Cap:** **Tip:** 1.7 – 2.0
Air Assisted Airless:	**Air Pressure:** N/A	**Fluid Pressure:** N/A	**Cap:** **Tip:** N/A
Airless:	**Pressure:** N/A	**Tip:** N/A	
Brush and Roll: Use for touch up only. The use of natural china chip bristle brushes or ¼" maximum nap mohair type rollers is highly recommended to limit the amount of orange peel.			
Note: The above parameters are to be used as a guideline only. Customer specific equipment may require a different set-up			

Surface Preparation

Do not apply if the application surface temperature is below 45°F (7°C) or above 110°F (43°C), or if the surface temperature is within 5°F of the dew point. It is highly recommended that sound practices as set forth by SSPC or NACE be followed when preparing a substrate for painting. At a minimum the surface should be clean of all grease, dirt, oil, rust and foreign material that would be detrimental to proper adhesion and desired performance of the coating system being applied.

Safety Precautions

This product is intended for professional use in an industrial environment only! Consult the Material Safety Data Sheet prior to application for detailed information on the health and safety hazards.

Shelf Life & Storage Conditions

Shelf life (protected from atmospheric moisture): 12 months from the date of manufacture. This product must be stored in accordance with local, state, and national regulations. Preferred storage conditions: Keep containers in a dry space with adequate ventilation.

Comments

Mix with a paint shaker prior to use. Agitate material while in use. Ambient application temperature should be between 60°F and 90°F. Best results with relative humidity above 10% and less than 80%.

Note

The above information is supplied as a guideline to our customers. The user must be aware of the cleaning, pretreatment, application and testing requirements for their specific job!

- Adjust as needed to get the desired/optimal fluid delivery for the spray gun, fluid tip and needle assembly being used.

NCP® Coatings, Inc. 225 Fort St. Niles, MI 49120
Phone: 269-683-3377 Fax: 269-683-3305
www.ncpcoatings.com

Rev. 04/29/19

11.9 Appendix IX – Technical Data Sheet for Single-Component (1K) Polysiloxane Topcoat, Semi-Gloss Gray (#26173)

BM1947
Single-Component (1K) Polysiloxane Topcoat
Semi-Gloss Gray #26173

Technical Data Sheet

Intended Uses:

The topcoat is a single component (1K) isocyanate-free and HAP's free system designed for ground support equipment. The topcoat does not require the addition of components or a catalyst before application, and thus provides a user-friendly system for applicators.

Physical Properties

Color:	Gray Fed. Std.#26173
Gloss:	15 min to 45 max. @ 60°
Volume Solids:	46.3 % +/- 1%
Weight Solids:	45.9 % +/- 1%
Weight Per Gallon:	10.74#/gal +/- 0.5 lbs/gallon
Theoretical Coverage:	743 sq ft/gal @ 1 mil dft
VOC:	0.82 #/gal or 98 g/l
Recommended Film Thickness:	1.7-2.3 mils DFT
Viscosity:	25-30 sec Ford#4

Chemical Resistance

MEK, 100 Double Rubs:	N/A	**10%-Hydrochloric Acid:**	N/A
Lubricating and Cutting Oils:	N/A	**10%-Acetic Acid:**	N/A
Hydraulic Fluids:	N/A	**10%-Sodium Hydroxide:**	N/A
Water Immersion:	N/A	**Gasoline:**	N/A

Application Characteristics

Mixing:	Single Component (1K).			
Induction time:	None. Ready to spray.			
Cleaning Solvent:	T-210 or urethane grade thinner.			
Dry Times: A function of time and temperature	**Dry to Touch:** 2-3 hr.	**Dry Hard:** 4-6 hrs	**Handle:** 6-8 hrs	**Dry Through:** 7-8 hrs
Note: Test Performed @ 72° F 50% Relative Humidity				

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Rev. 1/25/2019

BM1947
Single-Component (1K) Polysiloxane Topcoat
Semi-Gloss Gray #26173

Technical Data Sheet

Recommended Primers

Substrate	Recommended Primer
Aluminum/Galvanized Steel/Stainless Steel:	Approved aircraft primers
Ductile or Grey Iron Castings:	N-1981A/B or N-1088A/B
Plastics:	Due to the wide variety of plastic/fiberglass substrates, system performance should be tested and confirmed on actual substrate.
Previously Painted Surfaces:	Surface should be intact and sound. All loose and flaking material removed and bare spots primed with an appropriate primer. An area should be tested with the coating to assure compatibility.
Steel:	N-5751M2 Zinc Rich Epoxy, N-1088A/B or N-1981A/B Epoxy.
Wood:	Due to the wide variety of wood substrates, system performance should be tested and confirmed on actual substrate.

Application Equipment

Conventional Electrostatic:	**Air Pressure:** N/A	**Fluid Pressure:** N/A	**Cap:** N/A **Tip:**
Conventional Spray:	**Air Pressure:** 10 -50 psi	**Fluid Pressure:** 8 - 40 psi	**Cap:** **Tip:** 1.4 – 1.6
HVLP Spray:	**Air Pressure:** 10 psi	**Fluid Pressure:** 8 - 40 psi	**Cap:** **Tip:** 1.4 – 1.6
Air Assisted Airless:	**Air Pressure:** N/A	**Fluid Pressure:** N/A	**Cap:** **Tip:** N/A
Airless:	**Pressure:** N/A	**Tip:** N/A	
Brush and Roll: Use for touch up only. The use of natural china chip bristle brushes or ¼" maximum nap mohair type rollers is highly recommended to limit the amount of orange peel.			
Note: The above parameters are to be used as a guideline only. Customer specific equipment may require a different set-up			

Surface Preparation

Do not apply if the application surface temperature is below 45°F (7°C) or above 110°F (43°C), or if the surface temperature is within 5°F of the dew point. It is highly recommended that sound practices as set forth by SSPC or NACE be followed when preparing a substrate for painting. At a minimum the surface should be clean of all grease, dirt, oil, rust and foreign material that would be detrimental to proper adhesion and desired performance of the coating system being applied.

Safety Precautions

This product is intended for professional use in an industrial environment only! Consult the Material Safety Data Sheet prior to application for detailed information on the health and safety hazards.

Shelf Life & Storage Conditions

Shelf life (protected from atmospheric moisture): 12 months from the date of manufacture. This product must be stored in accordance with local, state, and national regulations. Preferred storage conditions: Keep containers in a dry space with adequate ventilation.

Comments

Mix with a paint shaker prior to use. Agitate material while in use. Ambient application temperature should be between 60°F and 90°F. Best results with relative humidity above 10% and less than 80%.

Note

The above information is supplied as a guideline to our customers. The user must be aware of the cleaning, pretreatment, application and testing requirements for their specific job!

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Rev. 1/25/2019

11.10 Appendix X – Safety Data Sheet for Single-Component (1K) Polysiloxane Aircraft Topcoat, Camouflage Gray (#36375)

SAFETY DATA SHEET

DATE ISSUED :	12/31/2020
SDS REF. No :	RH-142

Single-Comp (1K) Polysiloxane
Aircraft Topcoat, #36375 Medium Gray

1. PRODUCT AND COMPANY IDENTIFICATION

PRODUCT NAME: Single-Comp (1K) Polysiloxane
Aircraft Topcoat, #36375 Medium Gray

PRODUCT CODE: RH-142
PRODUCT USE: Refer to TDS and product label.

MANUFACTURER
NCP Coatings
225 Fort Street
Niles, MI,
269-683-3377

24 HR. EMERGENCY TELEPHONE NUMBER
CHEMTREC (US Transportation): (800)424-9300
CHEMTREC (International Transportation) : 1(202)483-7616

2. HAZARDS IDENTIFICATION

EMERGENCY OVERVIEW
PHYSICAL APPEARANCE : Liquid
IMMEDIATE CONCERNS : Flammable liquid and vapor.

CLASSIFICATION : Flammable Liquid 3, Eye Irrit. 2, Skin Irrit. 2, STOT SE 3 RTI

PICTOGRAMS

SIGNAL WORD : Warning

GHS HAZARD STATEMENTS : H226 Flammable liquid and vapor.
H315 Causes skin irritation.
H319 Causes serious eye irritation.
H335 May cause respiratory irritation.

