



FINAL REPORT

Qualification, Demonstration, & Validation of Non-Hazardous Solvent to Clean Composite Aircraft Components

ESTCP Project 14E WP4-034

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14. ABSTRACT This project evaluated the compatibility of NAVSOLVE™, a low-VOC/HAP-free cleaner, with common polymer matrix composites, adhesives, sealants, paints, and core materials individually and as assembled in aircraft structure. Completed tasks included: approved a new polymer/polymer matrix composite (PMC) cleaner specification MIL-PRF-32597, "Cleaner, Polymer and Polymer Matrix Composite Material, Non-Aqueous, HAP-Free"; qualified NAVSOLVE™ to the new specification through established mechanical test methodologies; measured the efficiency of removing hydraulic fluid from composite surfaces and from within core structure compared to existing cleaners; demonstrated cleaning and post-clean repair capability at multiple NAVY, AIR Force, and Army field sites; and documented processing steps for inclusion in depot specific Local Process Specifications (LPS) and Structural Repair Manuals (SRM). The project verified that long term exposure to NAVSOLVE™ did not degrade mechanical properties and/or repair capability of composites, adhesives and core materials used for fabrication of aircraft structures. Site demonstrations validated the ability of NAVSOLVE™ to be successfully substituted for current solvents called out in the respective depot procedures for cleaning and follow-on bonded repairs. NAVSOLVE™ effectively cleaned hydraulic fluid from honeycomb core without leaving a residue which could degrade the repair step. Savings are realized through reduced costs of hazardous waste disposal of current solvents and the increased ability to clean & repair contaminated composite parts resulting in reduced scrap rates and their associated disposal/replacement costs. Use of NAVSOLVE™ permits compliance with current and emerging federal and state clean air regulations and reduces the environmental footprint of scrapped parts that are currently buried in landfills.					
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List of Acronyms and Symbols

ACO	Advanced Composite Office
AFB	Air Force Base
AFRL	Air Force Research Lab
AMC	Army Materiel Command
AMCOM	Aviation and Missile Command
AMRDEC	Aviation and Missile Research Development and Engineering Center
ASTM	American Society of Testing Materials
AVIM	Aviation Intermediate Maintenance
BMI	Bismaleimide
CA	California
CAA	Clean Air Act
CLS	Compression Lap Shear
CSFWP	Commander Strike Fighter Wing, Pacific
DLA	Defense Logistics Agency
DoD	Department of Defense
DVD	Double Vacuum De-bulk
EPA	Environmental Protection Agency
ESTCP	Environmental Strategic Technology Certification Program
FRC-E	Fleet Readiness Center - East (Cherry Point)
FRC-SE	Fleet Readiness Center - South East (Jacksonville)
FRC-SW	Fleet Readiness Center - South West (North Island)
FTIR	Fourier Transform Infrared
FWT	Flatwise Tension
g/L	grams per Liter
HAP	Hazardous Air Pollutant
HAZMAT	Hazardous Material
IAW	In accordance with
IRAC	Interim Rapid Action Change
ISR	In Service Repair
JSF	Joint Strike Fighter
LPS	Local Process Specification
LO	Low Observable
MAG	Marine Aircraft Group
MACG	Marine Air Control Group
MALS	Marine Aviation Logistics Squadron
MAW	Marine Aircraft Wing
MCC	Mobile Calibration Complex
MCAS	Marine Corp Air Station
MEF	Marine Expeditionary Force
MEK	Methyl Ethyl Ketone
MIBK	Methyl Isobutyl Ketone
MLG	Main Landing Gear
MPK	Methyl Propyl Ketone
MWSS	Marine Wing Support Squadron

NAS	Naval Air Station
NAVAIR	Naval Air Systems Command
NDI	Non-Destructive Inspection
NISE	Naval Innovative Science and Engineering
NSN	National Stock Number
ODS	Ozone Depleting Substance
O&M	Operations and Maintenance
OO-ALC	Ogden - Air Logistics Center
PATTI	Pneumatic Adhesion Tensile Testing Instrument
PDM	Phased Depot Maintenance
PI	Principal Investigator
PIF	Prototype Integration Facility
PMC	Polymer-Matrix Composite
PMI	Planned Maintenance Interval
POC	Point of Contact
POTS	Pull Off Tensile Strength
OML	Outer Mold Line
QPD	Qualified Products Database
QPL	Qualified Products List
SCAQMD	South Coast Air Quality Management District
SRM	Structural Repair Manual
TASMG	Theater Aviation Sustainment Maintenance Group
TRC	Technology Research Center
UAV	Unmanned Aerial Vehicle
VARTM	Vacuum Assisted Resin Transfer Molding
VLCOE	Vertical Lift Center of Excellence
VOC	Volatile Organic Compound

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ABSTRACT

Introduction and Objectives

The objective of this project was to qualify and transition NAVSOLVE™, an environmentally compliant non aqueous cleaner, for the efficient removal of hydraulic fluid, heavy grease, and other contaminants from Department of Defense (DoD) aircraft composite structures. Existing compliant solvents are ineffective and, at best, inefficient at removing these contaminants. Hydraulic fluid ingress into honeycomb core often precludes repairs of composite structure resulting in high part scrap rates. Declining budgets, high costs for composite structure, inconsistent availability of spare parts, and environmental regulations restricting the use of more effective high volatile organic compound (VOC)/hazardous air pollutant (HAP) solvents severely impact DoD aircraft platforms which are incorporating a greater percentage of these light weight structural materials.

Technology Description

To meet emerging environmental regulations, the Aerospace Materials Division at Naval Air Warfare Center (NAWC) Patuxent River developed NAVSOLVE™, a low VOC, HAP-free cleaner that meets the performance requirements of MIL-PRF-32295B Type I and Type II for aircraft structural and engine metal components. This project extended that work by evaluating the compatibility of NAVSOLVE™ with the polymer matrix composites, adhesives, sealants, paints, and core materials individually and as assembled in a structure for use on DoD aircraft. The effort validated successful NAVSOLVE™ substitution for current hazardous solvents in approved DoD cleaning and repair procedures through end user site demonstrations. To support transition the project also established a new MIL specification, MIL-PRF-32597- “Cleaner, Polymer and Polymer Matrix Composite (PMC) Material, Non-Aqueous, HAP-Free” approving NAVSOLVE™ for use on aircraft composites.

Performance and Cost Assessment

Coupon-level testing verified that long-term exposure to NAVSOLVE™ did not degrade the mechanical properties and/or repair capability of composites or the adhesives and core materials used for fabrication and repair of structures. Site demonstrations validated the ability of the NAVSOLVE™ cleaner to be successfully substituted for current solvents called out in the respective depot composite repair procedures/local process specifications (LPSs). Savings are realized not only through reduced costs of hazardous waste disposal associated with current solvents, but through an increased ability to clean and repair contaminated composite parts resulting in reduced scrap rates and their associated disposal/replacement costs. Use of NAVSOLVE™ permits compliance with current and emerging federal, state, and local government regulations on solvents, improves mission readiness by reducing aircraft downtime for repair/replacement of parts, and reduces the environmental footprint of scrapped composite parts due to failed bonded repairs that are currently buried in landfills.

Implementation Issues

No additional equipment or materials are required for implementation of NAVSOLVE™. to the composite shops in the Services’ aircraft maintenance facilities. The cleaner has been qualified to MIL-PRF-32295B and the new MIL-PRF-32597 specifications. NAVSOLVE™ is commercially available from two vendors: Armick Chemicals in Grand Rapids, MI and Ecolink in Tucker, GA.

EXECUTIVE SUMMARY

1 Introduction

In an operational environment, aircraft composite structures become exposed to a range of liquid contaminants including fuels, oils, lubricants, and hydraulic fluids. As aircraft age, this problem is exacerbated, as damaged reservoirs and lines leak operational fluids into open regions, particularly core cells of composite honeycomb structures. While the majority of these fluids are not inherently damaging to the structural materials, residual fluids interfere with adhesively bonded patch repairs. These contaminants must be cleaned from a damaged part before any inspection or repair processes can be performed. Many of these parts are in proximity to essentially perpetual hydraulic leaks (e.g., landing gear and control surface actuators) such that frequent exposure is inevitable. Hydraulic fluid is absorbed through the paint/primer layers into the composite skin and can fill the underlying honeycomb core cells as well as cracks, micro-cracks, pores, and crevices common in legacy aircraft. The difficulty in cleaning hydraulic fluid from composite parts is due to the fluid's propensity to rapidly "creep back" or re-wet a cleaned or sanded composite surface. This surface recontamination is accelerated by both the elevated temperatures and vacuum bagging procedures utilized in standard bonded composite repair (see Figure 1 and Figure 2).

The solvents currently used to remove hydraulic fluid contamination include acetone, isopropyl alcohol, MEK, MIBK, and hexane. Multiple DoD bases in several Air Pollution Control Districts in California, though, are restricted from using high VOC/HAP containing MEK, MIBK, and hexane. The current compliant solvents (acetone, isopropyl alcohol) for removal of hydraulic fluid (primarily MIL-PRF-83282) and other contaminants from polymer matrix composite aircraft structures are ineffective and, at best, inefficient at removing these contaminants particularly when there has been ingress into honeycomb core. Ineffective removal of hydraulic fluid results in failed bonded repairs of composite structure resulting in high scrap rates of expensive parts (\$50K-\$250K). Declining budgets, high costs for composite structure, inconsistent availability of spare

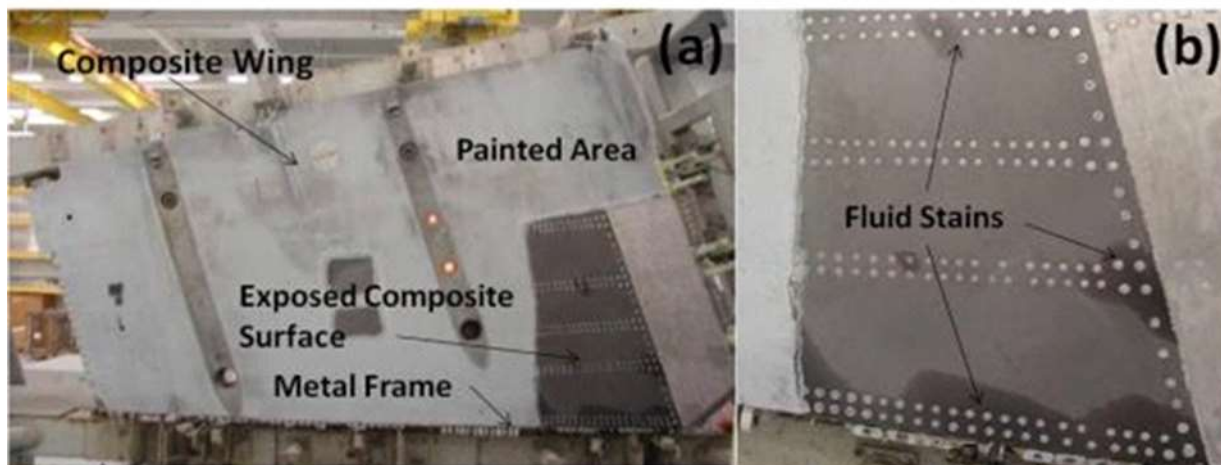


Figure 1. (a) Aircraft composite wing section with de-painted region and (b) close-up of re-contaminated sanded composite surface

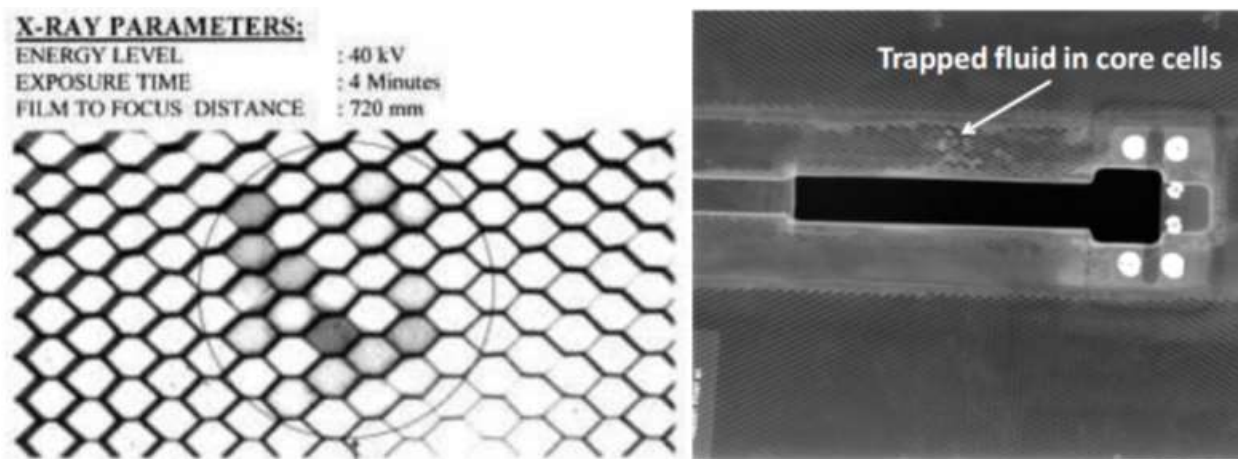


Figure 2. X-ray transmission images of fluid in honeycomb cells

parts, and environmental regulations restricting use of more effective high volatile organic compound (VOC)/hazardous air pollutant (HAP) solvents severely impact Department of Defense (DoD) aircraft platforms as they increase use of these light weight structural materials.

2 Objectives

The objective of this project was to qualify and transition NAVSOLVE™, an environmentally compliant cleaning solvent, for the efficient removal of hydraulic fluid and other contaminants from DoD aircraft composite structures. To accomplish this objective, the following tasks were performed: 1) assessed compatibility of NAVSOLVE™ with common polymer matrix composites, adhesives, and core materials individually and as assembled in a structure, 2) measured the efficiency of removing hydraulic fluid from composite surfaces and from within core structure compared to existing cleaners, 3) demonstrated post-clean bonded repair capability in the lab and at field sites, and 4) documented processing steps for inclusion in Local Process Specifications (LPS) and Structural Repair Manuals (SRM). NAVSOLVE™ is currently approved to MIL-PRF-32295B. As MIL-PRF-32295B is focused on cleaners for metal parts, the project identified a DoD wide requirement for a cleaner specification exclusive to fiber reinforced PMC's as composite mechanical tests to support qualification are fundamentally different from that of metallic materials. To support this need, an additional project task was to compose and publish a new MIL specification, MIL-PRF-32597- "Cleaner, Polymer and Polymer Matrix Composite (PMC) Material, Non-Aqueous, HAP-Free" specifically for PMC materials and qualify NAVSOLVE™ to the new specification.

3 Technology Description

The DoD has numerous facilities across the United States (US) and outside the continental US (OCONUS) affected by current and anticipated DoD Directives and federal, state, and local regulation concerning hazardous cleaners containing VOC's and HAP's. Executive Order 13834 mandates government agencies to measure, report, and reduce the greenhouse gas emissions from direct and indirect activities. The DoD "Strategic Sustainability Performance Plan" outlines

numerous directives for the DoD to comply with by an out date. The Agency Level Toxic and Hazardous Chemicals Reduction Plan (DoD EO 13423) also sets out goals to reduce procurement, use, release, and disposal of toxic and hazardous chemicals and materials. Under Title III of the 1990 Clean Air Act (CAA) amendments, the U.S. Environmental Protection Agency (EPA) has established emissions standards for categories and sub-categories of sources that emit or have the potential to emit listed HAPs. In addition, Air Pollution Control Districts in California have implemented the most stringent requirements, usually stated in terms of VOC content. Sixteen Air Quality Districts in California have solvent cleaning VOC limits of less than 25 g/L which applies to over sixteen DoD bases with a range of fixed and rotary wing aircraft. The VOC restriction limits the use of solvents with VOC content to 25g/L for immersion cleaning processes or limiting equipment to airtight cleaning systems. Other states have followed California's example and have formed regional air quality groups that follow stricter regulations than those currently set at the federal level. These states include: Illinois, Indiana, Ohio, Michigan, Minnesota, Wisconsin, Pennsylvania, Maryland, Delaware, New Jersey, New York, Connecticut, Rhode Island, Massachusetts, New Hampshire, Maine, and the District of Columbia.

To meet these emerging environmental regulations, the Aerospace Materials Division at the Naval Air Warfare Center, Patuxent River (NAVAIR) developed a new low VOC, HAP-free cleaner called NAVSOLVE™ that meets the low VOC/HAP-free environmental performance requirements of MIL-PRF-32295B Type II for metal components. This specification covers non-aqueous solvents that are free of HAPs and contain a low amount (no more than 25 grams per liter) of VOCs for cleaning aircraft components and ground support equipment. The properties of NAVSOLVE™ are listed in Table 1.below.

Table 1. Properties of NAVSOLVE™

Low VOC (19 g/L)	Non-Corrosive / Compatible with metals and non-metals
HAP free	Non-Toxic
Non-Ozone Depleting Substance	Recyclable
High Flash Point (140°F)	Cleaning Efficiency = Petroleum-Based Solvents
Non-Offensive Odor	Drying Time = Petroleum-Based Solvents

NAVAIR has updated the 01-1A-509 Aircraft Cleaning and Corrosion Control Technical Manual to incorporate MIL-PRF-32295B as an alternative to high VOC petroleum-based solvents for cleaning metal components. Before this ESTCP effort, the primary focus for NAVSOLVE™ has been in replacement of hazardous cleaners used in assorted metal part washers utilized at various aircraft maintenance facilities. During 2010-2013, NAVAIR conducted multiple field tests of NAVSOLVE™ for immersion cleaning of metal components at seven DoD sites (FRC Southeast, Jacksonville, FL; FRC Southwest, North Island, CA; Robins AFB, Warner Robins, GA; Fort Rucker Army Base, AL; NAS Lemoore, CA; 29 Palms Marine Corps Base, 29 Palms, CA; FRC-Support Equipment Facility, Solomon's Island, MD). The field tests were completed successfully. There is currently no cleaner qualified to MIL-PRF-32295B that has been validated for use on aircraft structural composites.

4 Performance Assessment

4.1 Coupon Level Mechanical Tests

Structural composite coupon-level testing verified that long-term exposure to NAVSOLVE™ did not degrade the mechanical properties and/or effect the repair capability of composites or the adhesives and core materials used for fabrication and repair of structures. The bulk laminate test matrix and results are listed in Table 2. The focus was on composites and repair materials used in next generation aircraft including the F-35, F-22, V-22, MQ-4C Triton, and H-53K. Success criteria was for specimens exposed to NAVSOLVE™ for fourteen days to have mechanical properties within the standard deviation of baseline control specimens. Tests used to assess compatibility with sealants included volume swell/weight gain per SAE AS5127/1, tensile strength and elongation per SAE AS5127/1, and hardness per ASTM D2240.

Table 2. Performance Objectives – Bulk Laminate Tests

Laminate Test Method	Laminate Type	Success Criteria	Results
Short Beam Shear Test per ASTM D2344	IM7/977-3	NAVSOLVE™ results fall within standard deviation of baseline	Passed
	IM7/5250-4		
	IM7/8552		
Flexure Test per ASTM D7264	IM7/977-3		
	IM7/5250-4		
	IM7/8552		
±45 Tension (In-Plane Shear) Test per ASTM D3518	IM7/977-3		
	IM7/5250-4		
	IM7/8552		
Open Hole Compression Test per ASTM D6484	IM7/977-3		
	IM7/5250-4		
	IM7/8552		
Sealant Test Method	Sealant Type	Success Criteria	Results
Hardness per ASTM D2240	PR-1826	NAVSOLVE™ results fall within standard deviation of baseline	Passed
Tensile/Elongation per AS5127/1 (7.7)	PR-1826	NAVSOLVE™ knockdown less than Acetone	NAVSOLVE™ knockdown is less than Acetone
Weight Loss and Volume Swell per AS5127/1 (7.5)	PR-1826	NAVSOLVE™ results fall within standard deviation of baseline	Passed

The bonded property test matrix and results are summarized in Table 3. To better capture any environmental contributions to the mechanical tests and/or potential synergistic degradation effects, a subset of the test specimens were moisture saturated in a humidity chamber before exposure to NAVSOLVE™. As most NAVY aircraft are sea based, the composite structure is moisture

saturated. Also, as a primary goal of the project is to clean hydraulic fluid contamination from honeycomb core, after specimen preparation, a subset of the specimens were saturated with hydraulic fluid (MIL-PRF-83282) before NAVSOLVE™ exposure.

Table 3. Performance Objectives – Bonded Property Tests

Test Method	Laminate / Core	Adhesive	Success Criteria	Results
Flatwise Tension per ASTM C297	IM7/977-3 / SynCore	N/A	NAVSOLVE™ results fall within standard deviation of baseline	Passed
	IM7/977-3 / Nomex	FM 300		
	IM7/977-3 / Kevlar	FM 300-2		
	IM7/8552 / Nomex	AF 163-2K		
Single Lap Shear per ASTM D5868	IM7/977-3	EA 9394NA		
	IM7/977-3	FM 300-2		
	IM7/5250-4	AF 191		
	IM7/8552	EA9690		
Single Lap Shear per ASTM D1002	Aluminum	FM 300-2		
	Aluminum	AF 163-2K		
	Aluminum	EA 9360		
	Aluminum	EA 9309.3		

4.2 Field Tests and Demonstrations

Site demonstrations validated the ability of the NAVSOLVE™ cleaner to be successfully substituted for current solvents called out in the respective depot composite repair procedures or local process specifications (LPSs). The sites selected corresponded with locations stakeholders determined were primary DoD aircraft composite repair sites for current and next generation composite aircraft including the F/A-18, F-35, F-22, V-22, H-53K, and MQ-4C Triton, or were located in California restrictive air quality control districts. The test sites in the program and the aircraft platforms represented included: Fleet Readiness Center-Southeast (FRC-SE) at Jacksonville Naval Air Station (NAS), Florida for the F/A-18, Predator, and MQ-4C repairs; Hill Air Force Base (AFB) in Ogden, Utah for F-35 and F-22 repairs; Prototype Integration Facility (PIF) at the Army's Redstone Arsenal, Alabama for H-47 repairs; NAS Lemoore, California (CA); Marine Corp Base Camp Pendleton, CA; and Army 1106th Theater Aviation Sustainment Maintenance Group (TASMG), Hammer Field Armory in Fresno, CA for V-22 and UH-60. The six field test sites were key customers for transition to NAVSOLVE™ for use on composite aircraft structure.

The performance criteria for the site demonstrations are listed in Table 4 and Table 5. The field tests were comprised of aircraft part cleaning demonstrations (as certain aircraft maintenance sites in CA are not approved to perform bonded repairs on composite parts), clean and repaint trials, and bonded repair demonstrations. NAVSOLVE™ effectively cleaned hydraulic fluid from honeycomb core without leaving a residue that could degrade the adhesive cure step in composite repair. Furthermore, NAVSOLVE™ did not leave a residue on a composite surface that would interfere with part repaint operations.

Table 4. Performance Objectives – Part Cleaning Demonstrations

Demonstration	Test Method	Data Requirements	Success Criteria	Results
Hill AFB F-35 BMI Panel Cleaning for Repaint	Water break	T.O. 1-1-8	Pass water break inspection	Passed
	PATTI	ASTM D4541	Failure at primer interface	Passed
	Paint Adhesion Tape Test	ASTM D3359	No peel or removal of paint	Passed
TASMG H-60 Part Cleaning for Repaint	Paint Adhesion Tape Test	TM 1-1500-345-23; 4-16B	No peel or removal of paint	Passed
Lemoore F/A-18 Door Cleaning	Feedback from shop floor Marine	N/A	No additional training required	Passed
Pendleton MCAS Composite Intercostal & Rotor Hub Cleaning	Feedback from shop floor Serviceman	N/A	No additional training required	Passed
Hill AFB F-35 Door Cleaning	Water break	T.O. 1-1-8	Pass water break inspection	Passed

Table 5. Performance Objectives – Bonded Repair Demonstrations

Demonstration	Test Method	Data Requirements	Success Criteria	Results
Redstone H-47 Blade Bonded Repair	PATTI	ASTM D4541	Honeycomb core failure	Passed
	Tap Test	TM 1-1500-345-11; Section 7	Pass tap test	Passed
FRC-SE UAV Wing Repair	PATTI	ASTM D4541	Honeycomb core failure	Passed
NAVSOLVE™ ease of use vs current shop cleaners	Feedback from shop floor artisans	N/A	No additional training required	Passed

Figure 3 shows the NAVSOLVE™ cleaning demonstration on an F/A-18 at Lemoore NAS while Figure 4 illustrates cleaning assorted V-22 parts at Marine Corps Base Camp (MCAS) Pendleton. Figure 5 shows a novel vacuum assisted cleaning demonstration with NAVSOLVE™ on an aircraft door at Hill AFB. Two composite bonded repair demonstrations using NAVSOLVE™ were performed by composite repair artisans on scrap H-47 composite blade sections at the Prototype Integration Facility (PIF), Army Redstone Arsenal. One repair demonstration used a heated bladder clamp to apply the necessary pressure to cure the adhesive bonded pre-cured composite patches. This repair process was typical for helicopter composite blade repair in the field. Tap tests were performed on the final repair bonds to identify any defects in adhesive/core bond caused by using NAVSOLVE™ cleaner instead of the approved solvent. Figure 6 shows the steps in the helicopter blade repair demonstration.



Figure 3. Cleaning demonstration with NAVSOLVE™ of F/A-18 bay on flight-line at NAS Lemoore



Figure 4. Cleaning demonstration on V-22 composite parts at MCB Camp Pendleton



Figure 5. Steps in vacuum assisted cleaning demonstration with NAVSOLVE™ at Hill AFB



Figure 6. Steps in bonded patch repair of helicopter composite blade section using bladder clamp

NAVAIR Fleet Readiness Center South-East utilized a scrapped unmanned air vehicle (UAV) composite wing section for the NAVSOLVE™ cleaning followed by bonded repair demonstration. Figure 7 illustrates the steps in the UAV composite wing section repair demonstration.

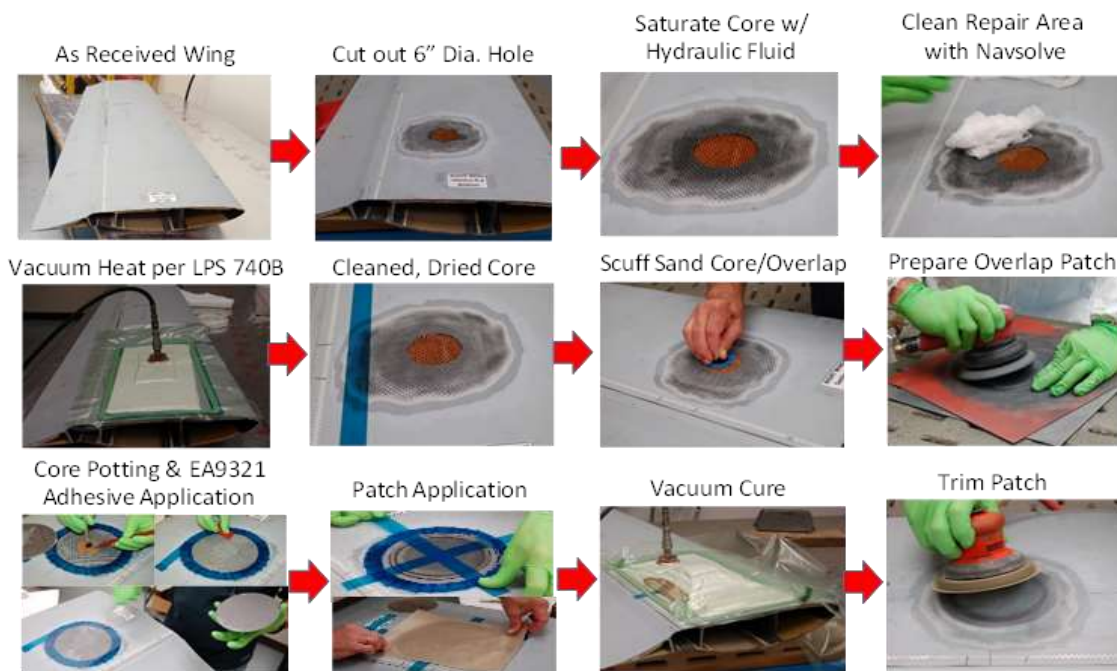


Figure 7. UAV composite wing section cleaning/repair demonstration

For this demonstration, first a section of the test article had its face-sheet removed and the area saturated with hydraulic fluid. The contaminated area was then cleaned with NAVSOLVE™ replacing the current solvent referenced in the SRM procedures. The test article was then vacuum heat treated to dry the repair area and remove any residual hydraulic fluid. After heat treatment, inspection of the repair area and breather cloth found no indication of residual hydraulic fluid. An adhesive bonded patch repair was then successfully cured onto the scrap part. The integrity of the adhesive bond was verified with several PATTI pull test on the repair patch.

5 Cost Assessment

Savings will be realized not only through reduced costs of hazardous waste disposal associated with current solvents, but also through an increased ability to clean and repair contaminated composite parts resulting in reduced scrap rates and associated disposal/replacement costs. Use of NAVSOLVE™ will permit compliance with current & emerging EPA, state, and local government regulations on solvents, improve mission readiness by reducing aircraft downtime, and reduce the environmental waste footprint of scrapped composite parts due to failed bonded repairs that are currently buried in landfills.

6 Implementation Issues

The transitioned technology will provide an efficient and environmentally compliant means to clean composite aircraft components. No additional equipment is needed and no scale up issues restrict transition to the composite shops in the Services aircraft maintenance facilities. Future efforts to implement NAVSOLVE™ in fleet composite maintenance and repair activities will require updates to associated local process specifications, Tech Orders, and/or process documentation at each respective facility. A first step for the NAVY is to update the General Composite Repair Manual (NAVAIR 01-1A-21) approving use of NAVSOLVE™ for certain procedures. Both Air Force and NAVAIR stakeholders for fixed wing fighter aircraft (ex. F-22, F35) indicated NAVSOLVE™ must also be qualified for use on low observable materials before use on these specific aircraft components. A current, funded DLA effort is performing this qualification.

1 INTRODUCTION

1.1 BACKGROUND

Lightweight, continuous fiber reinforced polymer matrix composites (PMC's) have been an enabling structural material for defense aircraft providing a unique combination of a high stiffness to weight ratio, corrosion resistance, and improved fatigue properties compared to metal parts. In an operational environment, though, aircraft composite structures become exposed to a range of liquid contaminants including fuels, oils, lubricants, and hydraulic fluids (typically MIL-PRF-83282 [1]). As aircraft age, this problem is exacerbated, as damaged reservoirs and lines leak operational fluids into open regions, particularly core cells of composite honeycomb structure. While the majority of these fluids are not inherently damaging to the structural materials, residual fluids interfere with adhesively bonded patch repairs. These contaminants must be cleaned from a damaged composite part before any inspection or repair processes can be performed. Many of these parts are in proximity to essentially perpetual hydraulic leaks (e.g., landing gear and control surface actuators) such that frequent exposure is inevitable. Hydraulic fluid is absorbed through the paint/primer layers into the composite skin and can fill the underlying honeycomb core cells as well as cracks, micro-cracks, pores, and crevices that are common in legacy aircraft. The difficulty in cleaning hydraulic fluid from composite parts is due to the fluid's propensity to rapidly "creep back" or re-wet a solvent cleaned or sanded composite surface. This surface recontamination is accelerated by both the elevated temperatures and vacuum bagging procedures utilized in standard bonded composite repair.

The solvents currently used to remove hydraulic fluid contamination include acetone, isopropyl alcohol, MEK, MIBK, and hexane. However, multiple DoD bases in several Air Pollution Control Districts in California, restrict the use of high VOC/HAP containing MEK, MIBK, and hexane. The current compliant solvents (acetone, isopropyl alcohol) for removal of hydraulic fluid are ineffective and, at best, inefficient at removing these contaminants particularly when there has been ingress into honeycomb core. Ineffective removal of hydraulic fluid results in failed bonded repairs of composite structure resulting in high scrap rates of expensive parts (\$50K-\$250K). In the future, it is anticipated more states will enact the CA clean air restrictions effecting additional DoD bases. Declining budgets, high costs for composite structure, inconsistent availability of spare parts, and environmental regulations restricting use of more effective high VOC/HAP solvents (MEK, MIBK, hexane) are severely impacting DoD aircraft platforms as they increasingly incorporate into their designs these light weight structural materials.

This project demonstrated an alternate, environmentally compliant, low VOC, HAP free cleaner called NAVSOLVE™ for the effective cleaning of hydraulic fluid and other contaminants from aircraft composite structure. The demonstrations validated the compatibility of NAVSOLVE™ with common polymer matrix composites, adhesives, and core materials assembled in a structure. Structural composite coupon-level testing verified that long-term exposure to NAVSOLVE™ did not degrade mechanical properties and/or repair capability of composites or the adhesives and core materials used for fabrication and repair of structures. Site demonstrations validated the ability of the NAVSOLVE™ cleaner to be successfully substituted for current solvents called out in the respective depot composite repair procedures or local process specifications (LPSs). NAVSOLVE™ effectively cleaned hydraulic fluid from honeycomb core without leaving a

residue that could degrade the adhesive cure step in composite repair. Savings are realized not only through reduced costs of hazardous waste disposal associated with current solvents, but through an increased ability to clean and repair contaminated composite parts resulting in reduced scrap rates and their associated disposal/replacement costs. Use of NAVSOLVE™ permits compliance with current and emerging federal, state, and local government regulations on solvents, improves mission readiness by reducing aircraft downtime for repair/replacement of composite parts, and reduces the environmental footprint of scrapped composite parts due to failed bonded repairs that are currently buried in landfills.

1.2 OBJECTIVE OF THE DEMONSTRATION

To meet emerging environmental regulations, the Aerospace Materials Division at Patuxent River Naval Air Station developed a new low VOC, HAP-free cleaner known as NAVSOLVE™ that meets the performance requirements of MIL-PRF-32295B Type II for metal components [2-9]. There is currently no cleaner qualified to this specification that has been validated for use on aircraft structural composites, especially for removing fluid contamination from honeycomb core. This demonstration evaluated the compatibility of NAVSOLVE™ with common polymer matrix composites, adhesives, and core materials assembled in a structure. The effort also measured the efficiency of removing hydraulic fluid from composite surfaces and from within core structure compared to existing cleaners. In addition, the project demonstrated the post-cleaning repair capability of NAVSOLVE™ in the lab and at field sites and documented processing steps for future inclusion in LPS's and SRM's.

During the course of the project, a requirement was identified for a DoD wide cleaner specification exclusive to fiber reinforced PMC's as composite mechanical tests to support qualification are fundamentally different from that of metallic materials. To support this need a new MIL specification, MIL-PRF-32597- "Cleaner, Polymer and Polymer Matrix Composite (PMC) Material, Non-Aqueous, HAP-Free" was composed, approved, and published specifically for PMC materials and NAVSOLVE™ was qualified to the new specification. MIL-PRF-32597 is included in appendix B.

Several composite repair demonstrations with the NAVSOLVE™ cleaner were conducted at Navy, Marine Corp., Air Force, and Army maintenance facilities. The primary objective of the site demonstrations was to validate the ability of the NAVSOLVE™ cleaner to be successfully substituted for current solvents called out in the respective depot procedures for cleaning and repair of composite aircraft parts. Table 6 shows details of the targeted hazardous materials that were substituted for NAVSOLVE™, the relevant specifications which apply, and the aircraft parts on which the substitution were demonstrated. Artisans from the associated composite shops and flight-lines performed the cleaning and repairs, rather than engineers or researchers, to prove the robustness of the cleaner and verify the process in real-world industrial environments. Demonstrating this technology to the cognizant depot artisans, technicians, and engineers was the first step in the approval process for transferring the technology to the DoD end user.

The transitioned technology provides an efficient and environmentally compliant means to clean composite aircraft components. Savings will be realized not only through reduced costs of hazardous waste disposal associated with current solvents, but also through an increased ability to clean and repair contaminated composite parts resulting in reduced scrap rates and associated disposal/replacement costs. Use of NAVSOLVE™ will permit compliance with current &

emerging federal, state, and local government regulations on solvents, improve mission readiness by reducing aircraft downtime, and reduce the environmental waste footprint of scrapped composite parts due to failed bonded repairs that are currently buried in landfills.

Table 6. Target Hazardous Material (HazMat) Summary

Target HazMat	Current Process	Applications	Current Specifications	Affected Programs	Candidate Parts and Substrates
Acetone	Cleaning & Degrease of parts & bond surfaces; hydraulic fluid removal from core	Aircraft composite parts w/core: wings, doors control surfaces	NAVAIR 01-1A-509-2[10], SMP-0021M1[11], SMP-0021M5[12], SRP-1012 RevB[13], LPS 751B[14], T.O. 1-1-690[15], Aircraft Repair SRM's	V-22, F/A-18, F-35, H-53K, F-22, Global Hawk	UAV Wing Section
Isopropyl Alcohol	Composite surface cleaning for bonded repair	Aircraft composite parts w/core: wings, doors control surfaces	T.O. 1-1-690, NA 01-1A-509-2, TM 1-1500-204-23-11[16]	V-22, F/A-18, F-35, H-53K, F-22, Global Hawk	H47 Composite Blade, UAV Wing section
MIBK	Moisture/fluid removal from composite parts	Aircraft composite parts w/core: wings, doors control surfaces	LPS-NI-MATL1115 B[17], LPS 751B, NAVAIR 01-1A-21[18]	F-35, F/A-18 C/D/E/F/G	UAV Wing Section
MEK	Cleaning & Degrease of parts & bond surfaces for paint/primer	Aircraft composite parts w/core: wings, doors control surfaces	T.O. 1-1-8[19], T.O. 1-1-690, NAVAIR 01-1A-21	F-35, F-22, F/A-18 A/B/C/D/E/F,	Hill AFB F-35 parts, H-60 Door

1.3 REGULATORY DRIVERS

The DoD has numerous facilities across the United States (US) and outside the continental US (OCONUS) affected by current and anticipated DoD Directives and federal, state, and local regulation concerning hazardous cleaners containing VOC's. VOCs are organic chemical compounds that have sufficiently high vapor pressures under normal conditions to significantly vaporize, thereby entering the atmosphere. They are released during cleaning operations, contributing to the formation of ground-level ozone (photochemical smog), damaged vegetation, and potential harm to the lungs, liver, and kidneys. The US Environmental Protection Agency (EPA) and various state regional boards regulate VOC's in the air, water, and land. Executive Order EO 13514[20] mandated government agencies to measure, report, and reduce the

greenhouse gas emissions from direct and indirect activities. EO 13514 was replaced by Executive Order 13693, titled Planning for Federal Sustainability in the Next Decade, issued on March 19, 2015. EO 13693 was replaced by EO 13834 on May 17, 2018. The DoD "Strategic Sustainability Performance Plan" outlines numerous directives for the DoD to comply with by an out date. The Agency Level Toxic and Hazardous Chemicals Reduction Plan (DoD EO 13423) also sets out goals to reduce procurement, use, release, and disposal of toxic and hazardous chemicals and materials.

Under Title III of the 1990 Clean Air Act (CAA) amendments, the U.S. Environmental Protection Agency (EPA) has established emissions standards for categories and sub-categories of sources that emit or have the potential to emit listed HAPs. In addition, Air Pollution Control Districts in California have implemented the most stringent requirements, usually stated in terms of VOC content. Sixteen Air Quality Districts in California have solvent cleaning VOC limits of 25 g/L which apply to over sixteen DoD bases with a range of fixed and rotary wing aircraft. The VOC restriction limits the use of solvents with VOC content to 25g/L for immersion cleaning processes or limiting equipment to airtight cleaning systems (Rule 1171). The districts include The South Coast Air Quality Management District (SCAQMD) where Marine Corps Base Camp Pendleton and Miramar MCAS are located and at which several V-22 squadrons are stationed. The districts also includes the San Joaquin Valley Air Pollution Control District (SJVAPCD) which incorporates NAS Lemoore where several F/A-18 squadrons are stationed. If a substitute material or process is not authorized, maintenance facilities at these sites will not be able to perform specific maintenance requirements in accordance with the NAVAIR technical manuals. Under the new rule, high VOC petroleum-based solvents such as MIL-PRF-680 are no longer allowed in cleaning operations.

In the future these clean air restrictions are anticipated to be adopted by additional US states further impacting the military bases in those jurisdictions. Other states have followed California's example and have formed regional air quality groups that work to improve air quality for the region. The groups are the California Air Resources Board (CARB), the Lake Michigan Air Directors Consortium (LADCO) and the Ozone Transport Committee (OTC). The following states abide by stricter regulations than those currently set at the federal level: California (CARB), Illinois (LADCO), Indiana (LADCO), Ohio (LADCO), Michigan (LADCO), Minnesota (LADCO), Wisconsin (LADCO), Pennsylvania (OTC), Maryland (OTC), Delaware (OTC), New Jersey (OTC), New York (OTC), Connecticut (OTC), Rhode Island (OTC), Massachusetts (OTC), New Hampshire (OTC), Maine (OTC), and the District of Columbia (OTC).

2 DEMONSTRATION TECHNOLOGY

2.1 TECHNOLOGY DESCRIPTION

To meet the emerging environmental regulations, the NAVAIR Materials Engineering Division at Patuxent River developed a MIL-PRF-32295B specification entitled "Cleaner, Non-Aqueous, Low-VOC, HAP-Free" which was published in 2010. This specification covers non-aqueous solvents that are free of HAPs and contain a low amount (no more than 25 grams per liter) of VOCs for cleaning aircraft components and ground support equipment. Type I is suitable for cleaning light soils such as oils and hydraulic fluids and Type II is suitable for cleaning greases and carbon deposit. Type III is intended for wipe cleaning applications. The NSN's for the qualified products

for Type I have been issued and listed in the QPL for MIL-PRF-32295B; three products have been qualified. In addition, NAVAIR has developed through Defense Logistics Agency (DLA) funding, a new, Type II product known as NAVSOLVE™ with the primary focus on replacement of hazardous cleaners used in assorted metal part washers utilized at various aircraft maintenance facilities. Currently, NAVSOLVE™ is the only cleaner that meets the testing requirements of MIL-PRF-32295B Type II. The properties of NAVSOLVE™ are listed in Table 7 below:

Table 7. Properties of NAVSOLVE™

Low VOC (19 g/L)	Non-Corrosive / Compatible with metals and non-metals
HAP free	Non-Toxic
Non-Ozone Depleting Substance	Recyclable
High Flash Point (140°F)	Cleaning Efficiency = Petroleum-Based Solvents
Non-Offensive Odor	Drying Time = Petroleum-Based Solvents

As most petroleum-based solvent cleaners contain a high percentage of VOC contents (>700 g/l), non-petroleum materials such as siloxane fluids were identified to formulate NAVSOLVE™ with low-VOC emissions. Siloxane fluids are used mainly as one of the ingredients in personal care products such as shampoos, hair conditioners, and other bath and soap products. The properties of siloxane fluids used for formulating NAVSOLVE™ are VOC exempt, colorless, odorless, and safe to use. To protect the intellectual properties of the developed cleaner formulation, two patent applications were issued. The composition of NAVSOLVE™ is found in Table 8. The cleaner has been qualified to the MIL-PRF-32295B specification. NAVSOLVE™ is commercially available from two vendors: Armick Chemicals in Grand Rapids, MI and Ecolink in Tucker, GA

Table 8. Composition of NAVSOLVE™

Ingredient	Parts by Weight
Decamethylcyclopentasiloxane (Cyclo 2245)	53.3 %
Octamethyltetracyclosiloxane (Cyclo 2244)	38 %
Decamethyltetrasiloxane fluid (OS-30)	5.7 %
Dipropylene Glycol n-Butyl Ether (Dowanol DPnB)	2.5 %
Hexylene Glycol	0.4 %

NAVSOLVE™ and its components have been tested for its level of toxicity. Silicone products include three categories: silicone fluids, elastomers, and resins. Silicone fluids are used for a wide range of applications, silicone elastomers are mainly used for sealants and rubbers, and resins are mainly used for paints. The most common and the most investigated as to toxicity are octamethylcyclotetrasiloxane (D4) and decamethylcyclopentasiloxane (D5). These compounds are widely used in cosmetic products and maintenance products under the name cyclomethicone. NAVSOLVE™ consists of 30-40% octamethylcyclotetrasiloxane (D4), and 50-60% decamethylcyclopentasiloxane (D5).

In a two-year study by Dow Corning [21], rats were exposed to D5 by inhalation at levels up to the highest possible vapor concentrations. Data showed an increase in a benign uterine tumor in female rats exposed to the highest level. There were no findings in male rats. An expert panel of

independent scientist [22, 23] reviewed the research results and indicated that this mode of action is well recognized as being rat specific and not relevant to humans. Currently, there is no data to show similar results in humans. Therefore, the results of this study indicates that D5 does not represent a hazard to human health.

In 2011 the Navy and Marine Corps Public Health Center (Portsmouth, VA) performed a Health Hazard Assessment (HHA) of NAVSOLVE™ (included in Appendix C). The recommendations from the HHA on the use of NAVSOLVE™ for cleaning applications are listed below [24]:

- 1- NAVSOLVE™ consists of 30-40% octamethylcyclotetrasiloxane (D4), 50-60% decamethylcyclopentasiloxane (D5) and solvents (2 proprietary solvents totaling less than 5% by weight).
- 2- The health hazards associated with using NAVSOLVE™ mainly include eye and skin irritation. The organic solvents can affect the central nervous system, causing headache, fatigue or confusion. Since the percentage of solvents is low, such effects are not expected unless NAVSOLVE™ is heated or aerosolized.
- 3- The commercial uses of D4 products do not represent a human risk. However, laboratory inhalation studies using octamethylcyclotetrasiloxane have reported evidence of adverse reproductive effects in female rates.

Based on the above information and the MSDS for octamethylcyclotetrasiloxane (D4) [25] and decamethylcyclopentasiloxane (D5) [26] by Dow Corning, uses of products containing D4 and D5 do not represent a risk to humans.

NAVAIR has updated the 01-1A-509 Aircraft Cleaning and Corrosion Control Technical Manual to incorporate MIL-PRF-32295B as an alternative to high VOC petroleum-based solvents for cleaning metal components. The updated 509 Manual was published in 2010. Over 2010- 2013 NAVAIR conducted multiple field tests of NAVSOLVE™ for immersion cleaning of metal components at seven DoD sites (FRC Southeast, Jacksonville, FL; FRC Southwest, North Island, CA; Robins AFB, Warner Robins, GA; Fort Rucker Army Base, AL; NAS Lemoore, CA; 29 Palms Marine Corps Base, 29 Palms, CA; FRC-Support Equipment Facility, Solomon's Island, MD). The field tests were completed successfully and showed promising results [27]. Currently the major use of NAVSOLVE™ is at Travis AFB, CA for cleaning of C17 landing gear (and other metal components).

Before this project, though, little work has been done on evaluating NAVSOLVE™ as a replacement for the hazardous solvents used in the cleaning and repair of aircraft structural composites. A range of composite materials are used on DoD fixed and rotary wing aircraft which include epoxies (977-3, 3501-6, 8552) and bismaleimides (5250-4, M665) based polymer matrix composites (PMC's) with carbon or glass fiber reinforcements. To further reduce weight, composites also are bonded to various cores (Aluminum, Nomex, Kevlar, SynCore) with either paste or film adhesives to form stiff, but lightweight, sandwich structures. These core structures are very susceptible to fluid contamination and difficult to clean. In addition, a large amount of testing is required to qualify a new solvent for use with a PMC, as increasingly primary and secondary structural composites are bonded together, not bolted or welded as metal parts. As such, extensive validation testing is required to ensure residual solvent or cleaner contamination does

not degrade the polymer (swelling) or bonding surfaces, either during the bonded repair process or at the elevated temperature and humidity (hot/wet) aircraft operational conditions.

2.2 TECHNOLOGY DEVELOPMENT

During 2010-2012, a NAVAIR Naval Innovative Science & Engineering (NISE) effort performed initial fluid sensitivity and bonded repair evaluations of the cleaner on two composite laminate materials and adhesives utilized on the F/A-18[28]. Results of this study found no knockdowns in room temperature mechanical properties after fourteen day exposure to NAVSOLVE™. The composites evaluated were Cycom IM7/977-3 and AS4/3501-6. IM7/977-3 is a toughened epoxy laminate system used on the F/A-18 E/F while AS4/3501-6 is incorporated on many legacy aircraft such as the F/A-18 C/D, AV-8B, H-1, and V-22. The repair adhesives tested included the paste adhesives Loctite® EA 9394NA and EA 9321 (used in repair of many legacy aircraft), and Solvay's film adhesive FM® 300.

The bulk composite mechanical tests performed were short beam shear per ASTM D2344[29] and flexure per ASTM D7264[30]. The adhesive bonded tests were flat-wise tension on composite skin-Aluminum core sandwich structures per ASTM C297[31] and compression lap shear tests on adhesively bonded laminates. The solvent conditioning entailed first machining the mechanical test specimens, then submerging a subset of the samples in the test cleaners for fourteen days. A subset of the samples was set aside to be used as baseline controls. After exposure to the new cleaners, the composite test specimens were dried per ASTM D5229[32] Procedure D and tested per ASTM specifications. Though hot/wet and cold/dry test conditions were not evaluated, based on the variance in the test data, NAVSOLVE™ did not degrade the mechanical properties of the composites evaluated or bonded elements of the same at room temperature conditions.

A part-cleaning demonstration also was performed with NAVSOLVE™ and another new solvent in July 2012 at FRC-SE, Jacksonville NAS, FL. Skin cutouts on a scrapped F/A-18D composite (AS4/3501-6/Al core) door with hydraulic fluid contamination were first cleaned with the solvents. Repair patches then were bonded to the cleaned areas, see Figure 8. shows the general steps in the cleaning and repair of the door. The overall conclusion by the artisans who performed the demonstration was that NAVSOLVE™ appeared to work as well as standard solvents used for hydraulic fluid removal (i.e. MIBK, acetone, isopropyl alcohol). In addition, the artisans commented on the lack of solvent odor and how NAVSOLVE™ did not give them headaches or heart palpitations as the case for the MIBK hazardous solvent typically used.

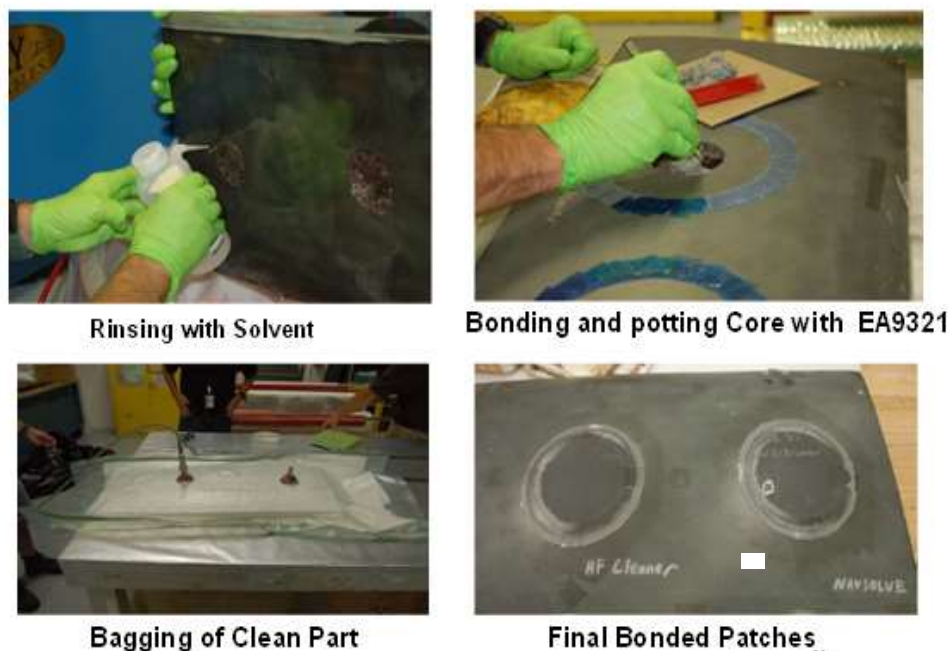


Figure 8. General steps in core cleaning and repair of F/A-18D Main Landing Gear (MLG) Outboard Door 621 at FCR-SE

In this earlier NISE program, though, no fluid sensitivity tests of NAVSOLVE™ were performed on polymeric based cores (i.e. Nomex, Kevlar, SynCore) which are extensively utilized on many newer aircraft models such as the V-22, F-35, and H-53K. Qualification tests and repair demonstrations on these materials was a primary focus of this ESTCP project.