GHS PRECAUTIONARY STATEMENTS : P302 + P352 IF ON SKIN: Wash with plenty of soap and water.
P304 + P341 IF INHALED: If breathing is difficult, remove victim to fresh air and keep at rest in a position comfortable for breathing.
P305 + P351 + P338 IF IN EYES: Rinse cautiously with water for several minutes. Remove contact lenses if present and easy to do. Continue rinsing.
P333 + P313 If skin irritation or rash occurs: Get medical advice / attention.
P342 + P313 If experiencing respiratory symptoms: Get medical advice / attention.
P210 Keep away from heat/sparks/open flames/hot surfaces. — No smoking.
P240 Ground/bond container and receiving equipment.
P241 Use explosion-proof electrical/ventilating/lighting/equipment.
P261 Avoid breathing dust/fume/gas/mist/vapors/spray.
P262 Do not get in eyes, on skin, or on clothing.
P270 Do no eat, drink or smoke when using this product.
P271 Use only outdoors or in a well-ventilated area.
P280 Wear protective gloves/protective clothing/eye protection/face protection.
P363 Wash contaminated clothing before reuse.
P501 Dispose of contents/container in accordance with local/national/international regulations.
P370 + P378 In case of fire: Use appropriate method to extinguish. See Section 5 of SDS.
P403 + P233 Store in a well-ventilated place. Keep container tightly closed.
P403 + P235 Store in a well-ventilated place. Keep cool.

3. COMPOSITION/INFORMATION ON INGREDIENTS

Chemical Name	Wt %	CAS Number	GHS
Parachlorbenzotrifluoride(PCBTF)	40-45%	98-56-6	H319 Causes serious eye irritation. H226 Flammable liquid and vapor. H335 May cause respiratory irritation. H315 Causes skin irritation.
Proprietary Resin	20-25%	Trade Secret	Not classified.
n-Pentyl Propionate	15-20%	624-54-4	H224 Flammable liquid and vapor.
Titanium Dioxide	4.23	13463-67-7	Conclusive but not sufficient for classification.

* Toxic chemical subject to the reporting requirements of section 313 of Title III and of 40 CFR 372.

4. FIRST AID MEASURES

EYES : Immediately flush eyes with water. Flush eyes with water for a minimum of 15 minutes, occasionally lifting and lowering upper lids. Get medical attention promptly.

SKIN : Wash with soap and water. Get medical attention if irritation develops or persists. Remove contaminated shoes and clothes and clean before reuse.

INGESTION : DO NOT induce vomiting. Get medical attention immediately.

INHALATION : Rescuers should put on appropriate protective gear. Remove from area of exposure. If not breathing, give artificial respiration. If breathing is difficult, give oxygen. Keep victim warm. Get immediate medical attention.

MOST IMPORTANT SYMPTOMS AND EFFECTS, BOTH ACUTE AND DELAYED

SYMPTOMS : May cause drowsiness or dizziness.

EFFECTS : Significant exposure to this chemical may adversely affect people with chronic disease of the respiratory system, central nervous system, kidney, liver, skin, and/or eyes.

5. FIRE FIGHTING MEASURES

SUITABLE EXTINGUISHING MEDIA : Water mist or fog, dry chemical, foam, carbon dioxide.

FIRE FIGHTING PROCEDURES : As in any fire, wear self-contained breathing apparatus pressure-demand (MSHA/NIOSH approved or equivalent) and full protective gear. Use water with caution. Material will float and may ignite on surface of water. Water may be ineffective in fighting the fire. Water spray to cool containers or protect personnel. Use with caution. Water runoff can cause environmental damage. Dike collect water used to fight fire. Small fires: carbon dioxide or dry chemical. Large fire: alcohol-type aqueous film-forming foam or water spray.

UNUSUAL FIRE AND EXPLOSION HAZARD : Flammable liquid and vapor. Vapors can travel to a source of ignition and flash back. Empty containers retain product residue (liquid and/or vapor) and can be dangerous. DO NOT pressurize, cut, weld, braze, solder, grind or expose such containers to heat, flame, sparks, static electricity, or other sources of ignition. Also, do not reuse container without commercial cleaning or reconditioning.

COMBUSTION PRODUCTS : During combustion carbon monoxide and/or carbon dioxide may be formed.

6. ACCIDENTAL RELEASE MEASURES

SMALL SPILL : Eliminate all sources of ignition. Provide good ventilation and minimize the breathing of vapors and avoid skin contact. Dike spill area and absorb the spilled liquid with earth, sawdust or a commercially available absorbent. Shovel spent absorbent into recovery or salvage drums for appropriate disposal.

LARGE SPILL : Wear appropriate personal protective equipment. Eliminate all ignition sources. Prevent additional discharge of material if able to do so safely. Do not touch or walk through spilled material. Avoid runoff into storm sewers and ditches which lead to waterways. Ventilate spill area. Stay upwind of spill. Use only non-combustible material for cleanup. Use clean, non-sparking tools to collect absorbed materials. Absorb spill with inert material (e.g. dry sand, earth or sawdust), then place in a chemical waste collector.

EMERGENCY PRECAUTIONS : Eliminate ignition sources. Avoid large exposures to vapors.

7. HANDLING AND STORAGE

PRECAUTIONS FOR SAFE HANDLING : Use only in a well ventilated area. Avoid breathing vapor, fumes, or mist. Avoid contact with eyes, skin, and clothing. Ground and bond containers when transferring material. Use spark-proof tools and explosion proof equipment. Always open containers slowly to allow any excess pressure to vent. Follow all SDS/label precautions even after containers are emptied because they may retain product residues.

CONDITIONS FOR SAFE STORAGE, INCLUDING INCOMPATIBILITIES : Keep away from heat, sparks, and flame. Store containers in a cool, well ventilated place. Keep container closed when not in use.

8. EXPOSURE CONTROLS\PERSONAL PROTECTION

EXPOSURE LIMITS

Components	CAS	Limits
Parachlorbenzotrifluoride(PCBTF)	98-56-6	ACGIH TLV NE OSHA PEL NE
Proprietary Resin	Trade Secret	OSHA PEL: NE ACGIH TLV: NE
n-Pentyl Propionate	624-54-4	ACGIH TLV: NE OSHA PEL: NE
Titanium Dioxide	13463-67-7	OSHA PEL 10 mg/m3 TWA Total Dust ACGIH TLV 10 mg/m3 Total Dust

OSHA TABLE COMMENTS:
NE = Not Established

ENGINEERING CONTROLS : Engineering controls should be in place to minimize exposure to vapors and any ignition sources.

PERSONAL PROTECTIVE EQUIPMENT

EYES AND FACE : Wear safety glasses with side shields, goggles, or a face shield.

SKIN : Wear impervious gloves to prevent contact with skin. Wear protective gear as needed - apron, suit, boots.

RESPIRATORY : NIOSH/MSHA approved respirators may be necessary if airborne concentrations are expected to exceed exposure limits.

WORK HYGIENIC PRACTICES : Do not eat, drink, or smoke in areas where this material is used. Avoid breathing vapors. Remove contaminated clothing and wash before reuse. Wash thoroughly after handling. Wash hands before eating.

OTHER USE PRECAUTIONS : Facilities storing or utilizing this material should be equipped with an eyewash facility and a safety shower.

9. PHYSICAL AND CHEMICAL PROPERTIES

APPEARANCE : Liquid

ODOR : Typical

ODOR THRESHOLD : Not determined.

pH : Not determined.

MELTING POINT/FREEZING POINT: Not determined.

INITIAL BOILING POINT : 282.0 F **BOILING RANGE:** Not determined.

FLASH POINT AND METHOD : 104ºF(40ºC)
SETAFLASH CLOSED CUP

EVAPORATION RATE: Not determined.

FLAMMABILITY (SOLID,GAS): Not determined.

EXPLOSIVE LIMITS : .9 TO 10.5

VAPOR PRESSURE : Not determined.

VAPOR DENSITY : Heavier than air

SPECIFIC GRAVITY : 1.1216713

SOLUBILITY: Not determined.

PARTITION COEFFICIENT: N-OCTANOL/WATER: Not determined.

AUTO-IGNITION TEMPERATURE : Not determined.

DECOMPOSITION TEMPERATURE: Not determined.

VISCOSITY: Semi-viscous.

VOC EPA METHOD 24 : 2.2784692 **lb/gal**

10. STABILITY AND REACTIVITY

STABILITY : No information available.

CONDITIONS TO AVOID : Avoid impact, friction, heat, sparks, flame and source of ignition.

INCOMPATIBLE MATERIALS : Prevent contact with strong oxidizing agents.

HAZARDOUS DECOMPOSITION PRODUCTS: During combustion carbon monoxide and/or carbon dioxide may be formed.

HAZARDOUS POLYMERIZATION : No information available.

11. TOXICOLOGICAL INFORMATION

SIGNS AND SYMPTOMS OF OVEREXPOSURE :

ACUTE EFFECTS :

EYE : Causes eye irritation.

SKIN : Causes skin irritation. Prolonged or repeated contact can result in defatting and drying of the skin which may result in skin irritation and dermatitis (rash).

INHALATION : Vapors are irritating to nasal passages and throat. High concentrations can cause stupor and headaches. May cause dizziness and drowsiness.

INGESTION : Irritating to mouth, throat, and stomach. May cause headache. May cause dizziness and drowsiness and/or stupor.

CHRONIC EFFECTS : Significant exposure to this chemical may adversely affect people with chronic disease of the respiratory system, central nervous system, kidney, liver, skin, and/or eyes.