In the earlier NAVAIR effort, a proof of concept vacuum assisted solvent cleaning procedure was devised and scaled up for use on full size composite parts. In the past, the composite repair community has done limited work on improved solvent-based cleaning procedures due to the difficulty of working with hazardous cleaners (harsh odors, fast evaporation rates). In a recently completed NAVAIR low VOC, HAP free solvent development program, it was realized that the environmentally friendly nature of NAVSOLVE™ afforded the opportunity to develop a potentially more efficient hydraulic fluid cleaning process for composite structure.

The benefits of the new cleaning process over the inefficient vacuum heat treatment method includes: 1) avoids vats of solvent for cleaning large parts, and 2) reduces waste byproducts. The process also uses established composite materials and processing techniques (i.e. vacuum bagging, VARTM, vacuum heating), thus is potentially more easily transitioned. The procedure uses standard composite vacuum bagging materials to form an enclosure around a large part, eliminating the need for a large vat to submerge the component (see Figure 9). After evacuating the part to remove any entrained air, NAVSOLVE™ is introduced into the bag to clean away any contaminants including hydraulic fluid. Next, the NAVSOLVE™ cleaner is pumped out of the bagged part, collected, and then rinsed through the bagged part again to maximize the cleaning efficiency.

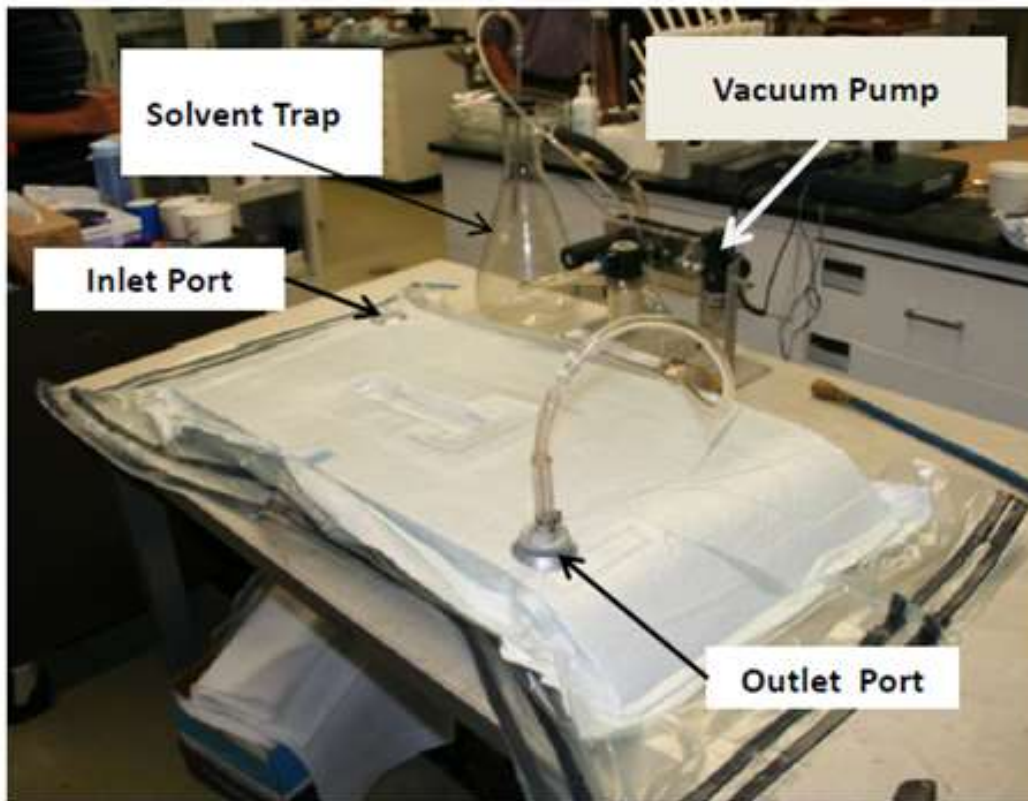


Figure 9. Vacuum bagged full-scale H-53E test article for NAVSOLVE™ solvent rinsing demonstration

After each rinse step, FTIR analysis is performed on the NAVSOLVE™ effluent to determine the concentration of hydraulic fluid (see Figure 10). Once the concentration of hydraulic fluid plateaus, a fresh batch of NAVSOLVE™ is used and the cycle of rinses is repeated to further lower the measured concentration of hydraulic fluid in the part. Using this new procedure in lab scale trials, the cleaning efficiency for removal of entrained hydraulic fluid from Aluminum honeycomb core was significantly improved compared to the standard thermal vacuum procedure (greater than 90% compared to 41%).

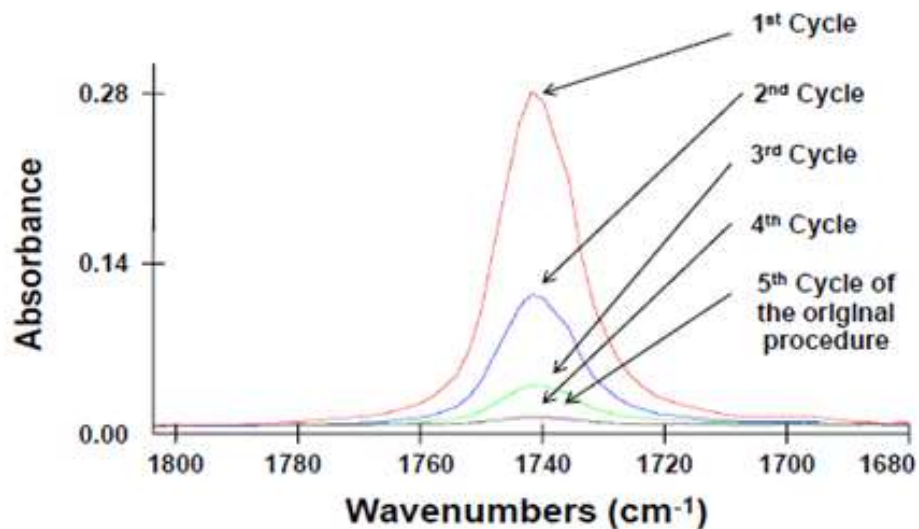


Figure 10. FTIR tracking of hydraulic fluid concentration in NAVSOLVE™ effluent

2.3 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

The primary advantage of NAVSOLVE™ over currently used solvents for cleaning composite aircraft components is that it meets the low VOC, HAP free requirements of MIL-PRF-32597 and MIL-PRF-32295B. Table 9 shows the properties of current solvents used for comparison.

Table 9. Properties of the Current Solvents Used for Cleaning Composites

Solvent	High VOC	HAP	Exempt	Flash Point (°F)
Acetone	Yes	No	Yes	-4
Hexane	Yes	Yes	No	-8.5
Methyl Isobutyl Ketone (MIBK)	Yes	Yes	No	60
Methyl Ethyl Ketone (MEK)	Yes	Yes	No	16
Isopropyl Alcohol	Yes	No	No	55

Site demonstrations at aircraft maintenance facilities also found the lower evaporation rate of NAVSOLVE™ allows for a longer residence time on the part surface. The longer soak time on the part was found to be beneficial for removing heavy soils such as carbonaceous contaminants deposited by exhaust wash and thick grease deposits. The lower vapor pressure was also beneficial for the vacuum-based, solvent rinsing procedure specified in a modified V-22 SMP-0021M5. In other applications, the slow drying time for NAVSOLVE™ is a disadvantage such as maintenance operations which do not allow the use of compressed air for drying of cleaned part surfaces.

Some additional advantages of NAVSOLVE™ for use in an industrial environment include non-offensive odor, non-carcinogenic, high flash point (141°F), non-ozone depleting, and compatible with metals & non-metals. The cleaning efficiency of NAVSOLVE™ has also been tested relative to current typical cleaning products used by DoD and shows to be comparable (see Figure 11).

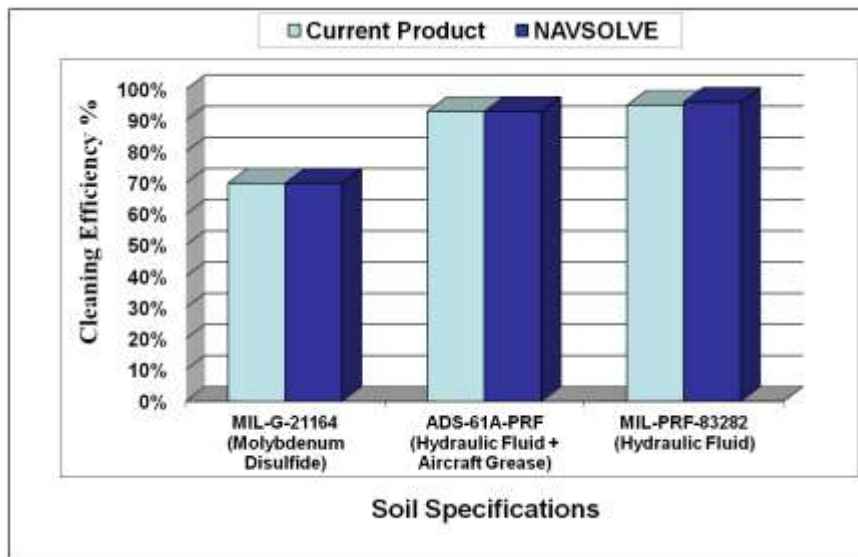


Figure 11. NAVSOLVE™ cleaning efficiency compared to current products

A disadvantage of NAVSOLVE™ is its higher cost than that of the current solvents used (listed in Table 9). This higher cost, though, is offset by the cost savings incurred by the reduction in the number of scrapped aircraft parts from failed bonded repairs.

3 PERFORMANCE OBJECTIVES

Prior to the field demonstrations, all Task 1 coupon level mechanical property testing described in the JTP for the specific demonstration part were completed and results compared against performance success criteria. The test matrix was formulated based on review of previous approved fluid compatibility test matrices for various aircraft Acquisition Programs (F/A-18E/F, V-22, F-35) and input from both the respective materials flight clearance POC's for the specific aircraft models and depot material SME's. The required test methods and materials for the Task 1 Bulk Laminate Tests are shown in Table 10.

The flexural strength properties of IM7/977-3, IM7/8552, and IM7/5250-4 composites materials after exposure to NAVSOLVE™ were determined in accordance with ASTM D7264. The flexural strength test was chosen as this measurement is sensitive to surface ply degradation. The 3-point bending moment during the test induces large in-plane compressive and tensile loads in the outer surfaces of the specimen. As such, the test is sensitive to any surface localized mechanical property knockdowns induced by the composites exposure to NAVSOLVE™. The test method is a component of a composite design allowable test matrix. The in plane shear (IPS) properties of IM7/977-3, IM7/8552, and IM7/5250-4 composites materials after exposure to NAVSOLVE™ were determined in accordance with ASTM D3518 [33]. This mechanical test also measures the bulk matrix properties as the SBS test. But the property scatter is greatly reduced in this test making it suitable as an aircraft structural design allowable. The open hole compression (OHC) properties of IM7/977-3, IM7/8552, and IM7/5250-4 composites materials after exposure to NAVSOLVE™ were determined in accordance with ASTM D6484 [34]. The test method is designed to generate critical notched compression strength data for composite structural design allowables. Since the notch dominates the strength value, the test is primarily measuring any potential chemical

Table 10. Performance Objectives – Bulk Laminate Tests

Laminate Test Method	Laminate Type	Success Criteria	Results
Short Beam Shear Test per ASTM D2344	IM7/977-3	NAVSOLVE™ results fall within standard deviation of baseline	Passed
	IM7/5250-4		
	IM7/8552		
Flexure Test per ASTM D7264	IM7/977-3		
	IM7/5250-4		
	IM7/8552		
±45 Tension (In-Plane Shear) Test per ASTM D3518	IM7/977-3		
	IM7/5250-4		
	IM7/8552		
Open Hole Compression Test per ASTM D6484	IM7/977-3		
	IM7/5250-4		
	IM7/8552		
Sealant Test Method	Sealant Type	Success Criteria	Results
Hardness per ASTM D2240	PR-1826	NAVSOLVE™ results fall within standard deviation of baseline	Passed
Tensile/Elongation per AS5127/1 (7.7)	PR-1826	NAVSOLVE™ knockdown less than Acetone	NAVSOLVE™ knockdown is less than Acetone
Weight Loss and Volume Swell per AS5127/1 (7.5)	PR-1826	NAVSOLVE™ results fall within standard deviation of baseline	Passed

degradation (ex. swelling) in the hole due to prolonged NAVSOLVE™ exposure. Performance objectives/success criteria for all tests were that NAVSOLVE™ results fall within the standard deviation of baseline values.

The Task 1 Bonded Property Tests are shown in Table 11. For the bonded test matrix, the flatwise tension properties of several composite laminate/polymeric core combinations after exposure to NAVSOLVE™ were determined in accordance with ASTM C297. The flat-wise tension test determines the tensile strength of the core, composite skin, and core-to-skin bond of a sandwich panel. In a sandwich panel, core-to-skin bond integrity is necessary to maintain skin stability and permit load transfer between the skin and the core. In the test, a tensile force is applied to the sandwich material via loading blocks which are bonded to the outer skins. This test method can also be used to produce flat-wise tensile strength data for the core material that can be used in structural design. For the current project, the test is used to determine if prolonged soaking of the sandwich structure in NAVSOLVE™ degrades the integrity of the adhesive film used in the core to skin bond.

Table 11. Performance Objectives – Bonded Property Tests

Test Method	Laminate / Core	Adhesive	Success Criteria	Results
Flatwise Tension per ASTM C297	IM7/977-3 / SynCore	N/A	NAVSOLVE™ results fall within standard deviation of baseline	Passed
	IM7/977-3 / Nomex	FM 300		Passed
	IM7/977-3 / Kevlar	FM 300-2		Passed
	IM7/8552 / Nomex	AF 163-2K		Passed
Compression Lap Shear per ASTM D3846	IM7/977-3	EA 9394NA		N/A
	IM7/8552	FM 300		N/A
	IM7/8552	AF 163-2K		N/A
Single Lap Shear per ASTM D5868	IM7/977-3	EA 9394NA		Passed
	IM7/977-3	FM 300-2		Passed
	IM7/5250-4	AF 191		Passed
	IM7/8552	EA9690		Passed
Single Lap Shear per ASTM D1002	Aluminum	FM 300-2		Passed
	Aluminum	AF 163-2K		Passed
	Aluminum	EA 9360		Passed
	Aluminum	EA 9309.3		Passed

The compression lap shear strength properties of a range of composite laminate/adhesive bond combinations after exposure to NAVSOLVE™ were determined in accordance with a modified ASTM D3846 [35]. In the test method, the in plane shear strength of an adhesive bond is measured by applying a compression load on a notched specimen of uniform thickness. Failure of the specimen occurs in shear between two centrally located notches machined halfway through its thickness and spaced a fixed distance apart (i.e. lap) on opposing faces. The modification to ASTM D3846 to measure the composite/adhesive bond strength is to first bond together the two composite specimens with the specified adhesive, then machine the two notches only through the composite laminate up to the bond surface of the adhesive. One advantage of the method compared to the single lap shear test (ASTM D5868[36]) is the difficulty to accurately align the test specimen in the test frame is greatly reduced as one need only ensure the ends of test specimen are machined flat and parallel. The main drawback in the method is the machining accuracy needed to ensure the thin adhesive layer in the notch is not damaged or removed.

Overall the compression lap shear results for the laminate/adhesive combinations where inconsistent with respect to both NAVSOLVE™ exposure and hot/wet conditioning. An analysis of the results is presented in Section 6.1.2. Given the challenges in machining the specimens and limited availability of the modified ASTM method as a test service from commercial mechanical test labs, ASTM D3846 was removed as a requirement from the new cleaner specification.

The single lap shear strength properties of a range of composite laminate/adhesives combinations after exposure to NAVSOLVE™ were determined in accordance with ASTM D5868. This test method covers the determination of the apparent shear strengths of adhesives for bonding composites. The shear strength measured with a single-lap specimen is not suitable for determining design-allowable stresses for designing structural joints. The single-lap test method is primarily comparative and used for selecting adhesives or bonding processes and discerning the susceptibility of the adhesive bond to environmental effects such as fluid exposures.

The composite/core/adhesive and composite/adhesive combinations for the FWT and shear specimens were chosen to represent the material systems found on current fixed and rotary wing aircraft such as F-35, V-22, and H-53K. The material combinations also link to the demonstration test articles to be evaluated in Task 2. Note for 977/Syncore honeycomb the composite skin is co-cured with the syncore film without the use of an adhesive. To better capture any environmental contributions to the mechanical tests and/or potential synergistic degradation effects, a subset of the test specimens were moisture saturated in a humidity chamber before exposure to NAVSOLVE™. As most NAVY aircraft are sea based, the composite structure is moisture saturated. Also, as a primary goal of the project is to clean hydraulic fluid contamination from honeycomb core, after specimen preparation a subset of the FWT specimens were saturated with hydraulic fluid (MIL-PRF-83282) before NAVSOLVE™ exposure.

During the field tests additional coupon level qualification tests were identified to support NAVSOLVE™ cleaner transition. At the request of Hill AFB, sealant qualification tests were added to the test matrix as candidate composite parts for cleaning contained attachment hinges with sealant gaskets. The sealant compatibility tests included Weight Loss and Volume Swell (SAE AS5127/1 (Section 7.5) [37]), Tensile/Elongation Test (SAE AS5127/1 (Section 7.7)[38]), and Hardness Test (ASTM D2240[39]). At the request of NAVAIR Fleet Readiness Center South-East (Jacksonville), a set of single lap shear tests using several aluminum/adhesives combinations after exposure to NAVSOLVE™ were performed in accordance with ASTM D1002 [40]. The rationale for the addition, as noted by FRC-SE, is that a number of legacy aircraft such as P-3, H-60, and C-130 incorporate components with metal to metal adhesive bonds that periodically need to be degreased and repaired.

The performance criteria for the site demonstrations are listed in Table 12 and Table 13. The field test were comprised of aircraft part cleaning demonstrations or bonded repair demonstrations as certain aircraft maintenance sites in CA are not approved to perform bonded repairs on composite parts. For these demonstrations there are a range of performance objectives which include repair quality assessments based on visual inspections, mechanical tests, NDI's, and subjective artisan feedback (see Table 12). The primary quality assurance measure for the demonstrations will be adherence to the steps prescribed in the validated specifications that will be used. For the part cleaning demonstrations with NAVSOLVE™, success is defined through a qualitative visual inspection of the breather cloth after the final, elevated temperature, vacuum drying step. The breather cloth (which encapsulates the part) will need to exhibit no wetting out of residue hydraulic fluid after a maximum of three vacuum dry cycles for a successful cleaning demonstration.

Table 12. Performance Objectives – Part Cleaning Demonstrations

Demonstration	Test Method	Data Requirements	Success Criteria	Results
Hill AFB F-35 BMI Panel Cleaning for Repaint	Water break	T.O. 1-1-8	Pass water break inspection	Passed
	PATTI	ASTM D4541[41]	Failure at primer interface	Passed
	Paint Adhesion Tape Test	ASTM D3359 [42]	No peel or removal of paint	Passed
TASMG H-60 Part Cleaning for Repaint	Paint Adhesion Tape Test	TM 1-1500-345-23; 4-16B[43]	No peel or removal of paint	Passed
Lemoore F/A-18 Door Cleaning	Feedback from shop floor Marine	N/A	No additional training required	Passed
Camp Pendleton Composite Intercostal & Rotor Hub Cleaning	Feedback from shop floor Serviceman	N/A	No additional training required	Passed
Hill AFB F-35 Door Cleaning	Water break	T.O. 1-1-8	Pass water break inspection	Passed

Table 13. Performance Objectives – Bonded Repair Demonstrations

Demonstration	Test Method	Data Requirements	Success Criteria	Results
Redstone H-47 Blade Bonded Repair	PATTI	ASTM D4541	Honeycomb core failure	Passed
	Tap Test	TM 1-1500-345-11; Section 7[44]	Pass tap test	Passed
FRC-SE UAV Wing Repair	PATTI	ASTM D4541	Honeycomb core failure	Passed
NAVSOLVE™ ease of use vs current shop cleaners	Feedback from shop floor artisans	N/A	No additional training required	Passed

For the part repair trials, the results of the NDIs will be the primary means to evaluate demonstration success. This is the case for actual in-service parts on which one would never perform destructive mechanical tests such as PATTI tensile tests. NDI will be used to assess any defects in the bonded repairs such as disbonds, voids, or porosity. The aircraft SRMs have established NDI criteria to validate a successful bonded repair that will be leveraged for this project's field tests. The NDI groups at the demonstration sites have repair NDI standards to ensure their equipment is functioning properly. Similar to the case of the mechanical test apparatus, the NDI groups already have in place procedures for the yearly calibration of all their NDI equipment. To assure the quality of the repair assessment data, only Level II certified repair artisans will perform the bonded repairs and only Level II certified NDI engineers will perform the NDIs.

The success of the demonstrations will be determined by both Strength & Analysis structural engineers in the respective aircraft FST's and the Senior Structural Engineer with the required flight clearance sign-off authority for each aircraft platform. Both the data collected during the Demonstration and the earlier coupon level validation results will weigh into their decision

4 SITE/PLATFORM DESCRIPTION

4.1 TEST PLATFORMS/FACILITIES

The six field test sites in the program include: Fleet Readiness Center-Southeast (FRC-SE), Jacksonville NAS, FL; Hill Air Force Base, Ogden, UT; Army Prototype Integration Facility (PIF), Redstone Arsenal, AL; Lemoore NAS, CA; Marine Corp. Base Camp Pendleton, CA; and Army 1106th TASMG, Hammer Field Armory, Fresno, CA. The six field test sites are key customers for transition of NAVSOLVE™ for use on composite aircraft structure. All six sites have certified composite repair artisans, technicians, and engineers to support the demonstrations. NAS Lemoore, MC Base Camp Pendleton, and Army 1106th TASMG were chosen for demonstrations as they are directly affected by the stringent CA air quality restrictions with regard to aircraft cleaners. Sixteen Air Quality Districts in California have solvent cleaning VOC limits of less than 25 g/L which applies to over sixteen DoD bases with a range of fixed and rotary wing aircraft (see Table 1). The South Coast Air Quality Management District (SCAQMD) includes Marine Corp. Base Camp Pendleton, CA.

Fleet Readiness Center- Southeast (FRC-SE) at Naval Air Station (NAS), Jacksonville was chosen as a demonstration site as it is the primary F/A-18 composite repair depot on the east coast and designated Aviation Maintenance training facility for several certification ratings. FRC-SE's activities include Phased Depot Maintenance (PDM) and Planned Maintenance Intervals (PMI) support, repair, conversion, modernization, Integrated Maintenance, and In-Service Repair (ISR) on the following types of aircraft: P-3 Orion, F/A-18 Super Hornet, EA-6B Prowler, SH-60 Seahawk, and the new P-8 Poseidon. FRC-SE is the designated depot for the F-35 engines as well as the MQ-4C Triton UAV system.

Hill AFB was chosen as a demonstration site as it is a primary composite repair facility for the Air Force whose tenants include the Ogden Air Logistics Center (OO-ALC) and AFRL Advanced Composites Office (ACO). OO-ALC is designated as the Air Force Technology Repair Center (TRC) for Composites and DoD Center of Industrial and Technical Excellence for Composites. OO-ALC performs depot repair, and modification and maintenance support on the F-35 Lightning II, the F-16 Fighting Falcon, F-22 Raptor, C-130 Hercules, T-38 Talon and A-10 Thunderbolt. OO-ALC teams also deploy worldwide to perform aircraft battle damage repair, crash damage repair, and field-level depot maintenance. The 570th Aircraft Maintenance Squadron, activated in June 2015, is responsible for depot-level maintenance, restoration, and modification on the F-35 Lightning II. Hill AFB is currently planned as the depot for both the Air Force's F-35A and Navy's F-35C carrier version.

The Army's Prototype Integration Facility Advanced Composites Laboratory at Redstone Arsenal is part of the Aviation and Missile Research Development and Engineering Center's (AMRDEC) engineering directorate. A primary function of the facility is rapid development of composite repair processes for Army rotary aircraft. Future Army plans include progressive upgrades of several

rotary aircraft with composite airframe structure. Personnel in the PIF advanced composites lab designed and developed repairs for damaged composite stabilators on the UH-60M Black Hawk helicopter and the AH-64E Apache helicopter. The Blackhawk repair is the first approved repair for primary composite structure on Army aircraft. The lab has also trained the instructors at the 128th Aviation Brigade, as well as the Aviation and Missile Command (AMCOM) logistics assistance representatives in the repair procedures. In addition to training, the PIF Advanced Composites Lab, in partnership with the Aviation Engineering Directorate, played a lead role in developing the Army Technical Manual 1-1500-204-23-11 "Advanced Composite Material General Maintenance and Practices" .

The primary drivers for a field test at Marine Corp Base Camp Pendleton were its location in the California SCAQMD as well as maintenance support of MV-22 helicopters whose airframe incorporates 35% composite by weight. The demonstration sites at Marine Corp. Base Camp Pendleton, CA were located in the Marine Aviation Logistics Squadron 39 (MALS-39), Marine Aircraft Group 39 (MAG-39) of the 3rd Marine Aircraft Wing. Marine Aircraft Group 39 provides utility helicopter support, close-in fire support, fire support coordination, aerial reconnaissance, observation and forward air control in aerial and ground escort operations during ship-to-shore movement and subsequent operations ashore of the Marine Corps. MAG-39 is currently composed of five AH-1Z "Viper" Cobra and UH-1Y "Venom" light attack squadrons, two MV-22 Osprey squadrons, an aviation logistics squadron, and a wing support squadron. The group falls under the command of the 3rd Marine Aircraft Wing (3rd MAW) and the 1st Marine Expeditionary Force (I MEF).

MALS-39 is an aviation logistics support unit of the US Marine Corps which provides aviation logistics support, guidance, planning, and direction to Marine Aircraft Group squadrons. MALS-39 also provides intermediate level maintenance for aircraft and aeronautical equipment of all supported units and performs first-degree repair on specific engines. They also provide aviation supply support for aircraft and Navy-funded equipment to all supported units. MALS-39 implements, audits, inspects, and provides oversight for the all policies and procedures relating to management of operations and maintenance of supported Navy aircraft. V-22 aircraft and related components for the site demonstration were provided from the Marine Medium Tiltrotor (V-22) Squadron 164 (VMM-164). The demonstrations were performed in the MALS-39 GSE W/C 940-SE Component Repair Branch.

The primary drivers for a field test at Lemoore NAS were its location in the CA San Joaquin Valley Air Quality District as well as its maintenance support of F/A-18 E/F fighters whose airframe incorporates 20% composite by weight (including skins, doors, and substructure). Aircraft maintenance activities at the base are distributed between the Commander Strike Fighter Wing, Pacific (CSFWP) and Fleet Readiness Center West. CSFWP provides the light attack aviation support to the Pacific Fleet and maintains fourteen F/A-18 squadrons. FRC West provides intermediate and depot level aviation maintenance, component repair and logistics support to the FA-18, including all type/model/series at all locations/detachments. The Aircraft Modification specializes in Phased Maintenance Intervals (PMI) and Aircraft Modifications for the FA-18 platform. In 2018, Lemoore also stood up the Navy's first operational fleet F-35C squadron, VFA-147. The F-35C airframe incorporates 35% composite by weight.

The 1106th Theater Aviation Sustainment Maintenance Group (TASMG) is a full-time operational depot of the California Army National Guard. TASMG provides year-round back-up aviation

intermediate maintenance (AVIM) and limited depot maintenance for ARNG aviation units of the thirteen western states. The 1106th TASMG also provides support to the federal and state governments, during natural disasters and other emergencies. Supported aircraft include the UH-60 Black Hawk, AH-64 Apache, and CH-47 Chinook.

4.2 PRESENT OPERATIONS

The site demonstrations will validate the ability of the NAVSOLVE™ cleaner to be successfully substituted for current solvents called out in the respective depot procedures for cleaning and follow-on bonded repair operations on composite aircraft parts. The hazardous solvents currently used include acetone, isopropyl alcohol, MEK, MIBK, and hexane. MIBK is not an effective cleaner for hydraulic fluid contamination removal; it is used mainly because it does not pose a significant health hazard in an industrial facility. Hexane is an effective solvent, but is a hazardous chemical with a low flash point so it must be used in a controlled environment to prevent prolonged human exposure. With few such controlled environments where aircraft are deployed, contaminated parts must be shipped to a controlled facility, such as a maintenance depot, for repair.

In an operational environment, aircraft composite structures become exposed to a range of liquid contaminants including fuels, oils, lubricants, and hydraulic fluids. As aircraft age, this problem is exacerbated, as damaged reservoirs and lines leak operational fluids into open regions, particularly core cells of composite honeycomb structure. These fluid contaminants must be cleaned from a damaged composite part before any inspection or repair processes can be performed at a depot. In particular, hydraulic fluid contamination is very difficult to remove in the fleet repair environment using current solvents and solvent based cleaning procedures, and leads to failures in bonded patch repairs on these components.

The difficulty in cleaning hydraulic fluid from composite parts is due to the fluid's propensity to rapidly "creep back" or re-wet a solvent cleaned or sanded composite surface. This surface recontamination is accelerated by both the elevated temperatures and vacuum bagging procedures utilized in standard bonded composite repair. A typical example of part surface re-contamination is shown in Figure 5. Composite damage was suspected at the outer metal frame/composite attachment area of a fighter aircraft composite wing (Figure 12 a). To assess the damage area with NDI tools, first the wing was cleaned of grease/dirt/fluids; then the wings' paint/primer layers were sanded away to expose the structural composite surface. By the next morning, though, when the NDI was to commence, residual fluid had wicked back along the outer metal frame and re-stained a portion of the previous clean composite surface (Figure 12 b).

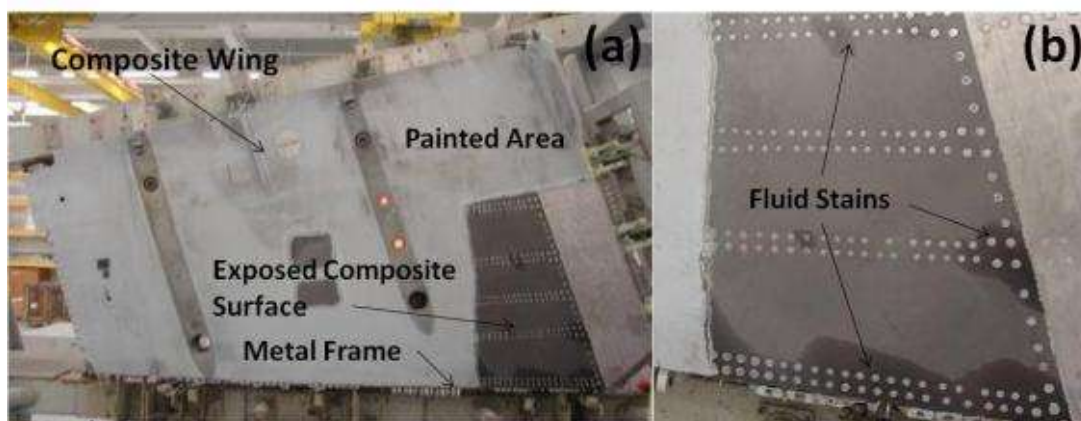


Figure 12. (a) Fighter aircraft composite wing section with de-painted region and (b) close-up of re-contaminated sanded composite surface

Hydraulic fluid contamination is particularly difficult to clean from aircraft composite sandwich structure due to its vulnerability to impact damage. Such damage can cause core/skin disbonds which over time allows fluid ingress (including hydraulic fluid oil, fuel, and water) into the core cells. To detect these fluids, every incoming aircraft honeycomb part to the depot is first inspected using X-ray transmission or thermography base NDI techniques (see Figure 13).

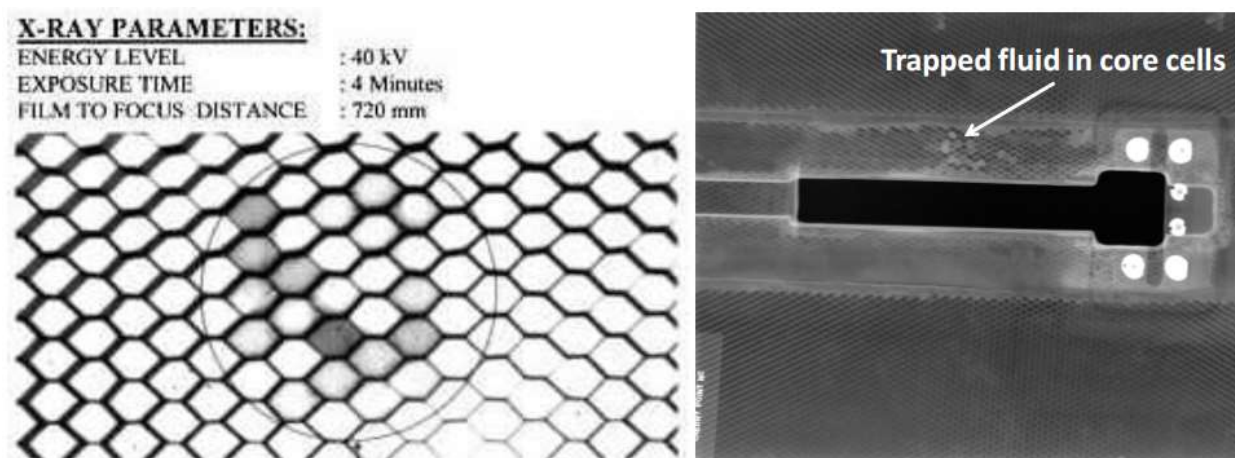


Figure 13. X-ray transmission images of fluid in honeycomb cells

Knowing the amount of fluid in the core is critical for determining if a part is repairable, or if it must be scrapped. Moisture in the core can be successfully removed via evaporation by careful vacuum thermal drying of the component. A drying process, though, is not effective in removing hydraulic fluid as the temperature needed to evaporate hydraulic fluid is above the thermal threshold one is allowed to take a polymer matrix based composite part. The amount and location of hydraulic fluid in the core is important because if this fluid is not adequately removed from the cells before a bonded patch repair, the contaminant can wick back to the surface under repair and degrade the bond during the high temperature adhesive cure step. Once this bond is damaged the composite part is typically scrapped.

Immersion cleaning of composite parts in solvent vats is typically not done due to the large amounts of hazardous cleaners required. The current method to remove hydraulic fluid contamination prior to the application of the bonded composite repair patch involves a combination of first rinsing the contaminated area with hazardous solvent followed by packing the area with breather cloth and heating at an elevated temperature under vacuum for many hours (> 24 hrs.). This thermal cycle can be repeated up to three times, after which the part has to be scrapped if not enough fluid is removed from the repair area (see Figure 14). This procedure is costly, time consuming, and often ineffective depending on the amount of hydraulic fluid entrained in the honeycomb cells. For example, up to 30% scrap rates are found on F/A-18 parts susceptible to

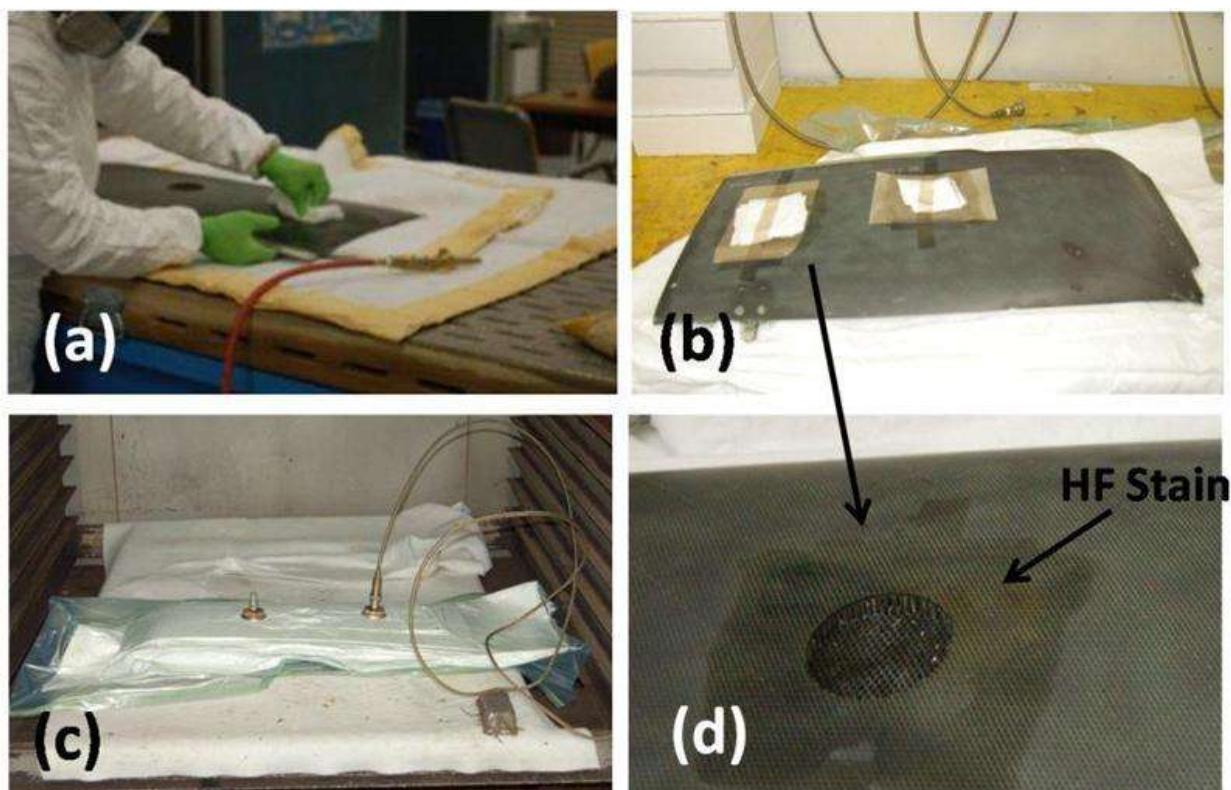


Figure 14. Thermal vacuum treatment to remove hydraulic fluid contamination in honeycomb: a) rinse core with hazardous solvent, b) pack repair area with breather cloth, c) vacuum bag part and heat treat, d) fluid stain after first vacuum heat treatment

hydraulic fluid contamination such as engine bay doors and lower control surfaces. This cost burden to the Navy is large as a typical composite components needing replacement can range from \$50,000 - \$150,000. These scrapped parts eventually end up buried in a landfill increasing the environmental waste impact.

Damage to composite honeycomb structure is the number one repair issue for naval aircraft. Depending on the depth of the damage, just the composite skin may need to be replaced, or for significant damage, both the core and skin. For parts with shallow contours, pre-cured composite patches can be adhesively bonded onto the part after removal of the damaged skin. For curved parts, a more involved Double Vacuum Debulk (DVD) process is used to cure/bond pliable, wet

layup patches onto the part to replace the damaged skin. Solvents are used at various steps in these above multi-step bonded repair processes.

The general steps involved in bonding a replacement core and pre-cured composite patch to the composite sandwich test article are depicted in Figure 15. For large parts that cannot fit in an oven or for on aircraft repairs, the heat and vacuum to cure the bonded repair patch is applied with a portable, hot bonder system (see Figure 16). The hot bonder consists of combined heat blanket/mat

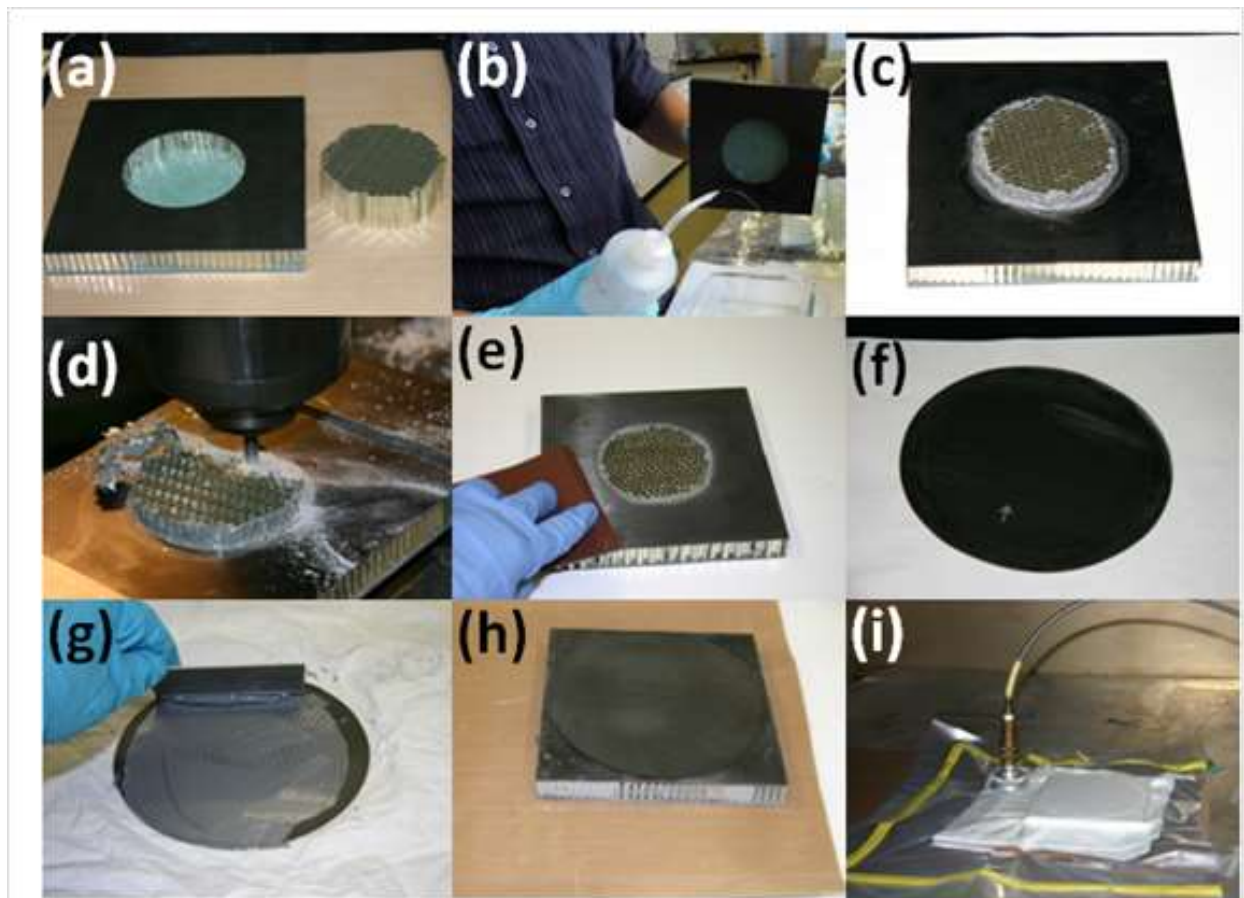


Figure 15. Steps in bonding of core and pre-cured composite patch to sandwich test article: a) remove 3” core section & prepare core insert, b) rinse test article w/cleaner, c) pot core insert, d) end mill excess core insert, e) sand top of skin, f) cut out/taper pre-cured composite patch, g) apply EA 9394NA adhesive to patch, h) let bonded article set, i) final vacuum bag cure in oven

rheostat, vacuum pump, and a programmable PID controller which is used to manage the curing process. The unit monitors and varies the heating profile of the wet lay-up repair patch on the part through the use of thermocouples and a conformable heat mat respectively. The bonded repair steps are detailed in the aircraft models respective SRM's or specific LPS's approved at the demonstration sites.

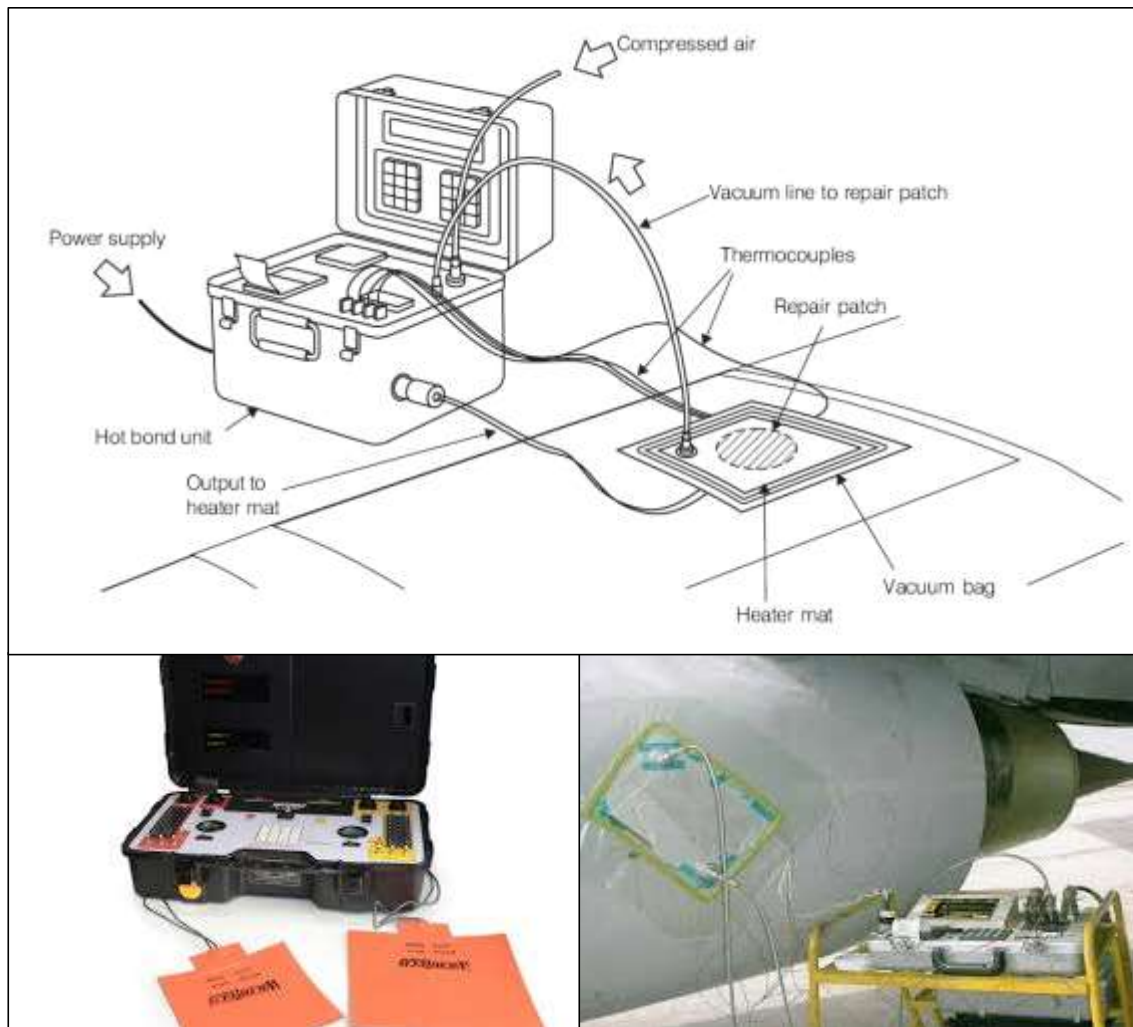


Figure 16. Schematic of portable hot bonder unit for composite repair and example of on-aircraft repair with system

4.3 SITE-RELATED PERMITS AND REGULATIONS

No additional site related permits or regulations are needed for the demonstrations to be conducted at the three demonstration sites.

5 TEST DESIGN

5.1 CONCEPTUAL EXPERIMENTAL DESIGN

Several composite cleaning and repair demonstrations using the NAVSOLVE™ cleaner were conducted at the Navy, Air Force, and Army maintenance facilities in the project. Multiple demonstrations sites were required as each Service and maintenance facility had different preferred solvents, cleaning, and repair procedures depending on the type of aircraft they support (i.e. aircraft

SRM's) and site legacy requirements (i.e. Local Process Specifications, LPS's). The demonstrations focused on cleaning and repair procedures specific to four primary aircraft systems: V-22, H-47, F-35, and MQ-4C Triton. The mix of materials and procedures used in the demonstrations are applicable to a range of both legacy and future aircraft across the Services.

The overall experimental design of the demonstration was to conduct the field tests on scrap composite parts typically retained by the facilities for training purposes. For the bonded repair demonstrations, one set of test articles was prepared using the current hazardous solvent called out in the procedure, and another set using NAVSOLVE™. The repair demonstrations on the aircraft parts were scheduled test events conducted over several days and witnessed by project stakeholders including the project Principle Investigator (PI), Co-PIs and relevant Fleet Support Team (FST) POCs.

5.2 PRE-DEMONSTRATION TESTING AND ANALYSES

No pre-demonstration testing was required. The earlier NAVAIR NISE program evaluated NAVSOLVE™ compatibility with the various bagging, breather, and tapes used for cleaning and bonded repair of composite aircraft structure. FRC-SE were participants in the NISE program, so these compatibility tests were performed with bagging material specific to their sites/procedures. Though Hill AFB was not part of the earlier NISE program, the qualified bagging materials evaluated are used across the DoD composite repair community.

5.3 DESIGN AND LAYOUT OF TECHNOLOGY COMPONENTS

All demonstration sites have active Composite Repair Shops with the qualified consumables (bagging films and tape, breather cloth), materials (core and adhesives), and repair processing equipment (hot bonders, ovens, DVD systems) available to complete the field tests. All sites have on site NDI facilities to provide post analysis/inspection of the demonstration articles to verify the performance objectives. All demonstration parts for the field tests were identified. Two demonstration sites (FRC-SE, Hill AFB) supported the Task 1 coupon level testing effort so have performed all the necessary testing and procedures to incorporate NAVSOLVE™ into their specific site's Industrial Chemical/HAZMAT logistics systems. As such, all sites have some handling experience with the NAVSOLVE™ cleaner before the demonstrations. No new demonstration equipment needs to be installed at the demonstration sites to complete the field tests.

5.4 FIELD TESTING

A description of the specific subtasks of each phase of the demonstrations/field tests follows.

5.4.1 Panel and Part Cleaning Demonstrations

5.4.1.1 Hill AFB: F-35 BMI Panel Cleaning and Re-paint

A F-35 Coating Application/Removal Composite Training Panel had all coatings removed and one side contaminated with hydraulic fluid. The hydraulic fluid was hand cleaned from the panel using NAVSOLVE™ following Hill AFB F-35 part-cleaning procedures. The artisans documented any handling or performance differences between using the current approved hazardous solvents and

the NAVSOLVE™ cleaner. The cleanliness of the panel surface was verified by the water break test per Air Force T.O. 1-1-8. Next, the cleaned composite training panel was repainted with PRF 85285 (White) paint per F-35 painting procedures. After painting, the integrity of the paint/primer bond to the BMI composite panel (and, thus, the success of the NAVSOLVE™ cleaning) was confirmed via the ASTM D4541 PATTI (Pneumatic Adhesion Tensile Testing Instrument) tensile test and ASTM D3359 (tape adhesion test). The metric for a successful PATTI test was observed failure at the paint/primer interface indicating the primer bond strength to the composite surface is greater than the primer/paint bond strength.

F-35 Door Vacuum Assisted Cleaning

Hill AFB used a vacuum-based, solvent rinsing procedure specified in a modified V-22 SMP-0021M5 for this cleaning step. A general vacuum bagging schematic is shown in Figure 17. The artisans documented any handling or performance differences between using the current approved hazardous solvents and the NAVSOLVE™ cleaner.