Primary Route(s) of Entry: Eye Contact, Ingestion, Inhalation, Skin Contact

ACUTE TOXICITY VALUES : The acute effects of this product have not been tested. Data on individual components are listed below.

CAS Number	TEST
98-56-6	Oral LD50: 13,000, Dermal LD50: 2,700, Vapor LC50: 33,
Trade Secret	No information available.
624-54-4	Oral LD50: >13,920 mg/kg Rat, Dermal LD50: >13,920 mg/kg Rabbit, Inhalation LC50: >10.7 mg/l,
13463-67-7	Vapor LC50: >6.82lg/L Rat, Dermal LD50: >10,000 mg/kg Rabbit, Oral LD50: >5,000 mg/kg Rat,

12. ECOLOGICAL INFORMATION

ECOTOXICOLOGICAL INFORMATION: Information not available on mixture. Information on individual components is listed below if available.

CAS Number	TEST
98-56-6	No Information available.
Trade Secret	No information available.
624-54-4	LC50: 96 hr, 56 mg/l (fathead minnow), LC50: 48 hr, 60 mg/l (water flea),
13463-67-7	96h LC50: >1,000 mg/L (fathead minnow), 72h EC50: 61 mg/L (green algae), 48h EC50: >1,000 gm/L (water flea),

13. DISPOSAL CONSIDERATIONS

DISPOSAL METHOD : Dispose of waste in accordance with all local, state, and federal regulations.

14. TRANSPORT INFORMATION

UN NUMBER/ PROPER SHIPPING NAME/ TRANSPORT HAZARD CLASS/ PACKING GROUP : UN1263;PAINT;3;III

15. REGULATORY INFORMATION

REGULATORY OVERVIEW: The regulatory data in section 15 is not intended to be all-inclusive, only selected regulations are represented.

TSCA: All components of this material are either listed or exempt from listing on the TSCA Inventory. This material contains no substances that are subject to TSCA 12(b) export notification.

SARA TITLE III (SUPERFUND AMENDMENTS AND REAUTHORIZATION ACT)
311/312/313 REPORTABLE INGREDIENTS: See Section 3.

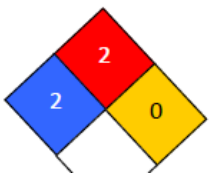
EPA HAZARDS:
FIRE : Yes **PRESSURE GENERATING :** No
REACTIVITY : No **ACUTE :** Yes **CHRONIC :** Yes

DSL: All components of this material are on or exempt from listing on the Canadian Domestic Substances List(DSL).

16. OTHER INFORMATION

HMIS RATING

NFPA CODES



Health :	2
Flammability :	2
Reactivity :	0
Personal Protection :	G

HMIS and NFPA rating scale: (0=minimal hazard; 4=severe hazard)

REVISION INDICATOR : 10/8/19

MANUFACTURER DISCLAIMER : The foregoing data has been compiled from sources which the company, in good faith, believes to be dependable and is accurate and reliable to the best of our knowledge and belief. However, the company cannot make any warranty or representation respecting the accuracy or completeness of the data and assumes no responsibility for any liability or damages relating thereto or for advising you regarding the protection of your employees, customers, or others. User should consult OSHA and other applicable safety laws and regulations before use.

11.11 Appendix XI – Safety Data Sheet for Single-Component (1K) Polysiloxane Topcoat, Semi-Gloss Gray (#26173)

SAFETY DATA SHEET

DATE ISSUED :	6/8/2021
SDS REF. No :	BM1947

1K Polysiloxane Semi-Gloss Gray #26173 Topcoat
#20-32-7

1. PRODUCT AND COMPANY IDENTIFICATION

PRODUCT NAME: 1K Polysiloxane Semi-Gloss Gray #26173 Topcoat #20-32-7
PRODUCT CODE: BM1947
PRODUCT USE: Refer to TDS and product label.

MANUFACTURER
NCP Coatings
225 Fort Street
Niles, MI,
269-683-3377

24 HR. EMERGENCY TELEPHONE NUMBER
CHEMTREC (US Transportation): (800)424-9300
CHEMTREC (International Transportation) : 1(202)483-7616

2. HAZARDS IDENTIFICATION

EMERGENCY OVERVIEW
PHYSICAL APPEARANCE : Liquid
IMMEDIATE CONCERNS : Flammable liquid and vapor.

CLASSIFICATION : Flammable Liquid 3, Eye Irrit. 2, Skin Irrit. 2, STOT SE 3 RTI

PICTOGRAMS

SIGNAL WORD : Warning

GHS HAZARD STATEMENTS : H226 Flammable liquid and vapor.
H315 Causes skin irritation.
H335 May cause respiratory irritation.
H319 Causes serious eye irritation.

GHS PRECAUTIONARY STATEMENTS : P210 Keep away from heat/sparks/open flames/hot surfaces. — No smoking.
P262 Do not get in eyes, on skin, or on clothing.
P241 Use explosion-proof electrical/ventilating/lighting/equipment.
P270 Do not eat, drink or smoke when using this product.
P261 Avoid breathing dust/fume/gas/mist/vapors/spray.
P280 Wear protective gloves/protective clothing/eye protection/face protection.
P302 + P352 IF ON SKIN: Wash with plenty of soap and water.
P304 + P341 IF INHALED: If breathing is difficult, remove victim to fresh air and keep at rest in a position comfortable for breathing.
P305 + P351 + P338 IF IN EYES: Rinse cautiously with water for several minutes. Remove contact lenses if present and easy to do. Continue rinsing.
P370 + P378 In case of fire: Use appropriate method to extinguish. See Section 5 of SDS.
P403 + P233 Store in a well-ventilated place. Keep container tightly closed.
P333 + P313 If skin irritation or rash occurs: Get medical advice / attention.
P342 + P313 If experiencing respiratory symptoms: Get medical advice / attention.
P501 Dispose of contents/container in accordance with local/national/international regulations.
P363 Wash contaminated clothing before reuse.
P271 Use only outdoors or in a well-ventilated area.
P240 Ground/bond container and receiving equipment.
P403 + P235 Store in a well-ventilated place. Keep cool.

3. COMPOSITION/INFORMATION ON INGREDIENTS

Chemical Name	Wt %	CAS Number	GHS
Parachlorbenzotrifluoride(PCBTF)	45-50%	98-56-6	H319 Causes serious eye irritation. H226 Flammable liquid and vapor. H335 May cause respiratory irritation. H315 Causes skin irritation.
Proprietary Resin	15-20%	Trade Secret	No classification.
Proprietary Resin	10-15%	Trade Secret	Not classified.
Titanium Dioxide	10.57	13463-67-7	Conclusive but not sufficient for classification.
Methyl-n-Amyl Ketone	1-5%	110-43-0	H226 Flammable liquid and vapor. H302 Harmful if swallowed. H332 Harmful if inhaled. H335 May cause respiratory irritation. H336 May cause drowsiness or dizziness.
1-Methoxy-2-Propanol Acetate	1-5%	108-65-6	H226 Flammable liquid and vapor.
Carbon Black	0.36	1333-86-4	Not sufficient for classification.

* Toxic chemical subject to the reporting requirements of section 313 of Title III and of 40 CFR 372.

4. FIRST AID MEASURES

EYES : Immediately flush eyes with water. Flush eyes with water for a minimum of 15 minutes, occasionally lifting and lowering upper lids. Get medical attention promptly.

SKIN : Wash with soap and water. Get medical attention if irritation develops or persists. Remove contaminated shoes and clothes and clean before reuse.

INGESTION : DO NOT induce vomiting. Get medical attention immediately.

INHALATION : Rescuers should put on appropriate protective gear. Remove from area of exposure. If not breathing, give artificial respiration. If breathing is difficult, give oxygen. Keep victim warm. Get immediate medical attention.

MOST IMPORTANT SYMPTOMS AND EFFECTS, BOTH ACUTE AND DELAYED

SYMPTOMS : May cause drowsiness or dizziness.

EFFECTS : Significant exposure to this chemical may adversely affect people with chronic disease of the respiratory system, central nervous system, kidney, liver, skin, and/or eyes.

5. FIRE FIGHTING MEASURES

SUITABLE EXTINGUISHING MEDIA : Water mist or fog, dry chemical, foam, carbon dioxide.

FIRE FIGHTING PROCEDURES : As in any fire, wear self-contained breathing apparatus pressure-demand (MSHA/NIOSH approved or equivalent) and full protective gear. Use water with caution. Material will float and may ignite on surface of water. Water may be ineffective in fighting the fire. Water spray to cool containers or protect personnel. Use with caution. Water runoff can cause environmental damage. Dike collect water used to fight fire. Small fires: carbon dioxide or dry chemical. Large fire: alcohol-type aqueous film-forming foam or water spray.