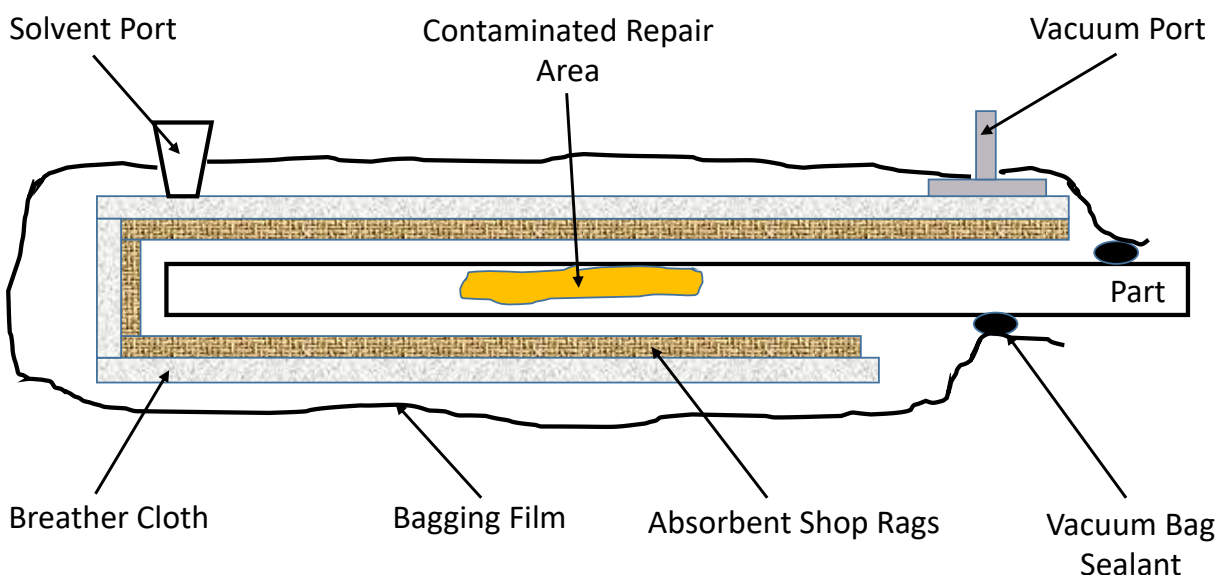


Figure 17. Vacuum Bagging Schematic

5.4.2 Composite Part Bonded Repair Demonstrations

In the second stage of the field tests, NAVSOLVE™ was demonstrated in the cleaning and repair of actual aircraft parts. Each site used scrapped rotary wing and UAV (Unmanned Air Vehicle) components suitable for these trials. A primary issue these tests resolved is that the solvent does not leave any residue on the core that would later disrupt the elevated temperature adhesive cure step. For typical bonded composite repair, the final cleaning step for a surface after degreasing/cleaning with a solvent is sanding followed by a dry wipe with cheesecloth. This last sanding step removes any possible solvent residue from the bonding surface. However, sanding the exposed surfaces of a core after rinsing with a solvent to remove hydraulic fluid is not feasible. The repairs performed in this task confirmed that NAVSOLVE™ effectively cleans hydraulic fluid from a core and does not leave a residue on the core that could degrade the adhesive cure step.

5.4.2.1 FRC-South-East Demonstration

FRC-SE utilized a scrapped Predator composite wing section for the NAVSOLVE™ cleaning followed by bonded repair demonstration. The test article is shown in Figure 18. For this demonstration, first a section of the test article had its face-sheet removed and the area saturated with hydraulic fluid. The contaminated area was then cleaned with NAVSOLVE™ replacing the current solvent referenced in the SRM procedures. An adhesive bonded patch repair was next performed on the scrap part following LMA 2ZSA00064 REV A[45] in which NAVSOLVE™ was used in place of the solvent called out in the specification. As the repair-curing step takes several hours, this site demonstration took place over several days (~3 days) including the post destructive inspections. The final repair was evaluated with NDI per NAVAIR 01-1A-16-1[46] to meet the demonstration performance metric. Visual inspection looked for any reappearance of hydraulic fluid after the repair. The repair artisans were surveyed for their feedback on the benefits and drawbacks of NAVSOLVE™ compared to the standard hazardous cleaners/ solvents typically used.



Figure 18. UAV Wing Section Demonstration Article at FRC-SE

The repair bond strength was also evaluated through PATTI tensile tests per ASTM D4541. This task was performed after the scheduled demonstration event as it takes several days to complete.

The PATTI tester is a portable mechanical testing system that allows relatively accurate tensile pull tests from large or curved composite parts. The unit is used to evaluate the strength of the core/adhesive bond or adhesive/composite skin bond in composite bonded repairs. A picture of the device is shown in Figure 19. In a typical test, the first step is to adhesively bond an aluminum “pull-stub” to the final bonded repair patch. Once the pull-stub epoxy has cured, the skin and adhesive/potting surrounding the stub is machined away down to the core interface. Next a self-aligning piston is attached to the pull-stub. The PATTI control module is supplied with pressurized gas and then connected to the piston via a hose. The user slowly increases the pressure to the piston until separation occurs between the pull-stub and the repair surface (or until some predetermined pressure is reached). The control module will indicate the maximum pressure applied to the piston, with or without pull-stub detachment. This burst pressure is then converted into tensile strength (pounds per square inch (psi)) by consulting a table for the appropriate piston and pull-stub.

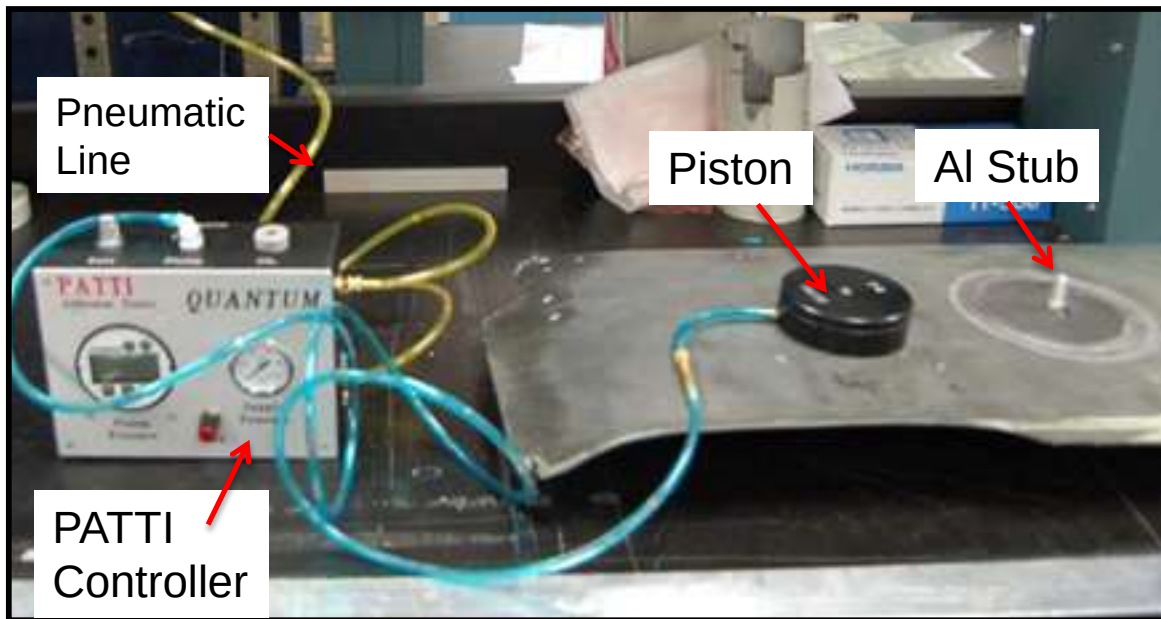


Figure 19. Set-up for PATTI Pull Test on repaired composite door

Evaluation of the measured PATTI tensile strength and failure surface indicates the quality of the repair bond. The tensile strength of the polymeric cores is typically less than the pristine tensile strength of both the repair adhesive and composite skin. Therefore, a quality repair will show pull out of the core. Likewise, a degraded repair bond can exhibit either adhesive or cohesive failures at the bondline or in the adhesive. Figure 20 shows examples of PATTI failure surfaces from bonded repair patches on an aircraft composite door.

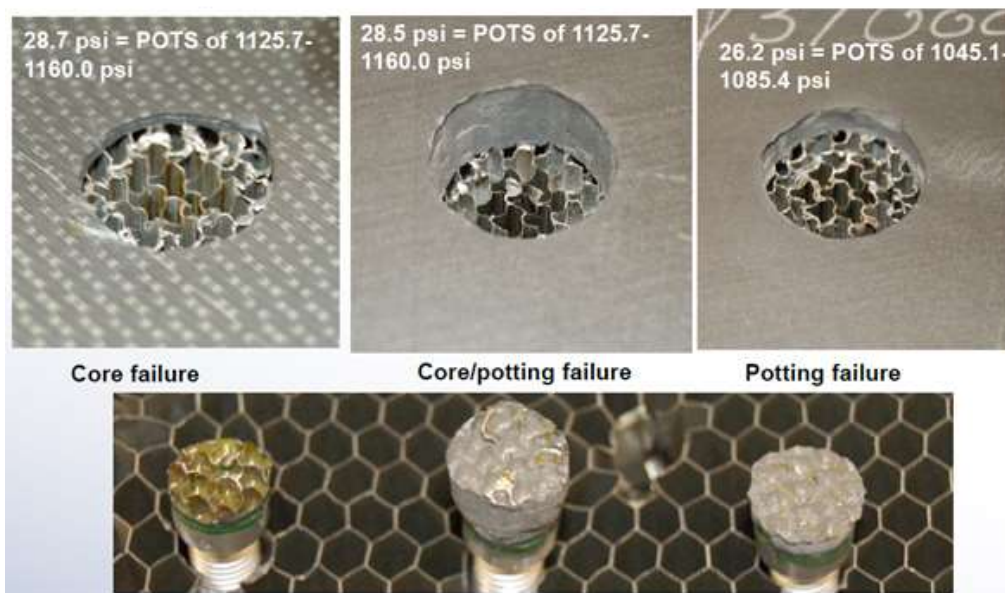


Figure 20. Failure surfaces from PATTI tests on bonded repair patches on Al Core

5.4.2.2 Army 1106th TASMG H-60 Part Cleaning and Re-paint Demonstration

The performance objective of this demonstration was to determine if NAVSOLVE™ performs as well as acetone when used as a hand-wipe cleaner on a UH-60 cargo door. Acetone was the control solvent for the demonstration. To determine if NAVSOLVE™ met the 1106th's cleaning requirements, a UH-60 cargo door was masked off, sanded, cleaned, tested for a water break free surface, primed, and painted. After the paint had cured seven days, a technician performed a paint adhesion test per TM 1-1500-345-23; 4-16B. Any handling or performance differences between using acetone and the NAVSOLVE™ cleaner were documented. A picture of the UH-60 cargo door is shown in Figure 21.



Figure 21. UH-60 Cargo Door (Exterior)

6 PERFORMANCE ASSESSMENT

Following the Demonstration, a performance assessment based on the Performance Objectives as listed in Table 10, Table 11, and Table 13 were performed. Discussed below are the performance criteria for the stages of the demonstration and the plan for how success was assessed.

6.1 LABORATORY TESTS

This section contains the results of laboratory tests performed on individual bulk composite specimens, bonded composite laminates with and without honeycomb core, and bonded aluminum substrates to test the effects of NAVSOLVE™ on bonded repair materials and performance. Tests were conducted on specimens exposed only to NAVSOLVE™ and to those exposed to hydraulic fluid followed by cleaning with NAVSOLVE™. Results were compared with effects of current cleaners used for fluid removal.

6.1.1 Bulk Composite Laminate Tests

For this task, the performance objective was to pass bulk composite laminate tests that included short beam shear, flexure, and in-plane shear. For statistically significant data, five specimens were tested for each method. Success criteria was for specimens exposed to NAVSOLVE™ for fourteen days to have mechanical properties within the standard deviation of baseline control specimens. The quality of the test data was controlled by strict adherence to the ASTM standard that defines the a) test specimen dimension (with tolerances), b) mechanical test apparatus configuration, c) test conditions, d) accepted failure modes, and e) test data analysis. Calibration of the mechanical test frames were performed at regular, yearly intervals through maintenance contracts with the equipment manufacturer (i.e. MTS, Instron).

Test results of bulk composite laminates using IM7/8552, IM7/977-3, and IM7/BMI (5250-4) are provided in Figure 22 (short beam shear), Figure 23 (flexure), Figure 24 (in-plane shear) and Figure 25 (open hole compression). For all four mechanical tests and for all three composite materials the statistical error of the exposed samples fell in the same range as the error in the baseline, unexposed specimens confirming no property knockdown caused by long term exposure to NAVSOLVE™.

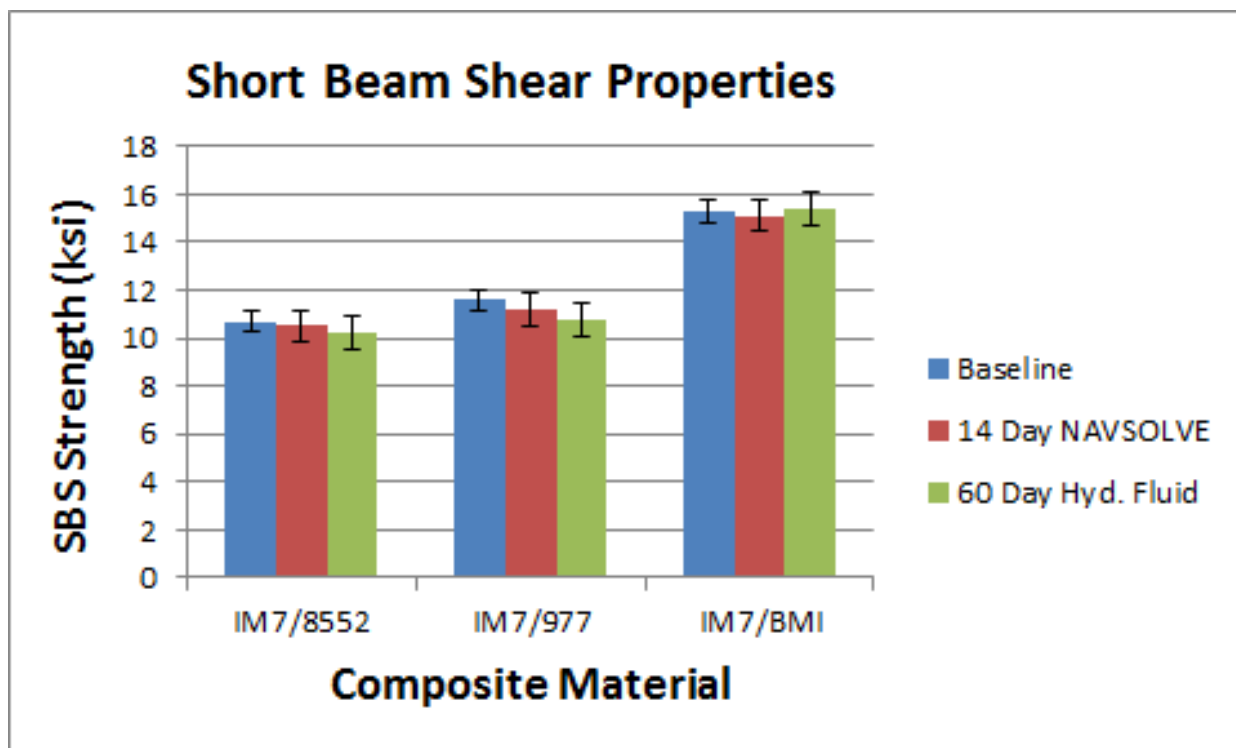


Figure 22. Short Beam Shear Properties of Composite Materials

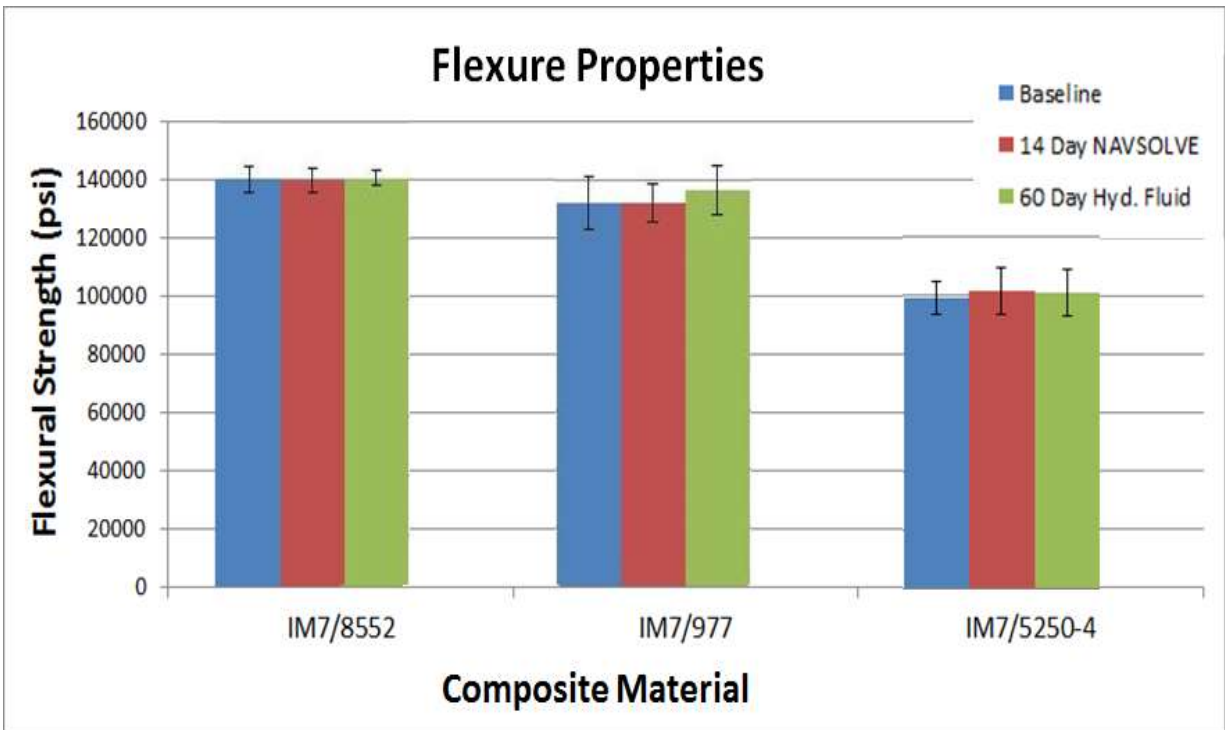


Figure 23. Flexure Properties of Composite Materials

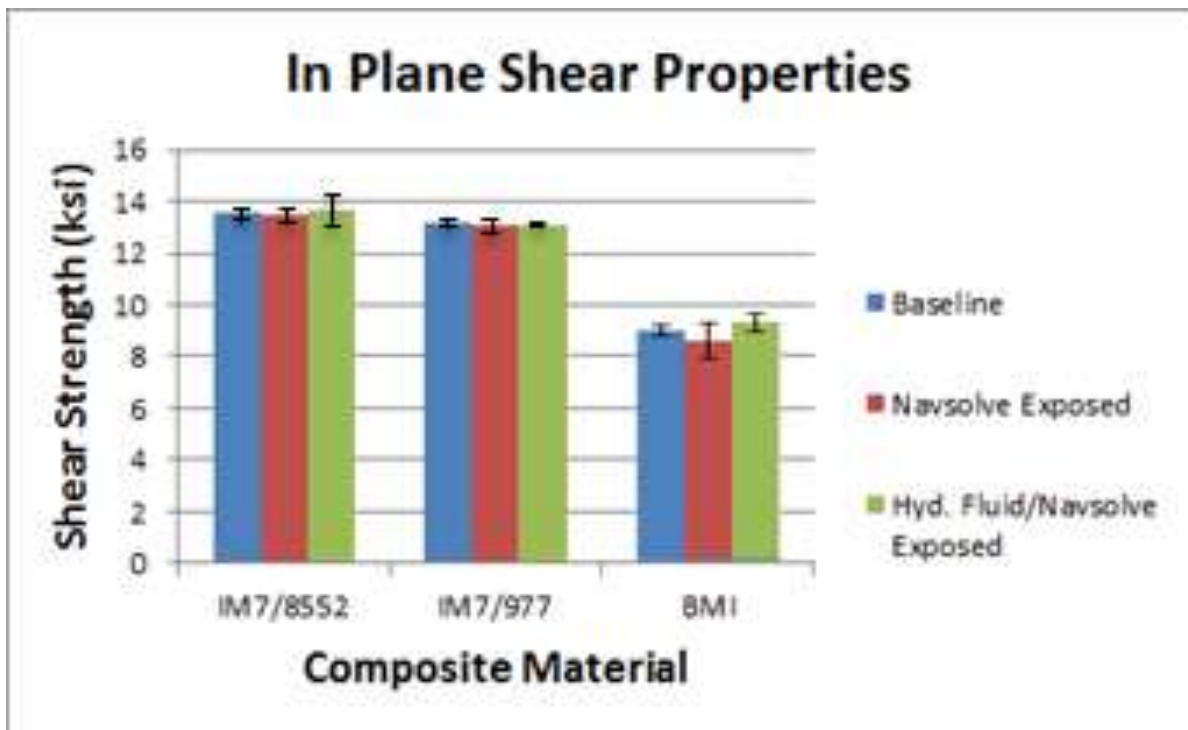


Figure 24. In-Plane Shear Properties of Composite Materials

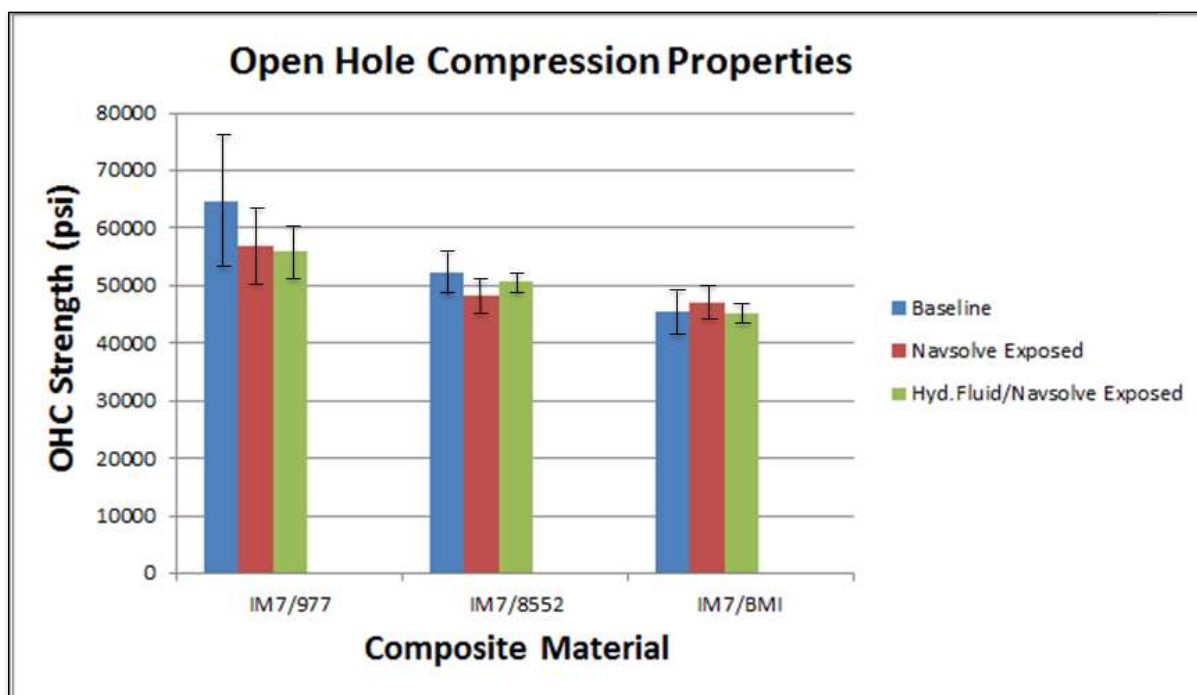


Figure 25. Open Hole Compression Properties of Composite Materials

6.1.2 Bonded Composite Laminate Tests

For this demonstration, the performance objective was a modified Flat Wise Tension (FWT) Test performed per ASTM C297. Modification from the ASTM was due to a step added for hydraulic fluid contamination of the core prior to bonding. For statistically significant data, five specimens were tested for each skin/core material system evaluated in the demonstration. The success criteria for the FWT test was a strength value of the NAVSOLVE™ exposed samples comparable to that of the baseline controls such that the standard deviation of the former was in the same range as the latter. The quality of the test data was controlled by strict adherence to the ASTM standard which defines the a) test specimen dimension (with tolerances), b) mechanical test apparatus configuration, c) test conditions, d) accepted failure modes, and e) test data analysis procedures. Calibration of the mechanical test frame is performed at regular, yearly intervals through a maintenance contract with the equipment manufacturer (i.e. MTS, Instron).

Test results of bonded composite laminate tests using various composite substrates with and without honeycomb core and with aluminum substrates are provided below. Flatwise tension (FWT) results are reported in Figure 26, Figure 27, and Figure 28. For all three core types (Nomex, Kevlar, Syncore) no FWT strength knockdown was found after exposure to NAVSOLVE™. The standard deviation of the NAVSOLVE™ exposed samples falls in the standard deviation of the baseline and Hot/Wet baseline values. The Syncore FWT results had a large degree of scatter attributed to the difficulty of FWT measurements on Syncore based materials.

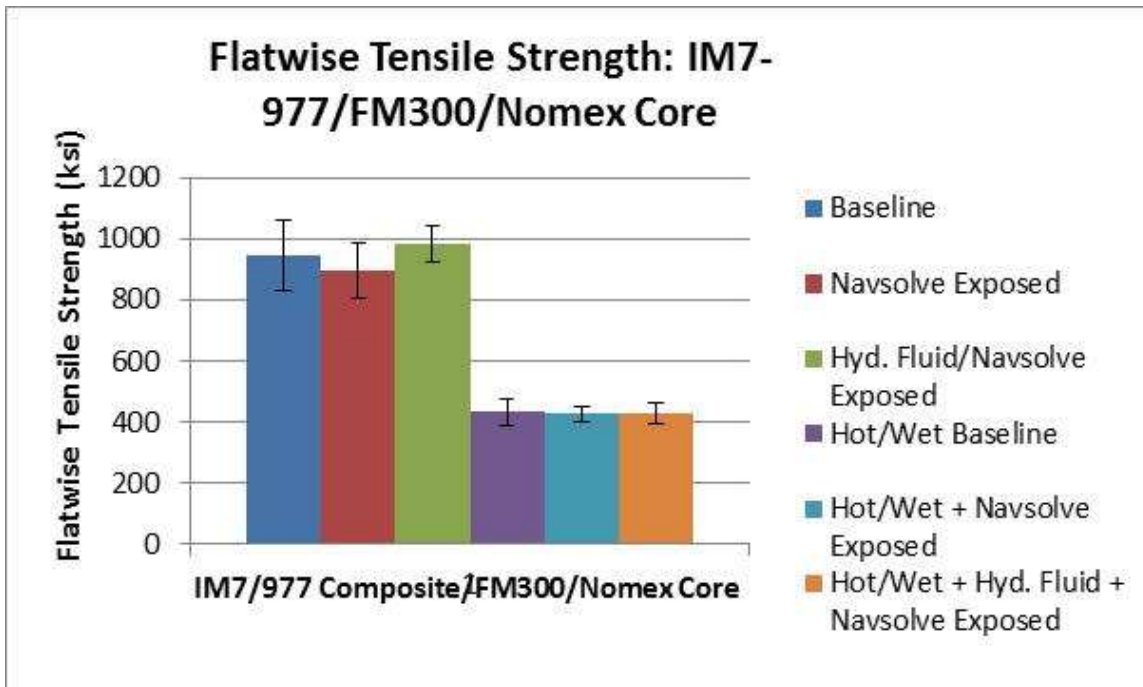


Figure 26. Flatwise Tension IM7/977-3 Laminate / FM 300 Adhesive / Nomex Core

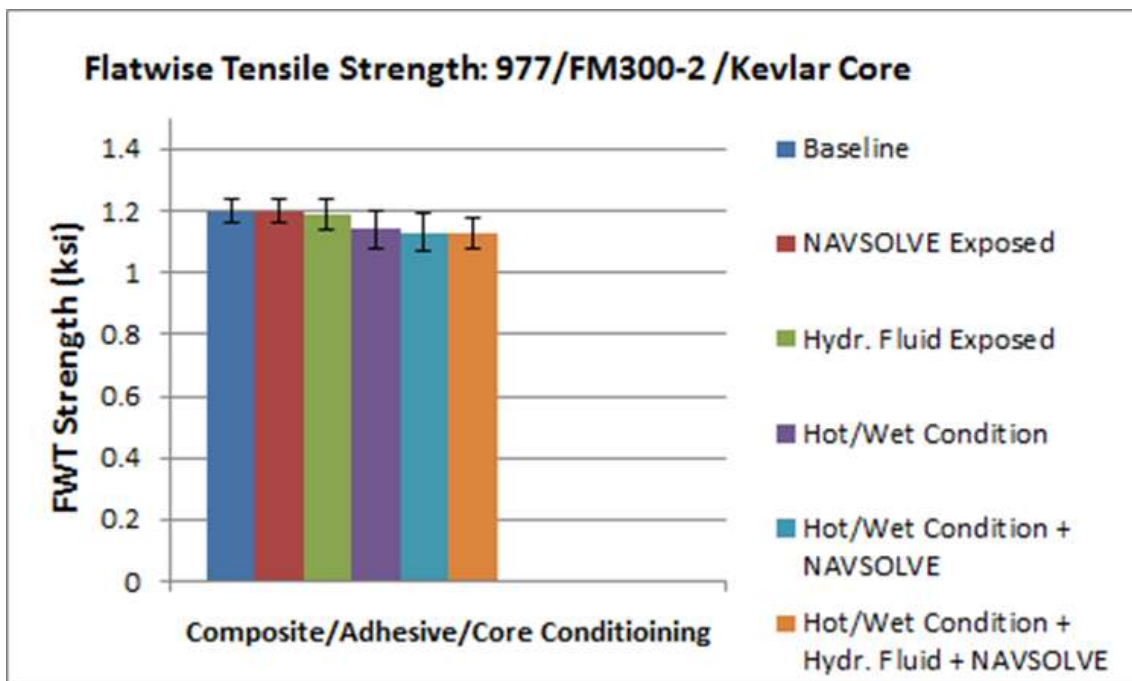


Figure 27. Flatwise Tension IM7/977-3 Laminate / FM 300-2 Adhesive / Kevlar Core

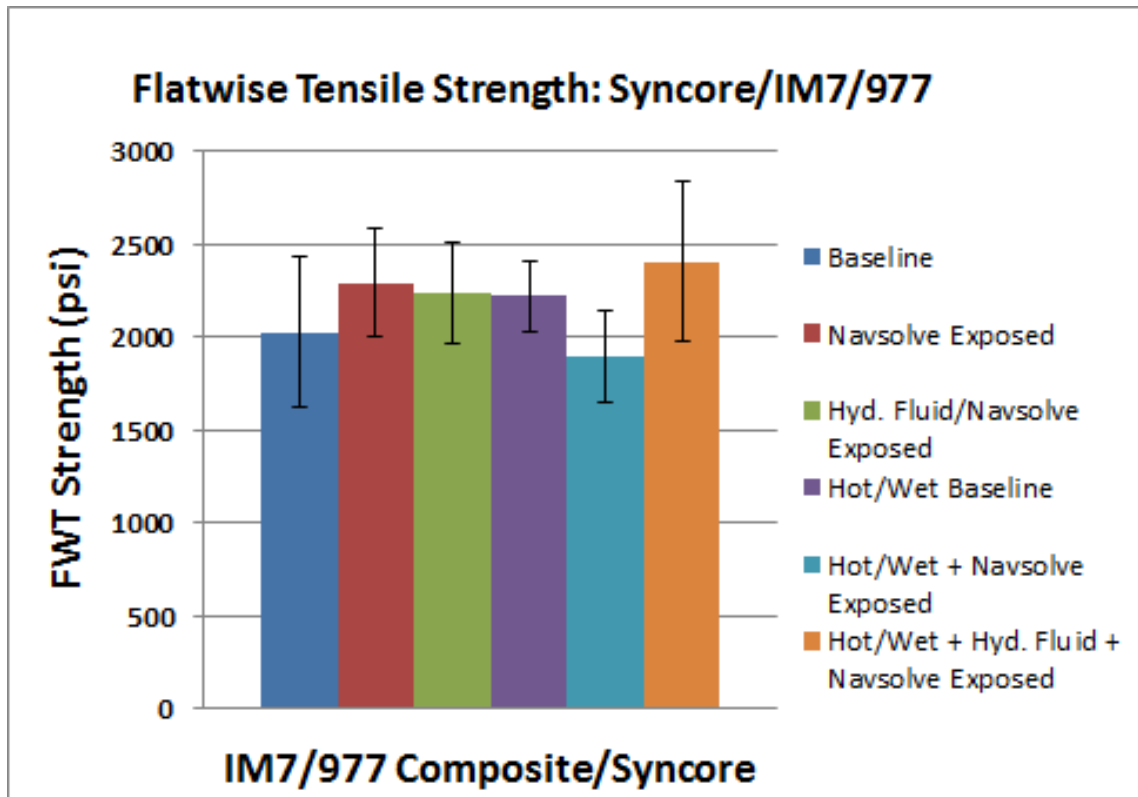


Figure 28. Flatwise Tension IM7/977-3 Laminate / SynCore

Compression lap shear (CLS) results are reported in Figure 29, Figure 30, and Figure 31. The 977/EA 9394 CLS data was inconsistent with a high COV measured. Both the NAVSOLVE™ exposed and hydraulic fluid/ NAVSOLVE™ exposed samples has higher shear strength values than the baseline unexposed, baseline sample. The hot/wet baseline condition also had a higher shear strength than the baseline condition. As the 9394 adhesive was cured at room temperature, the increase in shear strength for the hot/wet conditioned specimens might have been due to a post cure of the adhesive during the elevated temperature conditioning. Visual inspection of the failure surface of the test specimens indicated high porosity in the bond-line due to room temp cure. This porosity most likely contributed to the high scatter in the results given the small area of the lap joint.

The 8552/FM300 CLS specimens had very poor adhesion as indicated by the low shear strength measured (Figure 30). The poor adhesion was traced back to the original panels being cured at the wrong temperature (250°F instead of 350°F). This explains the roughly doubling of the shear strength for the hot/wet conditioned specimens as the elevated temperature conditioning further the cure of the adhesive (though the overall adhesion of all conditioned samples was low for FM300).

As the single lap shear test gives comparable adhesive bonding sensitivity data to compression lap shear and given the machining challenges with fabrication the lap area in CLS specimens, CLS was removed as a required mechanical test in the new composite cleaner specification. Few

commercial mechanical test labs perform the modified ASTM D3864 as one of their standard test services.

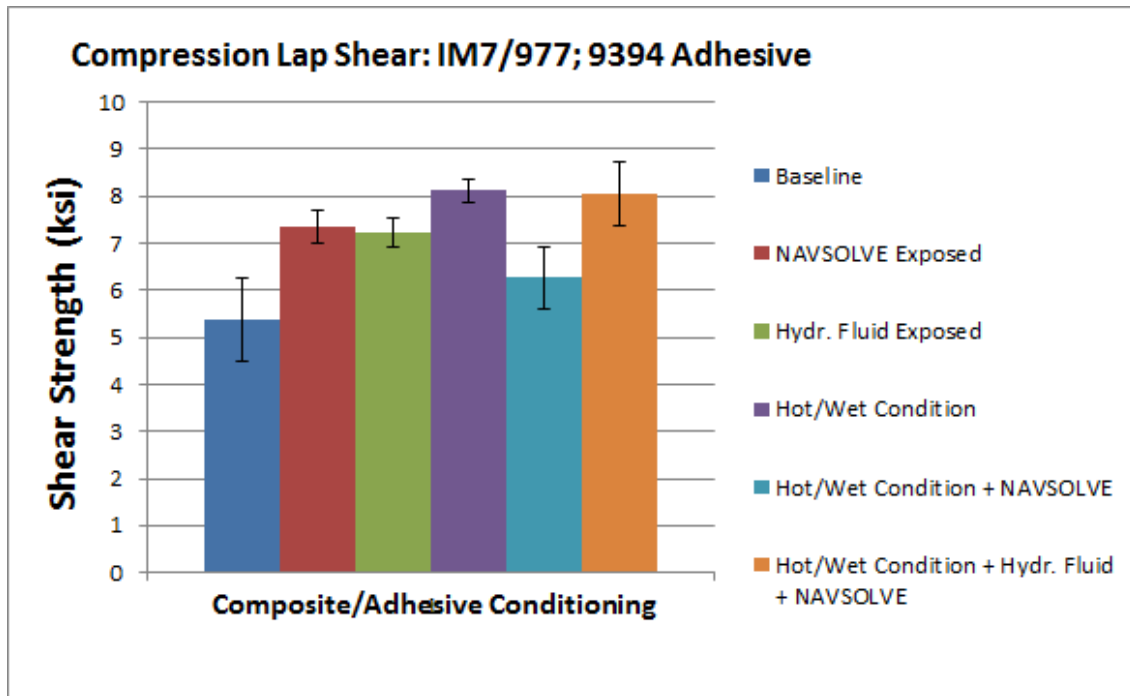


Figure 29. Compression Lap Shear with IM7/977-3 Laminate / EA 9394NA Adhesive

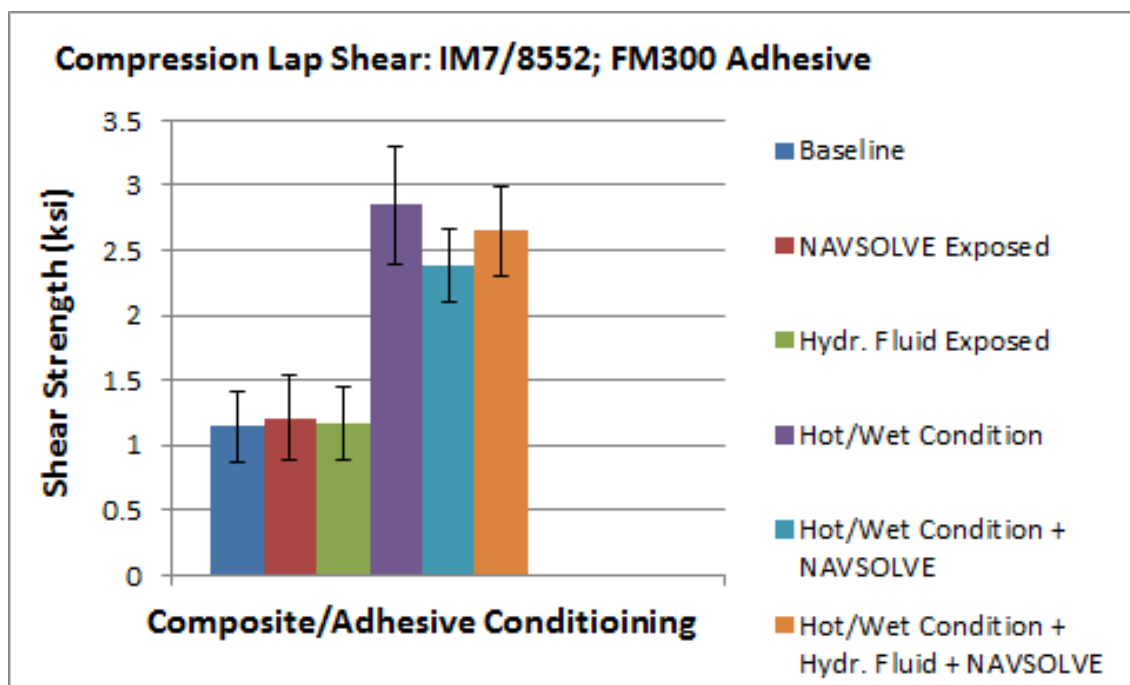


Figure 30. Compression Lap Shear with IM7/8552 Laminate / FM 300 Adhesive

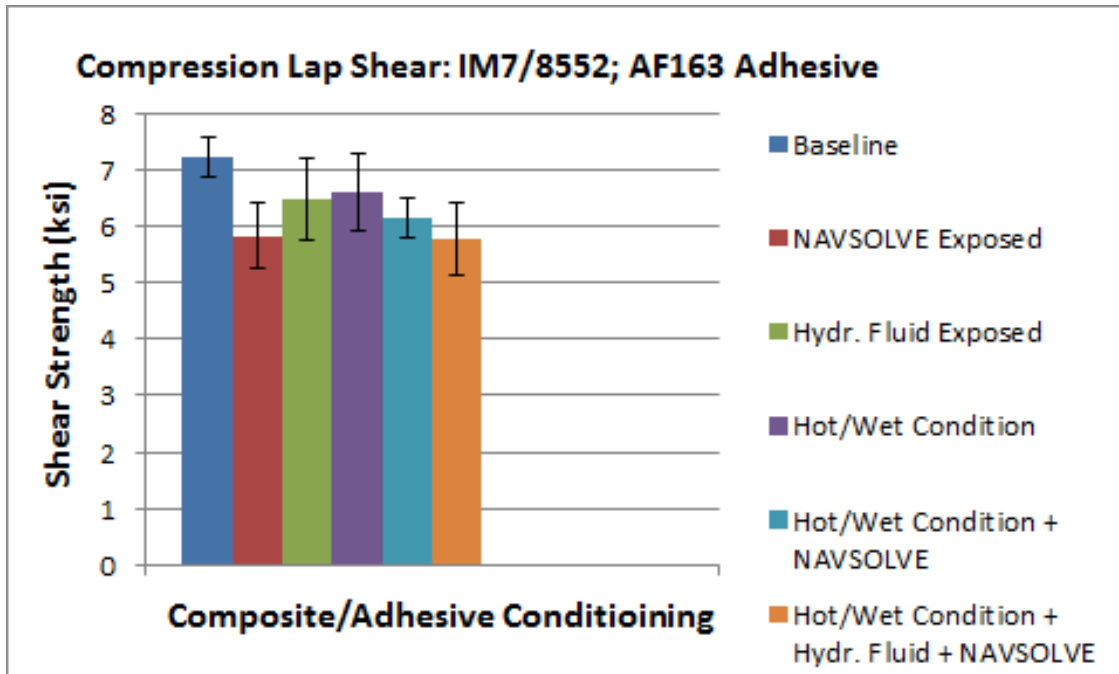


Figure 31. Compression Lap Shear with IM7/8552 Laminate / AF 163-2K Adhesive

Single lap shear results with composite substrates are reported in Figure 32, Figure 33, Figure 34, Figure 35, and Figure 36. For the 9394 adhesive (Figure 32), the FM3002 adhesive (Figure 33), and EA9690 adhesive (Figure 34), for all NAVSOLVE™ exposed conditions, the shear strength values fell within the standard deviation of the baseline value, validating the cleaner does not degrade the adhesive bond-line.

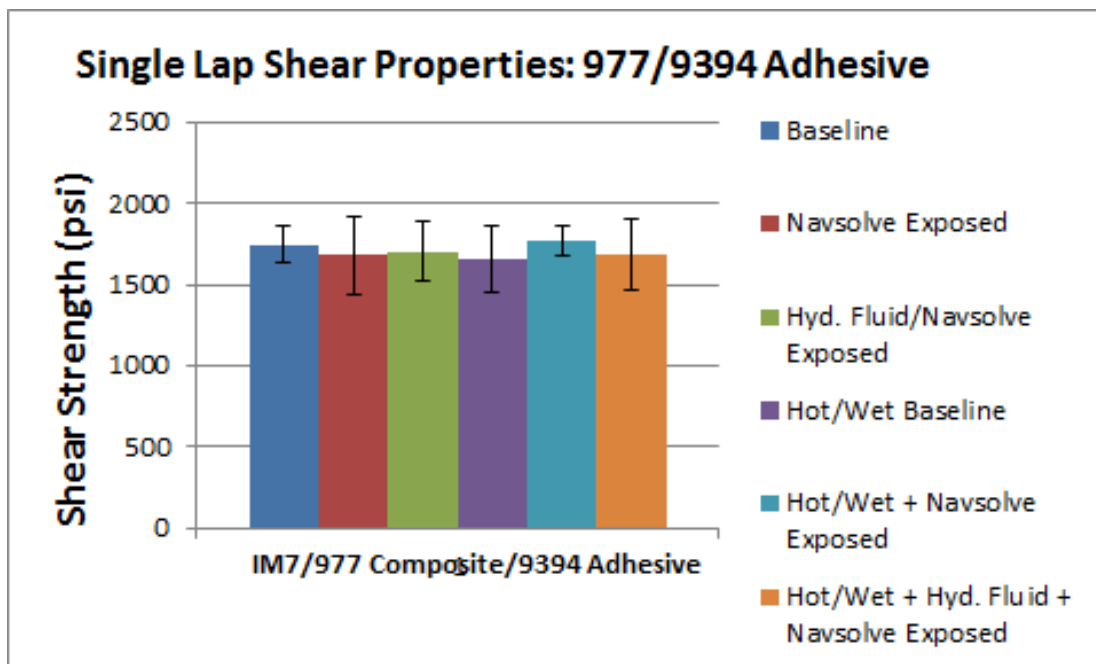


Figure 32. Single Lap Shear with IM7/977-3 Laminate / EA 9394NA Adhesive

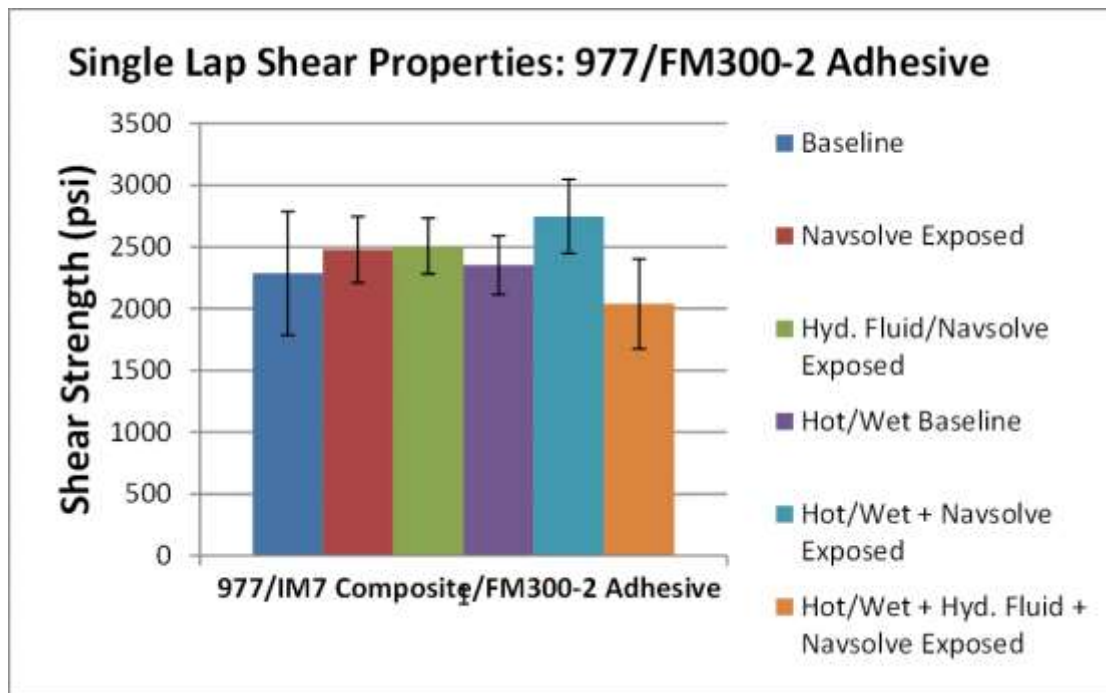


Figure 33. Single Lap Shear with IM7/977-3 Laminate / FM300-2 Adhesive

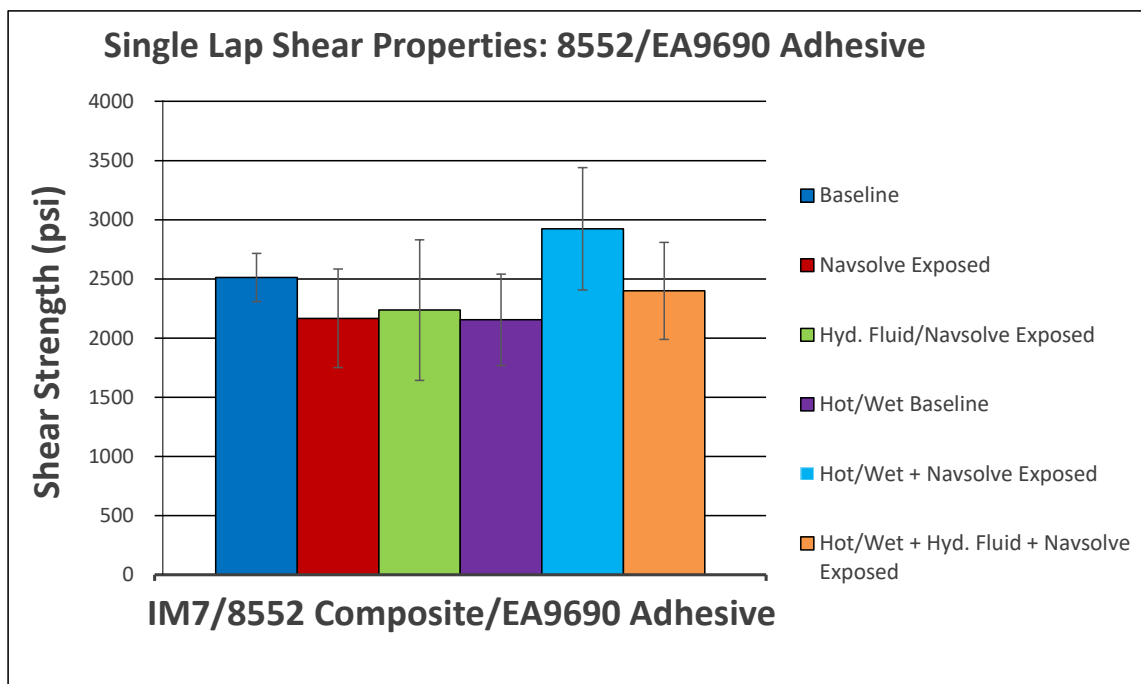


Figure 34. Single Lap Shear with IM7/8552 Laminate / EA9690 Adhesive

Figure 35 shows the Single Lap Shear results in bar graph form for the BMI composite /AF-191 film adhesive bond. Figure 36 displays photomicrographs of the specimens' failure surfaces. All baseline and NAVSOLVE™ exposure conditions showed first ply failure confirming that NAVSOLVE™ does not degrade the bulk adhesive or the adhesive/substrate bond-line (i.e.

Passed). If the adhesive layer had been degraded a cohesive failure would have resulted and if the adhesive/substrate bond had been degraded an adhesive failure at the bond-line would have occurred. All results fall within the standard deviation of the error bars except for the Hot/Wet + Hydraulic Fluid + NAVSOLVE™ condition. Dimensional inspection of the test specimens indicated the lower shear strength measured is attributed to a longer lap length in these samples which results in a larger lap area (given shear strength = shear load/lap area). The longer lap length is specific to this exposure condition as the five specimens are machined from an initial 6” x 4” bonded panel which had a lap length offset from the 1” length standard. The offset results in a 13% greater lap area compared to the baseline Hot/Wet specimens and a 17% greater lap area than the Hot/Wet + NAVSOLVE™ specimens resulting in a calculated lower shear strength value.

Single lap shear results of several legacy adhesives on aluminum substrates after 14 day NAVSOLVETM exposure are reported in Figure 37. No knockdown in lap shear strength was found for any of the legacy adhesives as all the exposure results fall in the standard deviation of the baseline (unexposed) value.