UNUSUAL FIRE AND EXPLOSION HAZARD : Flammable liquid and vapor. Vapors can travel to a source of ignition and flash back. Empty containers retain product residue (liquid and/or vapor) and can be dangerous. DO NOT pressurize, cut, weld, braze, solder, grind or expose such containers to heat, flame, sparks, static electricity, or other sources of ignition. Also, do not reuse container without commercial cleaning or reconditioning.

COMBUSTION PRODUCTS : During combustion carbon monoxide and/or carbon dioxide may be formed.

6. ACCIDENTAL RELEASE MEASURES

SMALL SPILL : Eliminate all sources of ignition. Provide good ventilation and minimize the breathing of vapors and avoid skin contact. Dike spill area and absorb the spilled liquid with earth, sawdust or a commercially available absorbent. Shovel spent absorbent into recovery or salvage drums for appropriate disposal.

LARGE SPILL : Wear appropriate personal protective equipment. Eliminate all ignition sources. Prevent additional discharge of material if able to do so safely. Do not touch or walk through spilled material. Avoid runoff into storm sewers and ditches which lead to waterways. Ventilate

spill area. Stay upwind of spill. Use only non-combustible material for cleanup. Use clean, non-sparking tools to collect absorbed materials. Absorb spill with inert material (e.g. dry sand, earth or sawdust), then place in a chemical waste collector.

EMERGENCY PRECAUTIONS : Eliminate ignition sources. Avoid large exposures to vapors.

7. HANDLING AND STORAGE

PRECAUTIONS FOR SAFE HANDLING : Use only in a well ventilated area. Avoid breathing vapor, fumes, or mist. Avoid contact with eyes, skin, and clothing. Ground and bond containers when transferring material. Use spark-proof tools and explosion proof equipment. Always open containers slowly to allow any excess pressure to vent. Follow all SDS/label precautions even after containers are emptied because they may retain product residues.

CONDITIONS FOR SAFE STORAGE, INCLUDING INCOMPATIBILITIES : Keep away from heat, sparks, and flame. Store containers in a cool, well ventilated place. Keep container closed when not in use.

8. EXPOSURE CONTROLS\PERSONAL PROTECTION

EXPOSURE LIMITS

Components	CAS	Limits
Parachlorbenzotrifluoride(PCBTF)	98-56-6	ACGIH TLV NE OSHA PEL NE
Proprietary Resin	Trade Secret	0.9 mg/m3: TWA EPA
Proprietary Resin	Trade Secret	0.9 mg/m3: TWA EPA
Titanium Dioxide	13463-67-7	OSHA PEL 10 mg/m3 TWA Total Dust ACGIH TLV 10 mg/m3 Total Dust
Methyl-n-Amyl Ketone	110-43-0	ACGIH TLV 50 PPM TWA OSHA PEL 100 PPM TWA
1-Methoxy-2-Propanol Acetate	108-65-6	OSHA PEL NE ACGIH TLV NE
Carbon Black	1333-86-4	OSHA PEL: 3.5 mg/m3 TWA ACGIH TLV: 3.5 mg/m3 TWA

OSHA TABLE COMMENTS:
NE = Not Established

ENGINEERING CONTROLS : Engineering controls should be in place to minimize exposure to vapors and any ignition sources.

PERSONAL PROTECTIVE EQUIPMENT

EYES AND FACE : Wear safety glasses with side shields, goggles, or a face shield.

SKIN : Wear impervious gloves to prevent contact with skin. Wear protective gear as needed - apron, suit, boots.

RESPIRATORY : NIOSH/MSHA approved respirators may be necessary if airborne concentrations are expected to exceed exposure limits.

WORK HYGIENIC PRACTICES : Do not eat, drink, or smoke in areas where this material is used. Avoid breathing vapors. Remove contaminated clothing and wash before reuse. Wash thoroughly after handling. Wash hands before eating.

OTHER USE PRECAUTIONS : Facilities storing or utilizing this material should be equipped with an eyewash facility and a safety shower.

9. PHYSICAL AND CHEMICAL PROPERTIES

APPEARANCE : Liquid

ODOR : Typical

ODOR THRESHOLD : Not determined.

pH : Not determined.

MELTING POINT/FREEZING POINT: Not determined.

INITIAL BOILING POINT : 282 F **BOILING RANGE:** Not determined.

FLASH POINT AND METHOD : SETAFLASH CLOSED CUP

EVAPORATION RATE: Not determined.

FLAMMABILITY (SOLID,GAS): Not determined.

EXPLOSIVE LIMITS : 0.9 TO 10.5

VAPOR PRESSURE : Not determined.

VAPOR DENSITY : Heavier than air

SPECIFIC GRAVITY : 1.2895853

SOLUBILITY: Not determined.

PARTITION COEFFICIENT: N-OCTANOL/WATER: Not determined.

AUTO-IGNITION TEMPERATURE : Not determined.

DECOMPOSITION TEMPERATURE: Not determined.

VISCOSITY: Semi-viscous.

VOC EPA METHOD 24 : 0.8165843 **lb/gal**

10. STABILITY AND REACTIVITY

STABILITY : No information available.

CONDITIONS TO AVOID : Avoid impact, friction, heat, sparks, flame and source of ignition.

INCOMPATIBLE MATERIALS : Prevent contact with strong oxidizing agents.

HAZARDOUS DECOMPOSITION PRODUCTS: During combustion carbon monoxide and/or carbon dioxide may be formed.

HAZARDOUS POLYMERIZATION : No information available.

11. TOXICOLOGICAL INFORMATION

SIGNS AND SYMPTOMS OF OVEREXPOSURE :

ACUTE EFFECTS :

EYE : Causes eye irritation.

SKIN : Causes skin irritation. Prolonged or repeated contact can result in defatting and drying of the skin which may result in skin irritation and dermatitis (rash).

INHALATION : Vapors are irritating to nasal passages and throat. High concentrations can cause stupor and headaches. May cause dizziness and drowsiness.

INGESTION : Irritating to mouth, throat, and stomach. May cause headache. May cause dizziness and drowsiness and/or stupor.

CHRONIC EFFECTS : Significant exposure to this chemical may adversely affect people with chronic disease of the respiratory system, central nervous system, kidney, liver, skin, and/or eyes.

Primary Route(s) of Entry: Eye Contact, Ingestion, Inhalation, Skin Contact

ACUTE TOXICITY VALUES : The acute effects of this product have not been tested. Data on individual components are listed below.

1-Methoxy-2-Propanol Acetate(108-65-6)
None known.
Carbon Black(1333-86-4)
Oral LD50: >8000 mg/kg
Methyl-n-Amyl Ketone(110-43-0)
Oral LD50:>1600 mg/kg
Dermal LD50: >2000 mg/kg
Vapr LC50: >16.7 mg/L
Parachlorbenzotrifluoride(PCBTF)(98-56-6)
Oral LD50: 13,000

Dermal LD50: 2,700
Vapor LC50: 33
Proprietary Resin(Trade Secret)
No information available.
Titanium Dioxide(13463-67-7)
Vapor LC50: >6.82lg/L Rat
Dermal LD50: >10,000 mg/kg Rabbit
Oral LD50: >5,000 mg/kg Rat

12. ECOLOGICAL INFORMATION

ECOTOXICOLOGICAL INFORMATION: Information not available on mixture. Information on individual components is listed below if available.

1-Methoxy-2-Propanol Acetate(108-65-6)
96h LC50: 161 mg/L (fathead minnow)
Carbon Black(1333-86-4)
Acute algae EC50: >10,000 mg/L
Acute fish LC50>1000 mg/L
Acute water flea EC50:>5600 mg/L
Methyl-n-Amyl Ketone(110-43-0)
No Information available.
Parachlorbenzotrifluoride(PCBTF)(98-56-6)
No Information available.
Proprietary Resin(Trade Secret)
No information available.
Titanium Dioxide(13463-67-7)
96h LC50: >1,000 mg/L (fathead minnow)
72h EC50: 61 mg/L (green algae)
48h EC50: >1,000 gm/L (water flea)

13. DISPOSAL CONSIDERATIONS

DISPOSAL METHOD : Dispose of waste in accordance with all local, state, and federal regulations.

14. TRANSPORT INFORMATION

UN NUMBER/ PROPER SHIPPING NAME/ TRANSPORT HAZARD CLASS/ PACKING GROUP :

15. REGULATORY INFORMATION

REGULATORY OVERVIEW: The regulatory data in section 15 is not intended to be all-inclusive, only selected regulations are represented.

TSCA: All components of this material are either listed or exempt from listing on the TSCA Inventory. This material contains no substances that are subject to TSCA 12(b) export notification.

SARA TITLE III (SUPERFUND AMENDMENTS AND REAUTHORIZATION ACT)
311/312/313 REPORTABLE INGREDIENTS: See Section 3.