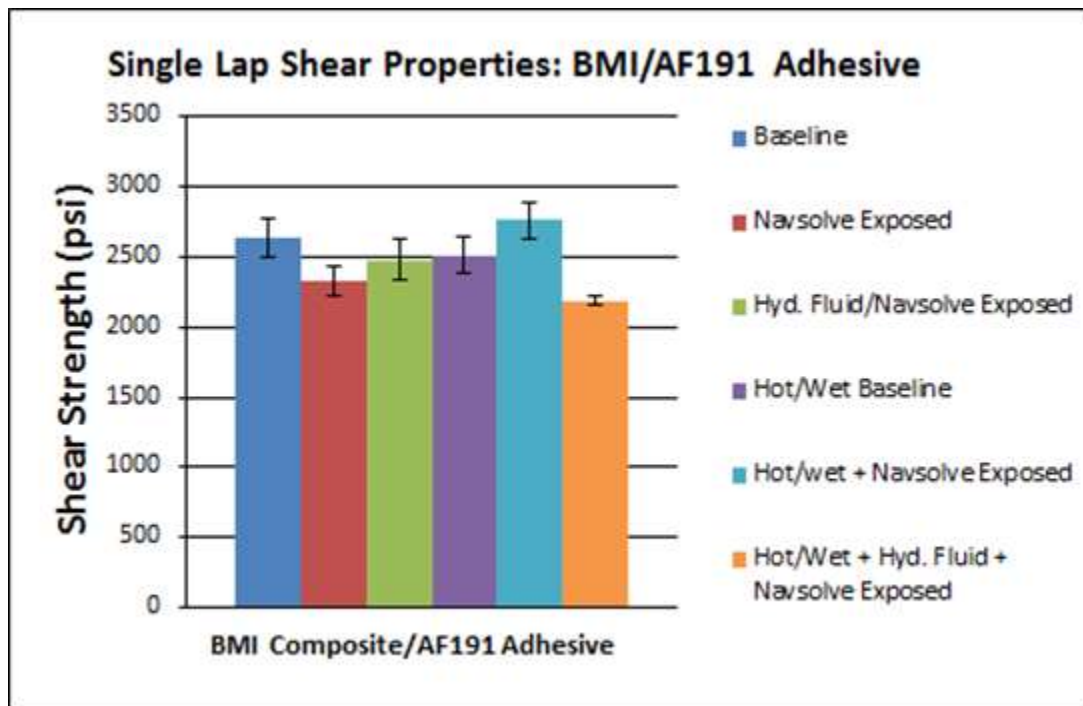


Figure 35. Single Lap Shear Results with BMI Laminate / AF 191 Adhesive

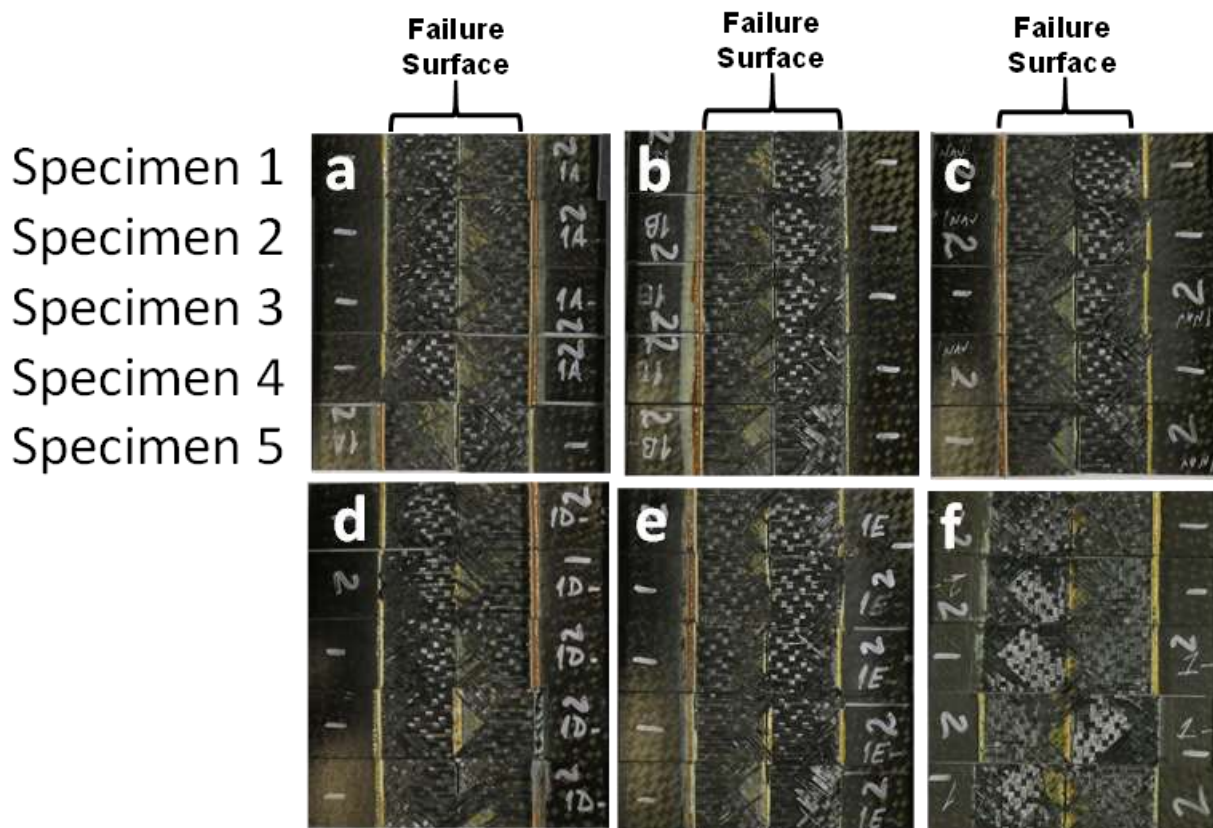


Figure 36. Single Lap Shear first ply failure surfaces of: a) Baseline, b) NAVSOLVE™ exposed, c) NAVSOLVE™ and hydraulic fluid exposed, d) Baseline Hot/Wet, e) Hot/Wet NAVSOLVE™ exposed, and f) Hot/Wet NAVSOLVE™ and hydraulic fluid exposed

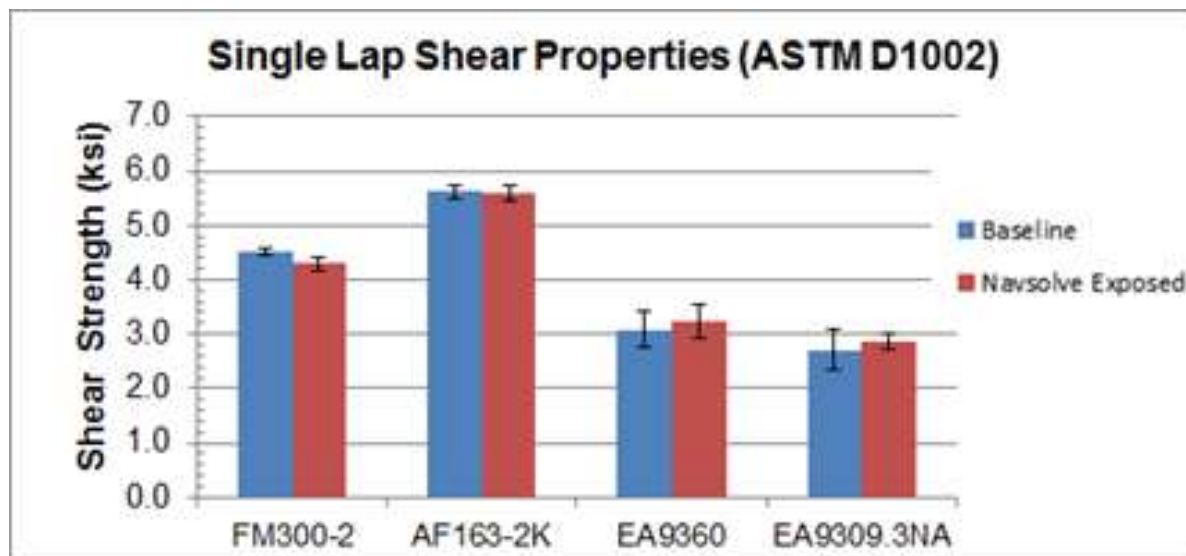


Figure 37. Single Lap Shear Results of Several Adhesives on Aluminum Substrates

6.1.3 Sealant Compatibility Tests

The NAVSOLVE™ also passed all sealant tests on both PR-1826 & PR-1829. The drop in tensile strength was much greater after exposure to acetone (42%) than exposure to NAVSOLVE™ (12%); all specimen values were above the specification minimum of 250 psi (no fluid exposure). The drop in elongation was also greater after exposure to acetone (151% delta) than NAVSOLVE™ (32% delta); all specimens met reduced elongation allowances, typically 100%, following fluid exposures. NAVSOLVE™ exposures had little effect on sealant hardness at the test temperatures (RT and 120°F). NAVSOLVE™ exposure also had little effect on sealant swell or weight change at exposure temperatures (RT and 120°F).

6.2 PERFORMANCE ASSESSMENT SUMMARY – LAB TESTS

Table 14 summarize the performance results for lab tests on bulk and bonded coupons.

Table 14. Performance Objectives – Bulk Laminate Test Results

Laminate Test Method	Laminate Type	Success Criteria	Results
Short Beam Shear Test per ASTM D2344	IM7/977-3	NAVSOLVE™ results fall within standard deviation of baseline	All NAVSOLVE™ results fell within standard deviation of baseline
	IM7/5250-4		
	IM7/8552		
Flexure Test per ASTM D7264	IM7/977-3		
	IM7/5250-4		
	IM7/8552		
±45 Tension (In-Plane Shear) Test per ASTM D3518	IM7/977-3		
	IM7/5250-4		
	IM7/8552		
Open Hole Compression Test per ASTM D6484	IM7/977-3		
	IM7/5250-4		
	IM7/8552		

Table 15. Performance Objectives – Bonded Coupon Test Results

Test Method	Laminate / Core	Adhesive	Success Criteria	Results
Flatwise Tension per ASTM C297	IM7/977-3 / SynCore	N/A	NAVSOLVE™ results fall within standard deviation of baseline	Passed
	IM7/977-3 / Nomex	FM 300		Passed
	IM7/977-3 / Kevlar	FM 300-2		Passed
	IM7/8552 / Nomex	AF 163-2K		Passed
Compression Lap Shear per ASTM D3846	IM7/977-3	EA 9394NA		N/A
	IM7/8552	FM 300		N/A
	IM7/8552	AF 163-2K		N/A
Single Lap Shear per ASTM D5868	IM7/977-3	EA 9394NA		Passed
	IM7/977-3	FM 300-2		Passed
	IM7/5250-4	AF 191		Passed
	IM7/8552	EA9690		Passed
Single Lap Shear per ASTM D1002	Aluminum	FM 300-2		Passed
	Aluminum	AF 163-2K		Passed
	Aluminum	EA 9360		Passed
	Aluminum	EA 9309.3		Passed

6.3 FIELD TESTS & DEMONSTRATIONS

6.3.1 FRC-SouthEast, NAS Jacksonville, FL

FRC-Southeast completed their NAVSOLVE™ cleaning/repair site demonstration on the UAV wing section during September 7-9, 2016. A six-inch diameter section of composite skin was removed from the wing exposing the honeycomb core. The core was cleaned with NAVSOLVE™ removing hydraulic fluid contamination. Next the repair area was vacuum heat treated per LPS 740B to dry the repair area and remove any residual hydraulic fluid. Inspection of repair area and breather cloth after drying showed no indication of hydraulic fluid contamination confirming the cleaning efficiency of NAVSOLVE™. Next an adhesively bonded repair patch was cured to the wing section. The repair steps are shown in Figure 38 and final patch in Figure 39.

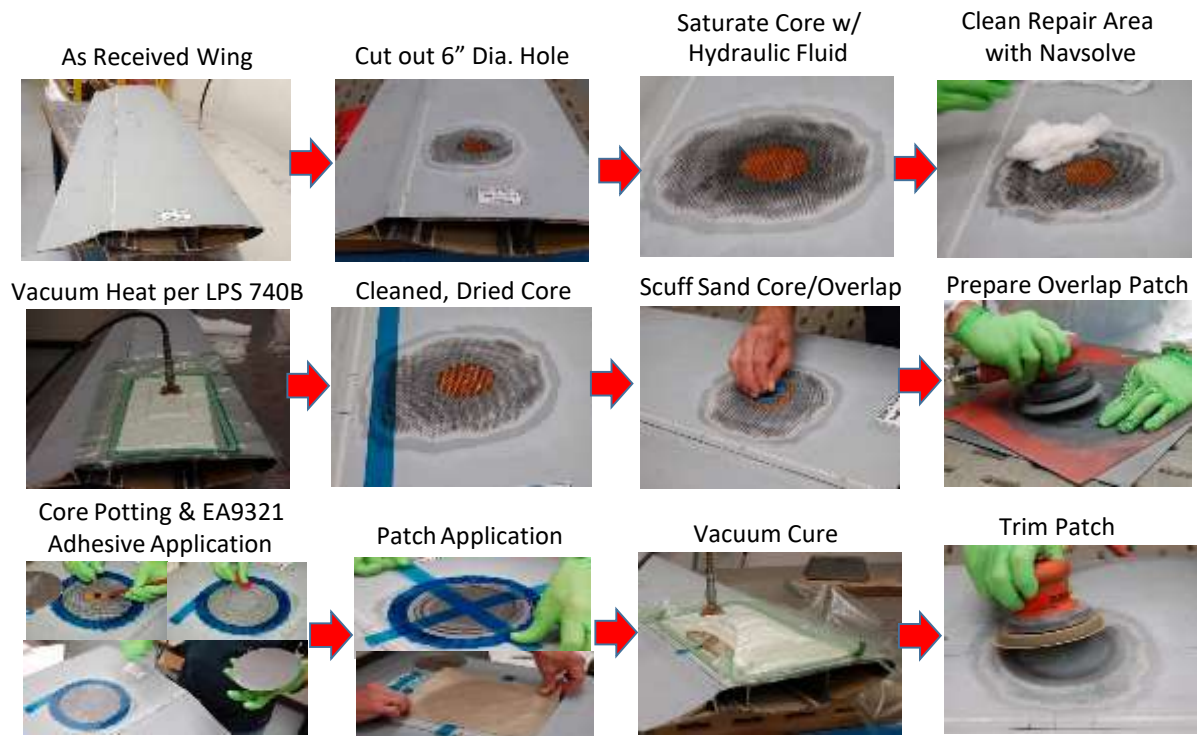


Figure 38. UAV wing section cleaning/repair demonstration

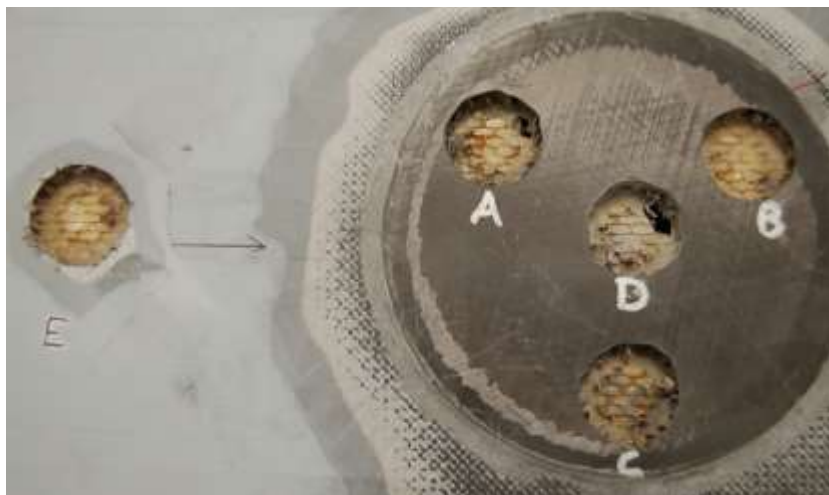


Figure 39. Bonded repair patch

Several PATTI pull tests were performed on the repair patch and compared to a PATTI pull test on an unrepaired section of wing to serve as baseline (see Figure 40). The results of the PATTI test are shown in Figure 41. The failure of the pull out stub was in the core material indicating no NAVSOLVE™ contamination of the adhesive bond, nor failure due to hydraulic fluid contamination. The Pull-Off Tensile Strength (POTS) results also indicate that the potted core repair cleaned with NAVSOLVE™ exceeds the strength of the undamaged area. FRC-SE repair artisans reported no issues with NAVSOLVE™ other than its long dry time. Blowing with shop air and repeated dry wiping accelerated the dry time.



Figure 40. PATTI test set-up; pull stubs bonded, and OML skin/core removed around stub prior to testing



Areas A-C: Repair patch overlap
Area D: Center of repair patch
Area E: Non-exposed

All failures within core / core-to
IML-skin



POTS = 364 psi 259 psi 396 psi 574 psi 187 psi

Figure 41. Pull out results of PATTI test on UAV wing section

6.3.2 Hill Air Force Base, UT

The Hill AFB site demonstration was performed June 13-15th, 2017. The cleaning demonstration consisted of three tests: 1) a NAVSOLVE™ wipe cleaning of a F-35 BMI composite laminate followed by a water break test per T.O.1-1-8; Section 3.1.1.1., 2) a wipe cleaning and repaint of a BMI composite laminate followed by both a PATTI test per ASTM D4541 and paint adhesion tape test per ASTM D3359, and 3) a vacuum assisted cleaning demonstration performed on a large F-35 composite component.

Figure 42 a-d shows the results of the NAVSOLVE™ wipe cleaning followed by water break test. A hydraulic fluid stain was first applied to the composite laminate surface (Figure 39a). DI water was sprayed on the stain to show water drop beading indicating an unclean surface. Next, the stained surface was wipe cleaned with NAVSOLVE™ (Figure 39b) and then the surface was dried with filtered compressed air (Figure 39c). Figure 39d shows the water break test performed on the cleaned composite surface with no evidence of water beading observed (i.e. surface passes test).

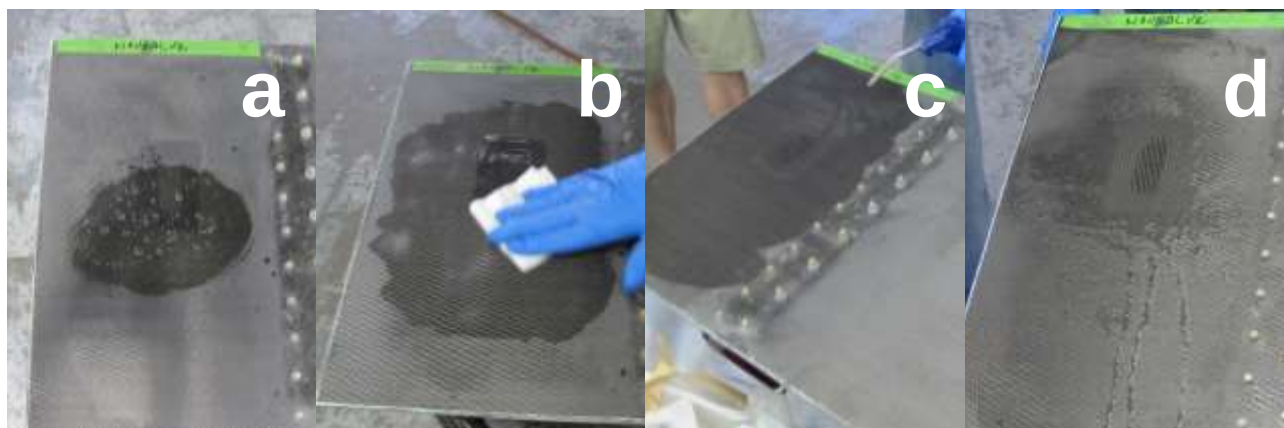


Figure 42. Water Break Test on NAVSOLVE™ cleaned composite surface

Next the panels were submitted to the Aircraft Paint facility for application of the base primers and JSF paint. The painted panels were shipped back to NAVAIR Pax for follow-on paint adhesion tests to demonstrate the NAVSOLVE™ cleaner does not leave a residual on the cleaned surface which might degrade paint adhesion. These tests included ASTM D4541 (PATTI Test AF requirement) and ASTM D3359 (tape adhesion test Navy requirement) for the paint.

As a follow on tasks to support an F-22 part-cleaning application, NAVAIR PAX prepared PR 1829 B1/2 sealant samples to perform fluid sensitivity tests with NAVSOLVE™ exposure. The sealant compatibility tests included Weight Loss and Volume Swell (SAE AS5127/1 (Section 7.5)), Tensile/Elongation Test (SAE AS5127/1 (Section 7.7)), and Hardness Test (ASTM D2240). Both PR-1826 & PR-1829 sealants were tested with acetone solvent as the baseline control for comparison to NAVSOLVE™. The paint on the BMI panels successfully passed both ASTM D4541 and ASTM D3359 adhesion tests. Note, the Army required adhesion test, TM 1-1500-345-23; 4-16B, was completed during the Army TASMG (Fresno) site demonstration.

Figure 43 a-c shows the results of the NAVSOLVE™ wipe cleaning/repaint demonstration followed by paint PATTI adhesion tests. Figure 43a shows the initial NAVSOLVE™ wipe cleaning

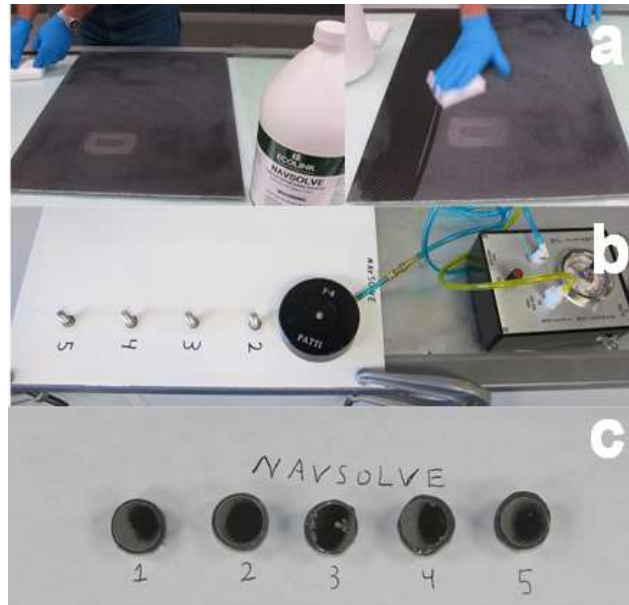


Figure 43. a) NAVSOLVE™ wipe cleaning of composite surface, b) PATTI setup with five stubs bonded to painted surface, c) de-bond surface of five PATTI stubs

of the composite panel. After wipe cleaning the panel was primed/painted with PRF 85285 (white) paint in the Hill AFB paint shop per F-35 process specification. Five PATTI stubs were next bonded to the cured paint surface per ASTM D4541 (see Figure 43b). Figure 43c shows the disbond surface of the five PATTI stubs after the test. All stubs indicate bond failure at the primer/paint interface indicating the NAVSOLVE™ wipe cleaning did not deposit any contaminate that would degrade the bond strength between the composite surface and primer layer (i.e. NAVSOLVE™ wipe cleaning passes ASTM D4541).

Figure 44 shows the results on the ASTM D3359 tape adhesion test on the same painted BMI

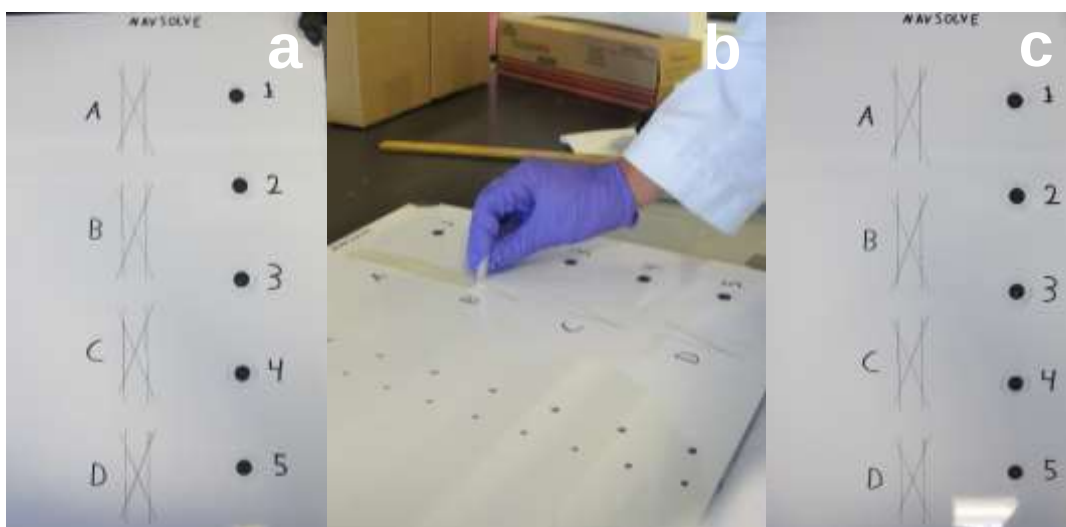


Figure 44. a) Initial scribed “X”s in paint layer, b) tape peel test, c) final scribed “X”

composite panel. Four “X’s” were scribed into the paint layer ensuring the cut did not damage the underlying composite surface (see Figure 44a). Tape was applied to each “X”, then rapidly peeled off per ASTM D3359 (see Figure 44b). The cross-over points of each cut were next examined for any peeling or delamination of the paint layer (see Figure 44c). No damage was observed; based on ASTM D3359, the cuts were designated Category “5A”, Passed

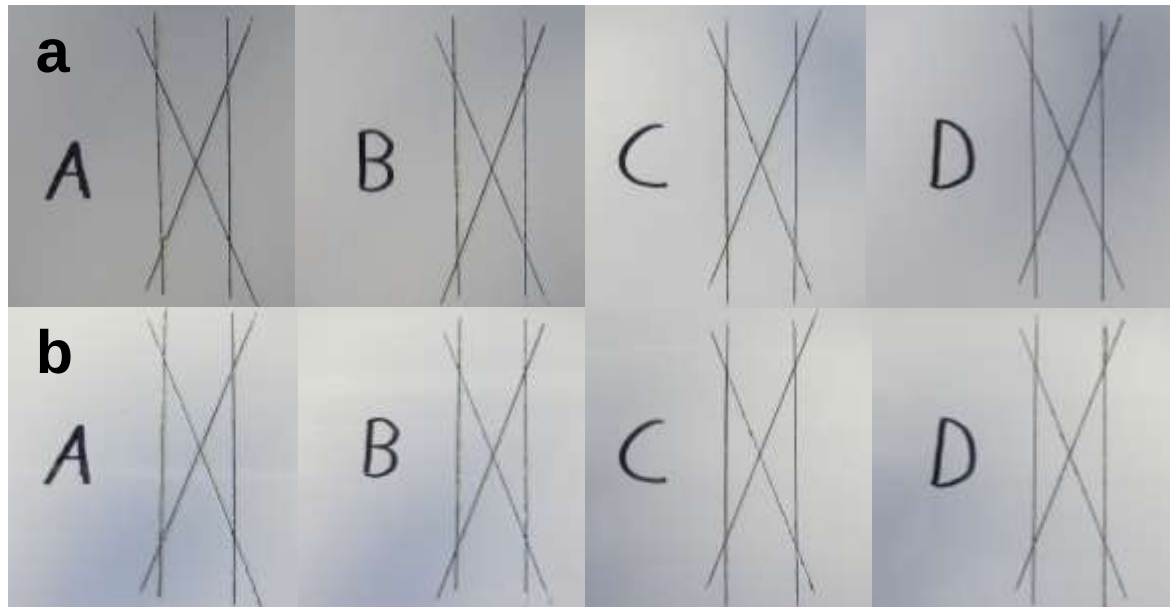


Figure 45. Results of ASTM D3359 test: Crosshatch cuts in paint layer a) before and b) after tape adhesion test

The vacuum-assisted cleaning demonstration was attended by a large number of the Hill AFB composite maintenance artisans. Several artisans pointed out relevance to other F-35 and F-22 parts that have recurring issues with heavy grease contamination. Noted was that for transition for use on these parts it would also need to be demonstrated that NAVSOLVE™ does not compromise the paint, coatings, and sealant used on the items.