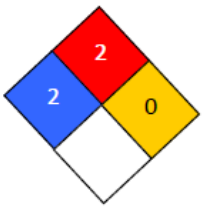
EPA HAZARDS:
FIRE : Yes **PRESSURE GENERATING :** No
REACTIVITY : No **ACUTE :** Yes **CHRONIC :** Yes

DSL: All components of this material are on or exempt from listing on the Canadian Domestic Substances List(DSL).

16. OTHER INFORMATION

HMIS RATING	
Health :	2
Flammability :	2
Reactivity :	0
Personal Protection :	G

NFPA CODES



HMIS and NFPA rating scale: (0=minimal hazard; 4=severe hazard)

REVISION INDICATOR : 10/8/19

MANUFACTURER DISCLAIMER : The foregoing data has been compiled from sources which the company, in good faith, believes to be dependable and is accurate and reliable to the best of our knowledge and belief. However, the company cannot make any warranty or representation respecting the accuracy or completeness of the data and assumes no responsibility for any liability or damages relating thereto or for advising you regarding the protection of your employees, customers, or others. User should consult OSHA and other applicable safety laws and regulations before use.

11.12 Appendix XII – Technical Data Sheet for Two-Component (2K) Polysiloxane Topcoat, Gloss White (#17925)

BM1681-2/BM1910-2
Two-Component (2K) Polysiloxane Coating
Gloss White #17925

Technical Data Sheet

Intended Uses:

Two-component, isocyanate-free, low-VOC polysiloxane topcoat for Navy ground support equipment and industrial applications.

Physical Properties

Color:	Fed Std. 595C #17925
Gloss:	>90 @ 60°
Volume Solids:	Comp A: 87.4 Comp B: 55.2 Mixed: 81.0
Weight Solids:	Comp A: 89.0 Comp B: 58.5 Mixed:84.8
VOC:	65 g/L 0.53 #/gal Mixed
Weight Per Gallon	Comp A 12.1 +/- 0.5 lbs/gl Comp B 7.7+/-0.5 lbs/gl Mixed:11.23+/- 0.5 lbs/gl
Recommended Film Thickness:	1.7-2.3 mils DFT
Viscosity:	<30 seconds on a #4 Ford Cup when mixed

Application Characteristics

Mixing:	Agitate BM1681-2 for 5 minutes using a mechanical shaker before opening. Then mix 4 parts BM1681-2 with 1 part BM1910-2 and mix for 3 minutes before spraying.			
Induction time:	None. Ready to spray when both components are mixed.			
Equipment:	HVLP spray: For best results we recommend using a 1.7 mm tip size. A smaller nozzle will not allow enough fluid delivery to fully wet the surface.			
Cleaning Solvent:	MEK, Acetone, or MAK			
Application Conditions:	Apply between 20% and 80% Relative Humidity (R.H.)			
Dry Times: A function of time and temperature	A function of temperature and humidity..	Dry-to-Touch: 2 Hour (@ 72 °F, 50% R.H.)	Dry Hard: 4-6 (@ 72 °F, 50% R.H.)	**Dry Through:** 6-8 hrs (@72 °F, 50% R.H.)

Recommended Primers

Substrate	Recommended Primer
Aluminum/Galvanized Steel/Stainless Steel:	B-875/T-99 or N-4718 Wash Primer, Near white, or White blast. **Note:** If blasted substrate is utilized then the recommended dry film thickness must be above the highest peak of the blast profile achieved. **Recommended blast profile .5-1.0 mils maximum!** Followed by N-8093A/B Epoxy Zinc Dust Primer.
Ductile or Grey Iron Castings:	DynaFill HS to fill profile followed by DynaSeal HS Urethane Primer.
Plastics:	Due to the wide variety of plastic/fiberglass substrates, system performance should be tested and confirmed on the actual substrate.
Previously Painted Surfaces:	Surface should be intact and sound. All loose and flaking material removed, and bare spots primed with an appropriate primer. An area should be tested with the coating to assure compatibility.
Steel:	Zinc phosphate, Iron phosphate pretreatment, Near white, or White blast. **Note:** If blasted substrate is utilized then the recommended dry film thickness must be above the highest peak of the blast profile achieved. **Recommended blast profile .5-2.0 mils maximum!** Followed by N-8093A/B Epoxy Zinc Dust Primer for maximum corrosion protection.
Wood:	Dependent on the wood grain use DynaSeal HS or DynaFill HS to achieve desired result.

NCP® Coatings, Inc. 225 Fort St. Niles, MI 49120
Phone: 269-683-3377 Fax: 269-683-3305
www.ncpcoatings.com

Rev. 8/19/19

BM1681-2/BM1910-2
Two-Component (2K) Polysiloxane Coating
Gloss White #17925

Application Equipment

Conventional Electrostatic:	**Air Pressure:** 40-60psi	**Fluid Pressure:** 10-20psi	**Cap:** Medium Visc. **Tip:** 1.2-1.5 mm
Conventional Spray:	**Air Pressure:** 40-60psi	**Fluid Pressure:** 10-20psi	**Cap:** Medium Visc. **Tip:** 1.2-1.5 mm
HVLP Spray:	**Air Pressure:** 15-20psi	**Fluid Pressure:** 10-20psi	**Cap:** Medium Visc. **Tip:** 1.2-1.5 mm
Air Assisted Airless:	**Air Pressure:** 15:1 ratio pump or larger @ 80-100psi to provide a tail free oblong pattern	**Atomizing Air:** Adjust as needed	**Cap:** Medium Visc. **Tip:** 0.09-0.13
Airless:	**Pressure:** 1500psi minimum	**Tip:** 0.09-0.11	
Brush and Roll: Touch up only. Utilize a China bristle brush or high-density foam roller and reduce with T-114 MAK.			
Note: The above parameters are to be used as a guideline only. Customer specific equipment may require a different set-up			

Surface Preparation

Do not apply if the application surface temperature is below 45°F (7°C) or above 110°F (43°C), or if the atmospheric temperature is within 5°F of the dew point. It is highly recommended that sound practices as set forth by SSPC or NACE be followed when preparing a substrate for painting. At a minimum the surface should be clean of all grease, dirt, oil, rust and foreign material that would be detrimental to proper adhesion and desired performance of the coating system being applied.

Safety Precautions

This product is intended for professional use in an industrial environment only! Consult the Material Safety Data Sheet prior to application for detailed information on the health and safety hazards.

Shelf Life & Storage Conditions

Shelf life (protected from atmospheric moisture): 12 months from the date of manufacture. This product must be stored in accordance with local, state, and national regulations. Preferred storage conditions: Keep containers in a dry space with adequate ventilation.

Comments

Use of a mechanical mixer is highly recommended. For additional information contact your NCP Coatings, Inc. Sales Representative, Customer Service Representative, or visit our website: www.ncpcoatings.com

Note

The above information is supplied as a guideline to our customers. The user must be aware of the cleaning, pretreatment, application and testing requirements for their specific job!

NCP® Coatings, Inc. 225 Fort St. Niles, MI 49120
Phone: 269-683-3377 Fax: 269-683-3305
www.ncpcoatings.com

Rev. 8/19/19

11.13 Appendix XIII – Safety Data Sheet for Two-Component (2K) Polysiloxane Topcoat, Gloss White (#17925), Part A (Base Component)

SAFETY DATA SHEET

DATE ISSUED :	7/25/2019
SDS REF. No :	BM1681-2

2K HAPS FREE GLOSS WHITE
COLOR 17925

1. PRODUCT AND COMPANY IDENTIFICATION

PRODUCT NAME: 2K HAPS FREE GLOSS WHITE COLOR 17925
PRODUCT CODE: BM1681-2
PRODUCT USE: Refer to TDS and product label.

MANUFACTURER
NCP Coatings
225 Fort Street
Niles, MI,
269-683-3377

24 HR. EMERGENCY TELEPHONE NUMBER
CHEMTREC (US Transportation): (800)424-9300
CHEMTREC (International Transportation) : 1(202)483-7616

2. HAZARDS IDENTIFICATION

EMERGENCY OVERVIEW
PHYSICAL APPEARANCE : Liquid
IMMEDIATE CONCERNS : Flammable liquid and vapor.

CLASSIFICATION : Flammable Liquid 3, Eye Irrit. 2, Skin Irrit. 2, STOT SE 3 RTI

PICTOGRAMS

SIGNAL WORD : Warning

GHS HAZARD STATEMENTS : H226 Flammable liquid and vapor.
H315 Causes skin irritation.
H319 Causes serious eye irritation.
H335 May cause respiratory irritation.

GHS PRECAUTIONARY STATEMENTS : P302 + P352 IF ON SKIN: Wash with plenty of soap and water.
P304 + P341 IF INHALED: If breathing is difficult, remove victim to fresh air and keep at rest in a position comfortable for breathing.
P305 + P351 + P338 IF IN EYES: Rinse continuously with water for several minutes. Remove contact lenses if present and easy to do - continue rinsing.
P333 + P313 If skin irritation or rash occurs: Get medical advice / attention.
P342 + P313 If experiencing respiratory symptoms: Get medical advice / attention.
P210 Keep away from heat/sparks/open flames/hot surfaces. — No smoking.
P240 Ground/bond container and receiving equipment.
P241 Use explosion-proof electrical/ventilating/lighting/equipment.
P261 Avoid breathing dust/fume/gas/mist/vapors/spray.
P262 Do not get in eyes, on skin, or on clothing.
P270 Do no eat, drink or smoke when using this product.
P271 Use only outdoors or in a well-ventilated area.
P280 Wear protective gloves/protective clothing/eye protection/face protection.
P363 Wash contaminated clothing before reuse.
P501 Dispose of contents/container in accordance with local/national/international regulations.
P370 + P378 In case of fire: Use appropriate method to extinguish. See Section 5 of SDS.
P403 + P233 Store in a well-ventilated place. Keep container tightly closed.
P403 + P235 Store in a well-ventilated place. Keep cool.

3. COMPOSITION/INFORMATION ON INGREDIENTS

Chemical Name	Wt %	CAS Number	GHS
Titanium Dioxide	29.85	13463-67-7	Conclusive but not sufficient for classification.
Parachlorbenzotrifluoride	5-10%	98-56-6	H319 Causes serious eye irritation. H226 Flammable liquid and vapor. H335 May cause respiratory irritation. H315 Causes skin irritation.

* Toxic chemical subject to the reporting requirements of section 313 of Title III and of 40 CFR 372.

4. FIRST AID MEASURES

EYES : Immediately flush eyes with water. Flush eyes with water for a minimum of 15 minutes, occasionally lifting and lowering upper lids. Get medical attention promptly.

SKIN : Wash with soap and water. Get medical attention if irritation develops or persists. Remove contaminated shoes and clothes and clean before reuse.

INGESTION : DO NOT induce vomiting. Get medical attention immediately.

INHALATION : Rescuers should put on appropriate protective gear. Remove from area of exposure. If not breathing, give artificial respiration. If breathing is difficult, give oxygen. Keep victim warm. Get immediate medical attention.

MOST IMPORTANT SYMPTOMS AND EFFECTS, BOTH ACUTE AND DELAYED

SYMPTOMS : May cause drowsiness or dizziness.

EFFECTS : Significant exposure to this chemical may adversely affect people with chronic disease of the respiratory system, central nervous system, kidney, liver, skin, and/or eyes.

5. FIRE FIGHTING MEASURES

SUITABLE EXTINGUISHING MEDIA : Water mist or fog, dry chemical, foam, carbon dioxide.

FIRE FIGHTING PROCEDURES : As in any fire, wear self-contained breathing apparatus pressure-demand (MSHA/NIOSH approved or equivalent) and full protective gear. Use water with caution. Material will float and may ignite on surface of water. Water may be ineffective in fighting the fire. Water spray to cool containers or protect personnel. Use with caution. Water runoff can cause environmental damage. Dike collect water used to fight fire. Small fires: carbon dioxide or dry chemical. Large fire: alcohol-type aqueous film-forming foam or water spray.

UNUSUAL FIRE AND EXPLOSION HAZARD : Flammable liquid and vapor. Vapors can travel to a source of ignition and flash back. Empty containers retain product residue (liquid and/or vapor) and can be dangerous. DO NOT pressurize, cut, weld, braze, solder, grind or expose such containers to heat, flame, sparks, static electricity, or other sources of ignition. Also, do not reuse container without commercial cleaning or reconditioning.

COMBUSTION PRODUCTS : During combustion carbon monoxide and/or carbon dioxide may be formed.

6. ACCIDENTAL RELEASE MEASURES

SMALL SPILL : Eliminate all sources of ignition. Provide good ventilation and minimize the breathing of vapors and avoid skin contact. Dike spill area and absorb the spilled liquid with earth, sawdust or a commercially available absorbent. Shovel spent absorbent into recovery or salvage drums for appropriate disposal.

LARGE SPILL : Wear appropriate personal protective equipment. Eliminate all ignition sources. Prevent additional discharge of material if able to do so safely. Do not touch or walk through spilled material. Avoid runoff into storm sewers and ditches which lead to waterways. Ventilate spill area. Stay upwind of spill. Use only non-combustible material for cleanup. Use clean, non-sparking tools to collect absorbed materials. Absorb spill with inert material (e.g. dry sand, earth or sawdust), then place in a chemical waste collector.

EMERGENCY PRECAUTIONS : Eliminate ignition sources. Avoid large exposures to vapors.

7. HANDLING AND STORAGE

PRECAUTIONS FOR SAFE HANDLING : Use only in a well ventilated area. Avoid breathing vapor, fumes, or mist. Avoid contact with eyes, skin, and clothing. Ground and bond containers when transferring material. Use spark-proof tools and explosion proof equipment. Always open containers slowly to allow any excess pressure to vent. Follow all SDS/label precautions even after containers are emptied because they may retain product residues.

CONDITIONS FOR SAFE STORAGE, INCLUDING INCOMPATIBILITIES : Keep away from heat, sparks, and flame. Store containers in a cool, well ventilated place. Keep container closed when not in use.

8. EXPOSURE CONTROLS\PERSONAL PROTECTION

EXPOSURE LIMITS

Components	CAS	Limits
Titanium Dioxide	13463-67-7	OSHA PEL 10 mg/m3 TWA Total Dust ACGIH TLV 10 mg/m3 Total Dust
Parachlorbenzotrifluoride	98-56-6	OSHA PEL NE ACGIH TLV NE

OSHA TABLE COMMENTS:
NE = Not Established

ENGINEERING CONTROLS : Engineering controls should be in place to minimize exposure to vapors and any ignition sources.

PERSONAL PROTECTIVE EQUIPMENT

EYES AND FACE : Wear safety glasses with side shields, goggles, or a face shield.

SKIN : Wear impervious gloves to prevent contact with skin. Wear protective gear as needed - apron, suit, boots.

RESPIRATORY : NIOSH/MSHA approved respirators may be necessary if airborne concentrations are expected to exceed exposure limits.

WORK HYGIENIC PRACTICES : Do not eat, drink, or smoke in areas where this material is used. Avoid breathing vapors. Remove contaminated clothing and wash before reuse. Wash thoroughly after handling. Wash hands before eating.

OTHER USE PRECAUTIONS : Facilities storing or utilizing this material should be equipped with an eyewash facility and a safety shower.

9. PHYSICAL AND CHEMICAL PROPERTIES

APPEARANCE : Liquid

ODOR : Typical

ODOR THRESHOLD : Not determined.

pH : Not determined.

MELTING POINT/FREEZING POINT: Not determined.

INITIAL BOILING POINT : 282.0 F **BOILING RANGE:** Not determined.

FLASH POINT AND METHOD : 111ºF(44ºC)
SETAFLASH CLOSED CUP

EVAPORATION RATE: Not determined.

FLAMMABILITY (SOLID,GAS): Not determined.

EXPLOSIVE LIMITS : .9 TO 10.5

VAPOR PRESSURE : Not determined.

VAPOR DENSITY : Heavier than air

SPECIFIC GRAVITY : 1.4543459

SOLUBILITY: Not determined.

PARTITION COEFFICIENT: N-OCTANOL/WATER: Not determined.

AUTO-IGNITION TEMPERATURE : Not determined.

DECOMPOSITION TEMPERATURE: Not determined.

VISCOSITY: Semi-viscous.

VOC EPA METHOD 24 : 0.1454800 **lb/gal**

10. STABILITY AND REACTIVITY

STABILITY : No information available.

CONDITIONS TO AVOID : Avoid impact, friction, heat, sparks, flame and source of ignition.

INCOMPATIBLE MATERIALS : Prevent contact with strong oxidizing agents.

HAZARDOUS DECOMPOSITION PRODUCTS: During combustion carbon monoxide and/or carbon dioxide may be formed.

HAZARDOUS POLYMERIZATION : No information available.

11. TOXICOLOGICAL INFORMATION

SIGNS AND SYMPTOMS OF OVEREXPOSURE :

ACUTE EFFECTS :

EYE : Causes eye irritation.

SKIN : Causes skin irritation. Prolonged or repeated contact can result in defatting and drying of the skin which may result in skin irritation and dermatitis (rash).

INHALATION : Vapors are irritating to nasal passages and throat. High concentrations can cause stupor and headaches. May cause dizziness and drowsiness.

INGESTION : Irritating to mouth, throat, and stomach. May cause headache. May cause dizziness and drowsiness and/or stupor.

CHRONIC EFFECTS : Significant exposure to this chemical may adversely affect people with chronic disease of the respiratory system, central nervous system, kidney, liver, skin, and/or eyes.

Primary Route(s) of Entry: Eye Contact, Ingestion, Inhalation, Skin Contact

ACUTE TOXICITY VALUES : The acute effects of this product have not been tested. Data on individual components are listed below.

CAS Number	TEST
13463-67-7	Vapor LC50: >6.82lg/L Rat, Dermal LD50: >10,000 mg/kg Rabbit, Oral LD50: >5,000 mg/kg Rat,
98-56-6	Oral LD50: 13,000, Dermal LD50: 2,700, Vapor LC50: 33,

12. ECOLOGICAL INFORMATION

ECOTOXICOLOGICAL INFORMATION: Information not available on mixture. Information on individual components is listed below if available.

CAS Number	TEST
13463-67-7	96h LC50: >1,000 mg/L (fathead minnow), 72h EC50: 61 mg/L (green algae), 48h EC50: >1,000 gm/L (water flea),
98-56-6	No Information available.

13. DISPOSAL CONSIDERATIONS

DISPOSAL METHOD : Dispose of waste in accordance with all local, state, and federal regulations.

14. TRANSPORT INFORMATION

UN NUMBER/ PROPER SHIPPING NAME/ TRANSPORT HAZARD CLASS/ PACKING GROUP :

15. REGULATORY INFORMATION

REGULATORY OVERVIEW: The regulatory data in section 15 is not intended to be all-inclusive, only selected regulations are represented.

TSCA: All components of this material are either listed or exempt from listing on the TSCA Inventory. This material contains no substances that are subject to TSCA 12(b) export notification.

SARA TITLE III (SUPERFUND AMENDMENTS AND REAUTHORIZATION ACT)
311/312/313 REPORTABLE INGREDIENTS: See Section 3.

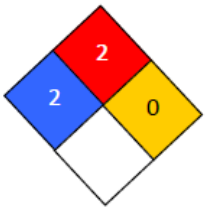
EPA HAZARDS:
FIRE : Yes **PRESSURE GENERATING :** No
REACTIVITY : No **ACUTE :** Yes **CHRONIC :** Yes

DSL: All components of this material are on or exempt from listing on the Canadian Domestic Substances List(DSL).

16. OTHER INFORMATION

HMIS RATING	
Health :	2
Flammability :	2
Reactivity :	1
Personal Protection :	G

NFPA CODES



HMIS and NFPA rating scale: (0=minimal hazard; 4=severe hazard)

REVISION INDICATOR : 9/25/18

MANUFACTURER DISCLAIMER : The foregoing data has been compiled from sources which the company, in good faith, believes to be dependable and is accurate and reliable to the best of our knowledge and belief. However, the company cannot make any warranty or representation respecting the accuracy or completeness of the data and assumes no responsibility for any liability or damages relating thereto or for advising you regarding the protection of your employees, customers, or others. User should consult OSHA and other applicable safety laws and regulations before use.

11.14 Appendix XIV – Safety Data Sheet for Two-Component (2K) Polysiloxane Topcoat, Gloss White (#17925), Part B (Activator/Hardener)

SAFETY DATA SHEET

DATE ISSUED :	7/25/2019
SDS REF. No :	BM1910-2

NCP COATINGS — Small Business • Veteran Owned — Family Owned since 1948 • ISO 9001 : 2008 — Worldwide Distribution

2K PART B

1. PRODUCT AND COMPANY IDENTIFICATION

PRODUCT NAME: 2K PART B
PRODUCT CODE: BM1910-2
PRODUCT USE: Refer to TDS and product label.

MANUFACTURER
NCP Coatings
225 Fort Street
Niles, MI,
269-683-3377

24 HR. EMERGENCY TELEPHONE NUMBER
CHEMTREC (US Transportation): (800)424-9300
CHEMTREC (International Transportation) : 1(202)483-7616

2. HAZARDS IDENTIFICATION

EMERGENCY OVERVIEW
PHYSICAL APPEARANCE : Liquid
IMMEDIATE CONCERNS : Highly flammable liquid and vapor

CLASSIFICATION : Eye Irrit. 2, Flam. Liq. 2, STOT SE 3 NE

PICTOGRAMS

SIGNAL WORD : Danger

GHS HAZARD STATEMENTS : H225 Highly flammable liquid and vapour.
H319 Causes serious eye irritation.
H336 May cause drowsiness or dizziness.

GHS PRECAUTIONARY STATEMENTS : P301 + P310 IF SWALLOWED: Immediately call a POISON CENTER or doctor / physician.
P302 + P352 IF ON SKIN: Wash with plenty of soap and water.

P304 + P341 IF INHALED: If breathing is difficult, remove victim to fresh air and keep at rest in a position comfortable for breathing.
P305 + P351 + P338 IF IN EYES: Rinse continuously with water for several minutes. Remove contact lenses if present and easy to do - continue rinsing.
P333 + P313 If skin irritation or rash occurs: Get medical advice / attention.
P342 + P313 If experiencing respiratory symptoms: Get medical advice / attention.
P210 Keep away from heat/sparks/open flames/hot surfaces. — No smoking.
P240 Ground/bond container and receiving equipment.
P241 Use explosion-proof electrical/ventilating/lighting/equipment.
P261 Avoid breathing dust/fume/gas/mist/vapors/spray.
P262 Do not get in eyes, on skin, or on clothing.
P270 Do no eat, drink or smoke when using this product.
P271 Use only outdoors or in a well-ventilated area.
P280 Wear protective gloves/protective clothing/eye protection/face protection.
P284 (In case of inadequate ventilation) wear respiratory protection.
P363 Wash contaminated clothing before reuse.
P501 Dispose of contents/container in accordance with local/national/international regulations.
P370 + P378 In case of fire: Use appropriate method to extinguish. See Section 5 of SDS.
P403 + P233 Store in a well-ventilated place. Keep container tightly closed.
P403 + P235 Store in a well-ventilated place. Keep cool.

3. COMPOSITION/INFORMATION ON INGREDIENTS

Chemical Name	Wt %	CAS Number	GHS
Ethanol	55-60%	64-17-5	H225 Highly flammable liquid and vapor. H312 Harmful in contact with skin. H315 Causes skin irritation. H319 Causes serious eye irritation. H335 May cause respiratory irritation. H May cause drowsiness or dizziness.
Methyl Acetate	40-45%	79-20-9	H225 Highly flammable liquid and vapor. H319 Causes serious eye irritatin. H335 May cause respiratory irritatin. H336 May cause drwsiness or dizziness.
*Methy Alcohol	2.16	67-56-1	H225 Highly flammable liquid and vapor. H301 Toxic if swallowed. H311 Toxic in contact with skin. H331 Toxic if inhaled. H360 May damage fertility or the unborn child. H362 May cause harm to breast-fed children. H370 Causes damage to organs.
*4-Methyl-2-pentanone	1.11	108-10-1	H225 Highly flammable liquid and vapor. H319 Causes serious eye irritation. H332 Harmful if inhaled. May cause respratory irritation.

* Toxic chemical subject to the reporting requirements of section 313 of Title III and of 40 CFR 372.

4. FIRST AID MEASURES

EYES : Immediately flush eyes with water. Flush eyes with water for a minimum of 15 minutes, occasionally lifting and lowering upper lids. Get medical attention promptly.

SKIN : Wash with soap and water. Get medical attention if irritation develops or persists. Remove contaminated shoes and clothes and clean before reuse.

INGESTION : DO NOT induce vomiting. Get medical attention immediately.

INHALATION : Rescuers should put on appropriate protective gear. Remove from area of exposure. If not breathing, give artificial respiration. If breathing is difficult, give oxygen. Keep victim warm. Get immediate medical attention.

MOST IMPORTANT SYMPTOMS AND EFFECTS, BOTH ACUTE AND DELAYED

SYMPTOMS : May cause drowsiness or dizziness.

EFFECTS : Significant exposure to this chemical may adversely affect people with chronic disease of the respiratory system, central nervous system, kidney, liver, skin, and/or eyes.

5. FIRE FIGHTING MEASURES

SUITABLE EXTINGUISHING MEDIA : Water mist or fog, dry chemical, foam, carbon dioxide.

FIRE FIGHTING PROCEDURES : As in any fire, wear self-contained breathing apparatus pressure-demand (MSHA/NIOSH approved or equivalent) and full protective gear. Use water with caution. Material will float and may ignite on surface of water. Water may be ineffective in fighting the fire. Water spray to cool containers or protect personnel. Use with caution. Water runoff can cause environmental damage. Dike collect water used to fight fire. Small fires: carbon dioxide or dry chemical. Large fire: alcohol-type aqueous film-forming foam or water spray.

UNUSUAL FIRE AND EXPLOSION HAZARD : Flammable liquid and vapor. Vapors can travel to a source of ignition and flash back. Empty containers retain product residue (liquid and/or vapor) and can be dangerous. DO NOT pressurize, cut, weld, braze, solder, grind or expose such containers to heat, flame, sparks, static electricity, or other sources of ignition. Also, do not reuse container without commercial cleaning or reconditioning.

COMBUSTION PRODUCTS : During combustion carbon monoxide and/or carbon dioxide may be formed.

6. ACCIDENTAL RELEASE MEASURES

SMALL SPILL : Eliminate all sources of ignition. Provide good ventilation and minimize the breathing of vapors and avoid skin contact. Dike spill area and absorb the spilled liquid with earth, sawdust or a commercially available absorbent. Shovel spent absorbent into recovery or salvage drums for appropriate disposal.

LARGE SPILL : Wear appropriate personal protective equipment. Eliminate all ignition sources. Prevent additional discharge of material if able to do so safely. Do not touch or walk through spilled material. Avoid runoff into storm sewers and ditches which lead to waterways. Ventilate

spill area. Stay upwind of spill. Use only non-combustible material for cleanup. Use clean, non-sparking tools to collect absorbed materials. Absorb spill with inert material (e.g. dry sand, earth or sawdust), then place in a chemical waste collector.

EMERGENCY PRECAUTIONS : Eliminate ignition sources. Avoid large exposures to vapors.

7. HANDLING AND STORAGE

PRECAUTIONS FOR SAFE HANDLING : Use only in a well ventilated area. Avoid breathing vapor, fumes, or mist. Avoid contact with eyes, skin, and clothing. Ground and bond containers when transferring material. Use spark-proof tools and explosion proof equipment. Always open containers slowly to allow any excess pressure to vent. Follow all SDS/label precautions even after containers are emptied because they may retain product residues.

CONDITIONS FOR SAFE STORAGE, INCLUDING INCOMPATIBILITIES : Keep away from heat, sparks, and flame. Store containers in a cool, well ventilated place. Keep container closed when not in use.

8. EXPOSURE CONTROLS\PERSONAL PROTECTION

EXPOSURE LIMITS

Components	CAS	Limits
Ethanol	64-17-5	ACGIH TLV 1000 PPM TWA OSHA VPEL 1000 PPM TWA
Methyl Acetate	79-20-9	OSHA TWA 200 PPM ACGIH PEL 200 PPM
*Methy Alcohol	67-56-1	ACGIH TLV 200 PPM OSHA PEL 200 PPM
*4-Methyl-2-pentanone	108-10-1	OSHA PEL 50 PPM TWA ACGIH TLV 50 PPM TWA

OSHA TABLE COMMENTS:
NE = Not Established

ENGINEERING CONTROLS : Engineering controls should be in place to minimize exposure to vapors and any ignition sources.

PERSONAL PROTECTIVE EQUIPMENT

EYES AND FACE : Wear safety glasses with side shields, goggles, or a face shield.

SKIN : Wear impervious gloves to prevent contact with skin. Wear protective gear as needed - apron, suit, boots.

RESPIRATORY : NIOSH/MSHA approved respirators may be necessary if airborne concentrations are expected to exceed exposure limits.

WORK HYGIENIC PRACTICES : Do not eat, drink, or smoke in areas where this material is used. Avoid breathing vapors. Remove contaminated clothing and wash before reuse. Wash thoroughly after handling. Wash hands before eating.

OTHER USE PRECAUTIONS : Facilities storing or utilizing this material should be equipped with an eyewash facility and a safety shower.

9. PHYSICAL AND CHEMICAL PROPERTIES

APPEARANCE : Liquid

ODOR : Typical

ODOR THRESHOLD : Not determined.

pH : Not determined.

MELTING POINT/FREEZING POINT: Not determined.

INITIAL BOILING POINT : 135.0 F **BOILING RANGE:** Not determined.

FLASH POINT AND METHOD : 10ºF(-12ºC)
SETAFLASH CLOSED CUP

EVAPORATION RATE: Not determined.

FLAMMABILITY (SOLID,GAS): Not determined.

EXPLOSIVE LIMITS : 1.2 TO 36.0

VAPOR PRESSURE : Not determined.

VAPOR DENSITY : Heavier than air

SPECIFIC GRAVITY : 0.9275724

SOLUBILITY: Not determined.

PARTITION COEFFICIENT: N-OCTANOL/WATER: Not determined.

AUTO-IGNITION TEMPERATURE : Not determined.

DECOMPOSITION TEMPERATURE: Not determined.

VISCOSITY: Semi-viscous.

VOC EPA METHOD 24 : 2.2599274 **lb/gal**

10. STABILITY AND REACTIVITY

STABILITY : No information available.

CONDITIONS TO AVOID : Avoid impact, friction, heat, sparks, flame and source of ignition.

INCOMPATIBLE MATERIALS : Prevent contact with strong oxidizing agents.

HAZARDOUS DECOMPOSITION PRODUCTS: During combustion carbon monoxide and/or carbon dioxide may be formed.

HAZARDOUS POLYMERIZATION : No information available.

11. TOXICOLOGICAL INFORMATION

SIGNS AND SYMPTOMS OF OVEREXPOSURE :

ACUTE EFFECTS :

EYE : Causes eye irritation.

SKIN : Causes skin irritation. Prolonged or repeated contact can result in defatting and drying of the skin which may result in skin irritation and dermatitis (rash).

INHALATION : Vapors are irritating to nasal passages and throat. High concentrations can cause stupor and headaches. May cause dizziness and drowsiness.

INGESTION : Irritating to mouth, throat, and stomach. May cause headache. May cause dizziness and drowsiness and/or stupor.

CHRONIC EFFECTS : Significant exposure to this chemical may adversely affect people with chronic disease of the respiratory system, central nervous system, kidney, liver, skin, and/or eyes.

Primary Route(s) of Entry: Eye Contact, Ingestion, Inhalation, Skin Contact

ACUTE TOXICITY VALUES : The acute effects of this product have not been tested. Data on individual components are listed below.

CAS Number	TEST
64-17-5	Oral LD50:>7,060 mg/kg, Dermal LD50:>1,440 mg/kg, Vapor LC50:>19,977.18,
79-20-9	Oral LD-50:(Rat):6,482 mg/kg, Dermal LD-50: (Rabbit):>2,000 mg/kg, LC50 (Rat, 4h): >49 mg/L,
67-56-1	Oral LD50:>2528 mg/kg, Dermal LD50:17100 mg/kg, Vapor LC50:128.2,
108-10-1	Oral LD50:>2,080 mg/kg, Dermal LD50:>2,000 mg/kg, Vapor LC50: 16.4 mg/L,

12. ECOLOGICAL INFORMATION

ECOTOXICOLOGICAL INFORMATION: Information not available on mixture. Information on individual components is listed below if available.

CAS Number	TEST
64-17-5	No Information available.
79-20-9	LC-50 (Fathead Minnow, 96 h): 320-399 mg/l, EC-50 (daphnid, 48 h): 1,027 mg/l, EC-50 (Selenastrum capiricomutum,72 h):>120 mg/., Biodegradation 70% (28d),
67-56-1	No information available
108-10-1	No information available

13. DISPOSAL CONSIDERATIONS

DISPOSAL METHOD : Dispose of waste in accordance with all local, state, and federal regulations.

14. TRANSPORT INFORMATION

UN NUMBER/ PROPER SHIPPING NAME/ TRANSPORT HAZARD CLASS/ PACKING GROUP :

15. REGULATORY INFORMATION

REGULATORY OVERVIEW: The regulatory data in section 15 is not intended to be all-inclusive, only selected regulations are represented.

TSCA: All components of this material are either listed or exempt from listing on the TSCA Inventory. This material contains no substances that are subject to TSCA 12(b) export notification.

SARA TITLE III (SUPERFUND AMENDMENTS AND REAUTHORIZATION ACT)
311/312/313 REPORTABLE INGREDIENTS: See Section 3.

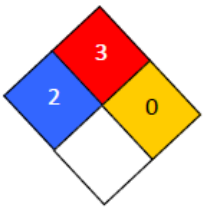
EPA HAZARDS:
FIRE : Yes **PRESSURE GENERATING :** No
REACTIVITY : No **ACUTE :** Yes **CHRONIC :** Yes

DSL: All components of this material are on or exempt from listing on the Canadian Domestic Substances List(DSL).

16. OTHER INFORMATION

HMIS RATING	
Health :	2
Flammability :	3
Reactivity :	1
Personal Protection :	G

NFPA CODES



HMIS and NFPA rating scale: (0=minimal hazard; 4=severe hazard)

REVISION INDICATOR : 9/25/18

MANUFACTURER DISCLAIMER : The foregoing data has been compiled from sources which the company, in good faith, believes to be dependable and is accurate and reliable to the best of our knowledge and belief. However, the company cannot make any warranty or representation respecting the accuracy or completeness of the data and assumes no responsibility for any liability or damages relating thereto or for advising you regarding the protection of your employees, customers, or others. User should consult OSHA and other applicable safety laws and regulations before use.

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