Figures 46, 47, and 48 show set-up details of the final cleaning process implemented. A large stain of hydraulic fluid was wiped onto the outer mold line (OML) surface of the part for the cleaning demonstration. Three lengths of 3/8" OD x .062" Wall polyethylene Spiral Wrap were attached across the surface of the part, one in the center of the part and the other two near the edges (see Figure 46a) The center tube was used for injection of the cleaner to the part surface while the tubes on the edges of the part serve as liquid collection ports. A large sheet of breather cloth was placed on the OML surface with the spiral wrap tubes placed on top of the breather. The spiral wrap tubes were connected to 1/4" ID x 3/8" OD x 1/16" Wall Flexelene™ SFX polyethylene tubing (see Figure 46b). Two strips of tacky tape were applied around the edge of the OML of the part (to minimize fluid leakage during vacuum bagging), and tacky tape wrapped around the circumference of the tubing to produce a vacuum seal with the vacuum bag (Figure 47). Assorted 3/8" Tube OD Super Speedfit® Polypropylene Shut-Off Valves, Male Pipe Connectors and Swivel Branch Tee Tube Fittings were used to connect the center tube to a one-gallon bottle of NAVSOLVE™ cleaner

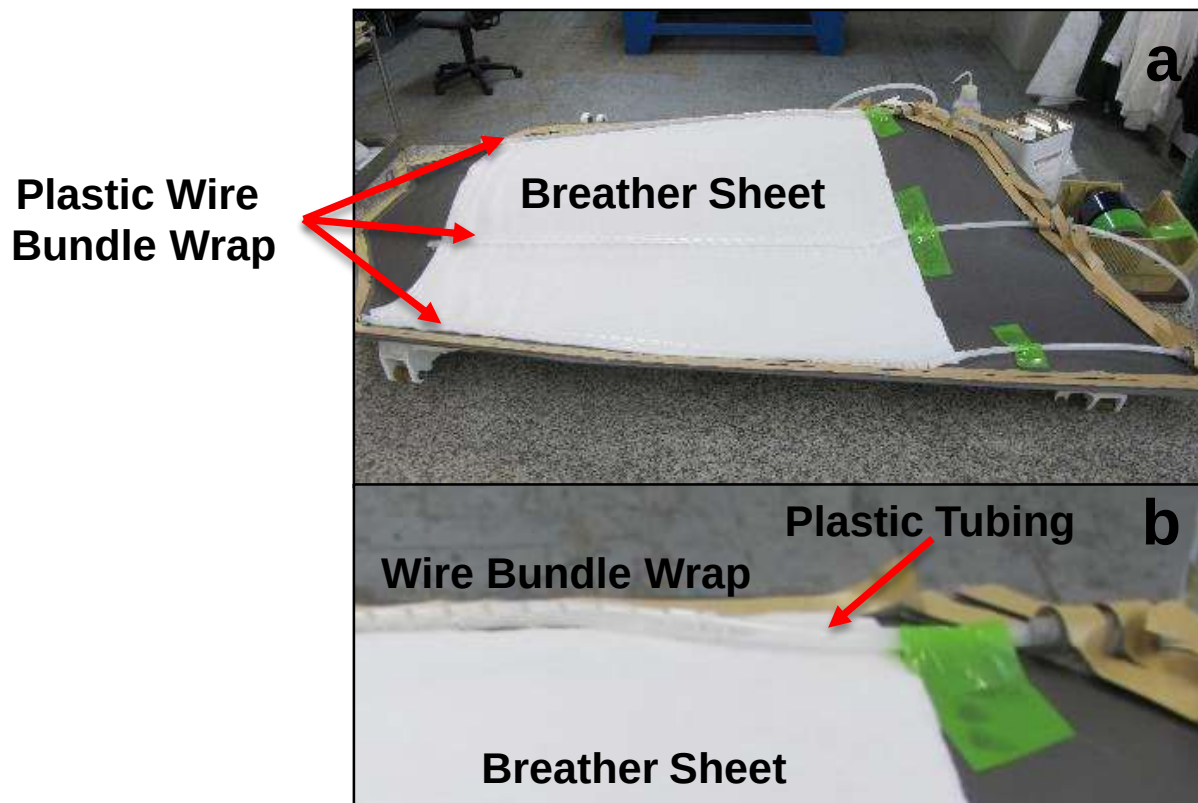


Figure 46. Bagging Setup for Vacuum Assisted Cleaning: a) location of three-wire bundle wraps and b) detail of wire bundle wrap connected to plastic tubing

Tacky Tape for Tubing Vacuum Feedthroughs

Two Strips of
Tacky Tape for
Vacuum Bag

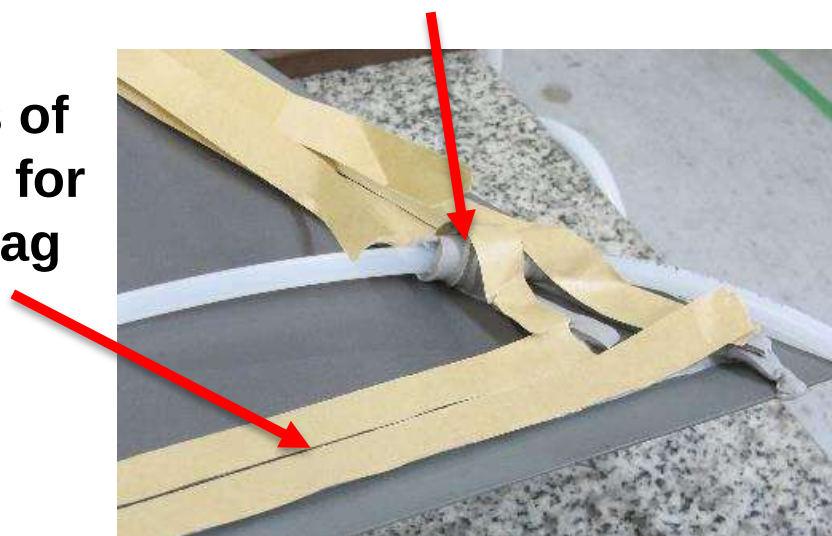


Figure 47. Detail of vacuum seals using tacky tape



Figure 48. Tubing connection to a) VARTM resin trap and b) jug of NAVSOLVE™ cleaner

(Figure 48b) and the two outer collection tubes to a VARTM resin trap (Fiberglast 1500-A; Figure 48a).

Figure 49 shows the steps in the vacuum assisted part cleaning demonstration. First, a large grease stain was applied to the OML surface of the composite door. The part was then vacuum bagged by the Hill composite maintenance artisans per the details described above. The collection tube was inserted directly into the gallon bottle of NAVSOLVE™ (making sure the height of the jug was lower than the height of the part). A vacuum was applied to the VARTM resin trap/bagged part pulling NAVSOLVE™ cleaner up from the bottle, across the part surface, and then collected into the resin trap. The vacuum shut-off valve was quickly opened and closed to agitate the cleaner as it flowed across the part surface, improving the cleaning efficiency. Figure 50 shows a series of images of the flow of NAVSOLVE™ across the part surface. After vacuum cleaning, the bagging material was removed and the residual cleaner was dry wiped from the part surface. After the part surface had dried a water break test was successfully performed confirming the cleanliness of the door surface. The Hill participants commented on the benefits of the reduced odor generated while using the NAVSOLVE™ cleaner compared to acetone and MIBK, easy clean up after the cleaning as the cleaner fluid was contained in the bag and resin trap, and reduced exposure to chemicals using the vacuum bagging cleaning step.



Figure 49. Steps in vacuum assisted cleaning demonstration with NAVSOLVE™ at Hill AFB

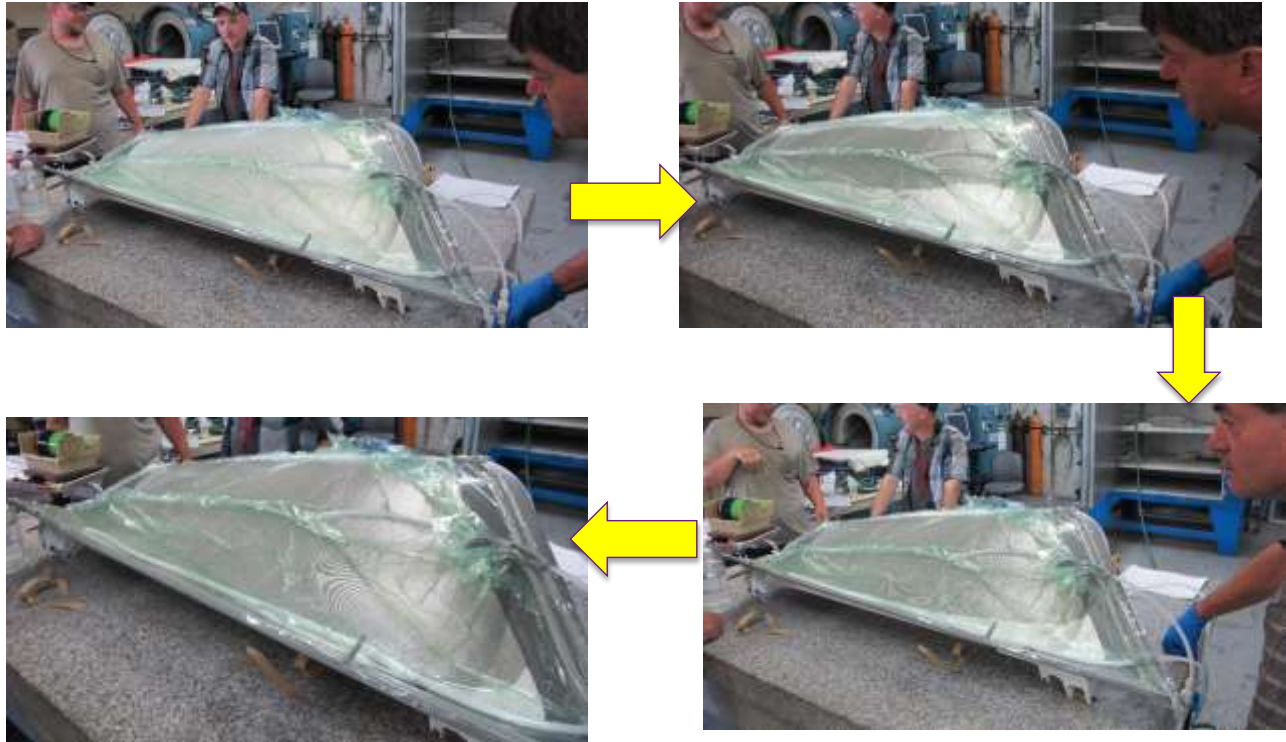


Figure 50. Flow of NAVSOLVE™ across the part surface during vacuum assisted cleaning

6.3.3 Prototype Integration Facility (PIF), Army Redstone Arsenal

Two composite bonded repair demonstrations using NAVSOLVE™ were performed by composite repair artisans on scrap H-47 composite blade sections at the Prototype Integration Facility (PIF), Army Redstone Arsenal. One repair demonstration followed Army TM 1-1500-204-23-11; Section 7 (Honeycomb Bonded Repair Procedures) which used a heated bladder clamp to apply the necessary pressure to cure the adhesive bonded pre-cured composite patches. This repair process was typical for helicopter composite blade repair in the field. Tap tests were performed on the final repair bonds to identify any defects in adhesive/core bond caused by the using NAVSOLVE™ cleaner instead of the approved. No ultrasonic NDI such as A scan was called out in the Army specifications to inspect the final repair bond. The second bonded patch repair demonstration used a new envelope vacuum bagging technique (of interest to the Army) suited for a depot facility. In this demonstration the success of the patch repair was confirmed with PATTI testing (which is not yet approved for Army aircraft bonded composite repair evaluations).

For the bladder clamp based composite repair demonstration, bonded patch repairs were performed on scrap H-47 composite skin/Nomex core helicopter blade sections using pre-cured composite patches. Four bonded patch repairs were executed using the cleaning solvents acetone, MPK (Methyl Propyl Ketone), NAVSOLVE™, and NAVWIPE™ following Army TM 1-1500-204-23-11; Section 7. The bladder clamp-based cure process is what is approved for in-service field repairs where access to vacuum is not readily available. Figure 51 shows the major steps in the bonded patch repair of the helicopter composite blade section using NAVSOLVE™. First, the composite skin of the blade was removed and a three-inch diameter section of Nomex honeycomb core replaced. A pre-cured composite patch was cut out, release ply removed, and bonding surface cleaned with NAVSOLVE™. The sanded surface area around the replaced honeycomb core was

also wiped cleaned with NAVSOLVE™. EA9309.3 adhesive was next applied to the bonding surface of the pre-cured composite patch and the sanded area around the replaced core. The patch was next positioned onto the exposed core area and four thermocouples temporarily secured with blue flashtape around its perimeter. A circular heat blanket was applied over the repair area followed by a bladder clamp attached to the blade section. The adhesively bonded repair was cured under the bladder pressure with a hot bonder programmed with the Army approved cure cycle for EA9309.3 adhesive. Figure 52a shows the final cured composite repair patch. The NAVSOLVE™ cleaned repair patch successfully passed the tap test (Figure 52b). Bonded repairs using the cleaning solvents acetone, MPK (Methyl Propyl Ketone), and NAVWIPE were also performed on composite blade sections using the same procedures described above. No difference was found by the Army composite artisans in the behavior of NAVSOLVE™ compared to the other cleaners approved for use in composite bonded repair except for a longer drying time. However, the longer drying time of NAVSOLVE™ was under the maximum dry time specified in the TM. The Army participants commented on the benefits of the reduced odor generated while using the NAVSOLVE™ cleaner compared to acetone and MPK. NAVSOLVE™ was also found to remove vacuum tacky tape residue on repaired composite parts better than acetone.



Figure 51. Steps in bonded patch repair of helicopter composite blade section using bladder clamp

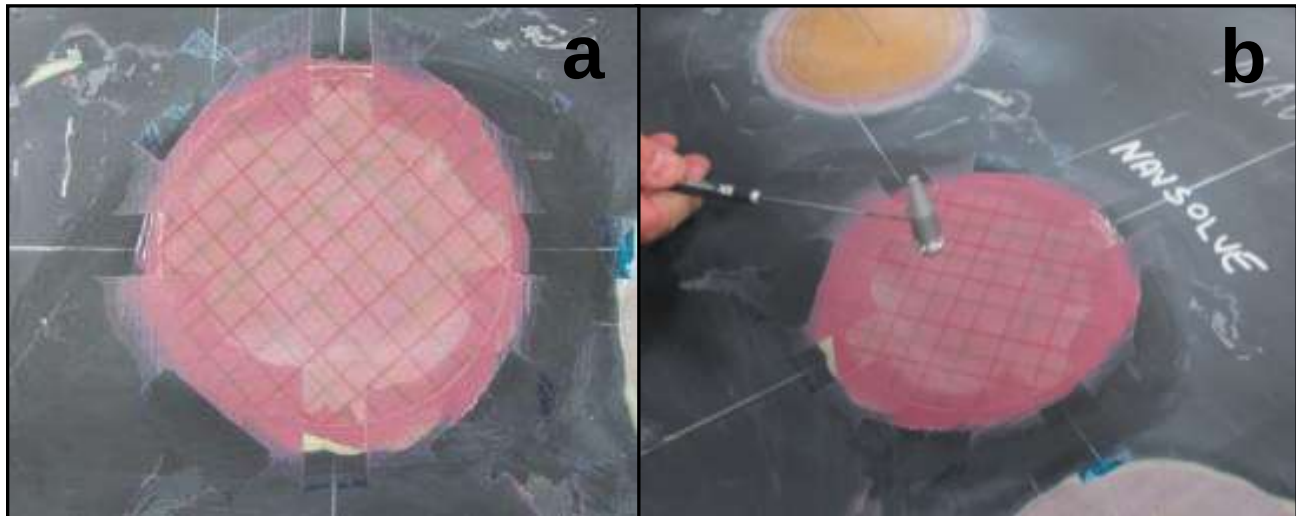


Figure 52. a) Final cured bonded composite repair patch and b) tap test on patch.

A second NAVSOLVE™ cleaning demonstration of a series of composite bonded repairs was performed on a scrap H-47 composite blade section which could accommodate four, six-inch diameter pre-cured composite repair patches. Each patch repair area was cleaned with only one of the four solvents being compared: NAVSOLVE™, NAVWIPE, acetone, and MPK. The size of the repair patches was increased compared to the bladder clamp demonstration to permit a minimum of three PATTI stubs to be tested in the final repair bond area.

Figure 53 shows a few of the major steps in the bonded repair on the composite blade section. The skins and sections of Nomex honeycomb core were removed from the four designated repair areas on the blade section. Replacement core sections were cut out to match the simulated damage cut out area and adhesively bonded in place. The entire blade section was enveloped bagged to cure in place the replacement core sections in a walk-in oven. After cure the bonded cores were sanded flush with the composite skin OML surface and a one-inch wide area on the skin around the core perimeters was scuff sanded with a rotary sander. Four pre-cured S2/8552 composite skins were cut to size. In succession, each cleaner was used to wipe the buffed skin around the perimeter of the core followed by the bonding side of the pre-cured patch using a PURE WIPE V100 (BMS 15-5F Class A/SAE AMS3819 Grade A[52]) cleaning cloth soaked with the cleaner. Next Loctite EA 9309.3 paste adhesive was applied to the one-inch wide perimeter and the pre-cured patch. The patch was next attached to the repair area making sure to match the alignment grid on the pre-cured skin with the existing grid pattern on the blade surface.

After the four repair areas (labeled A, B, C, D) were cleaned and bonded with the pre-cured patches, the entire blade section was enveloped bagged and vacuum cured in the walk-in oven. After cure, each repair area was visually inspected. Army protocol for post cure bonded repair inspection for the helicopter blades is just visual inspection and tap test. Ultrasonic NDI, such as A-scan, is not called out in the Army specifications.

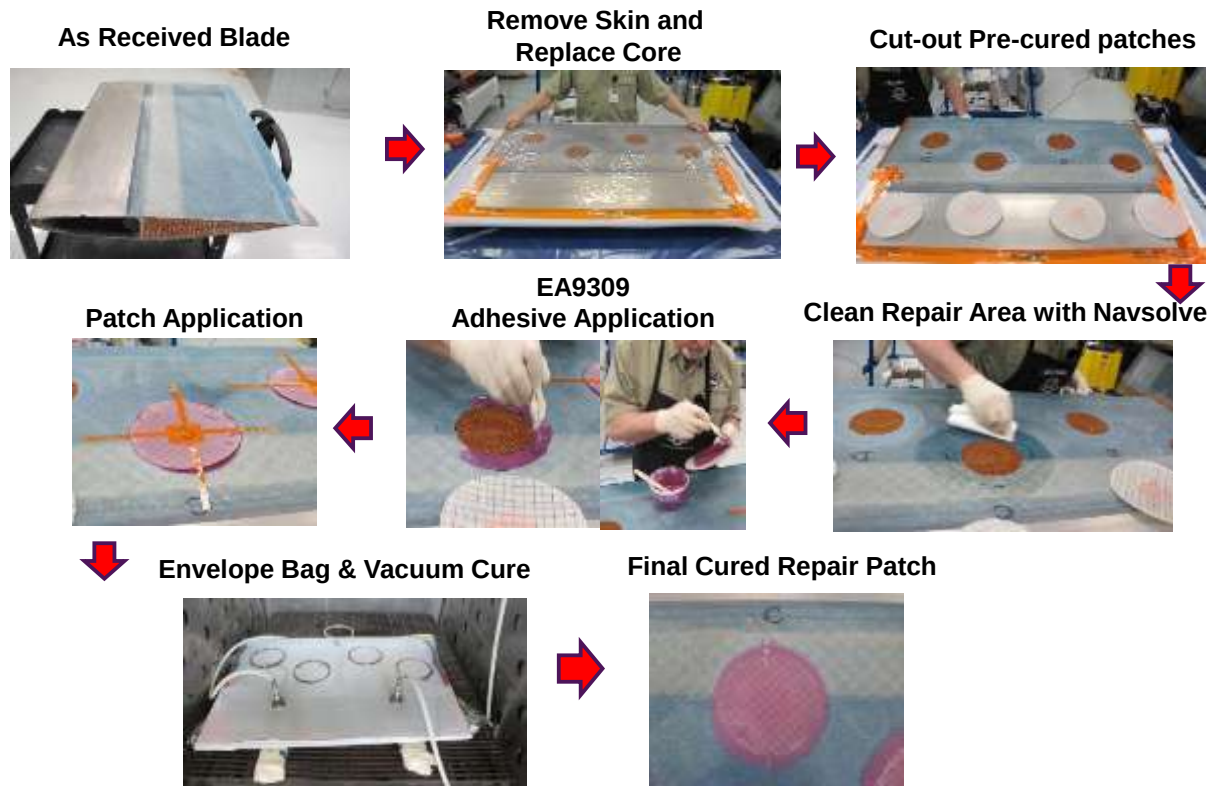


Figure 53. Steps in bonded patch repair of helicopter composite blade section using envelope bagging

As the blade section was too large to allow core drilling in each repair area (for the PATTI testing) with the PIF drill press, the test article was cut into smaller sections with a band saw. With the smaller blade sections, three sites were core drilled into each bonded patch area as well as two sites adjacent to the repairs to serve as baseline controls. PATTI stubs were next bonded to the test sites and allowed to cure at room temperature overnight (see Figure 54). After cure of the stubs, PATTI

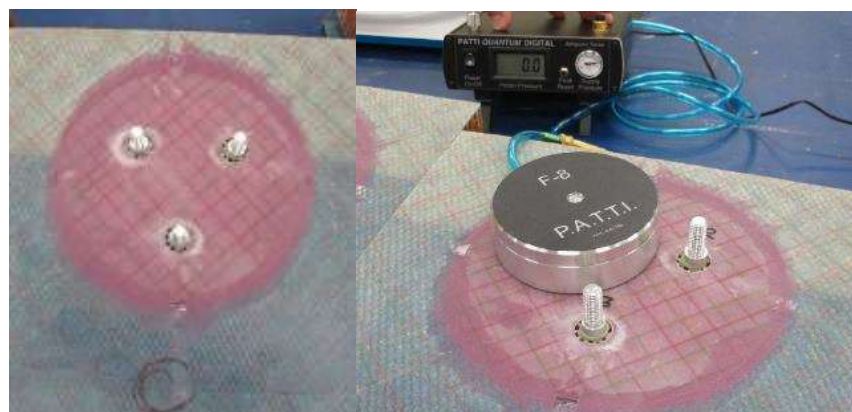


Figure 54. PATTI set-up for NAVSOLVE™ cleaned bonded repair patch

pull tests were performed on the four repair patch areas (A, B, C, D) corresponding to the four cleaners tested. The NAVSOLVE™ cleaned patched passed the PATTI test with all three pull stubs

exhibiting core failure, successfully completing the site demonstration, see Figure 55.



Figure 55. PATTI results for NAVSOLVE™ cleaned, bonded repair patch

6.3.4 Army 1106th TASMG, Hammer Field Armory, Fresno, CA

NAVSOLVE™ cleaning demonstrations were held at TASMG aircraft maintenance facility located at Hammer Field Armory, Fresno, CA on August 9th and 10th, 2018. A vacuum assisted cleaning demonstration with NAVSOLVE™ was performed on a scrap H-60 helicopter composite engine nacelle component for the Army composite repair artisans at the depot, see Figure 56. The cleaning demonstration followed V-22 Process Specification SMP-0021M5 Rev -V22- “Removal of Oil and Grease from Composite Laminate”.

The second demonstration was the cleaning followed by repaint of a UH-60 Cargo Door. The performance objective of this demonstration was to determine if NAVSOLVE™ performs as well as acetone when used as a hand-wipe cleaner on a UH-60 Cargo Door. Acetone was the control solvent for the demonstration. The materials used in the demonstration include: masking tape, acetone per ASTM D329[47], NAVSOLVE™, cloths (CCC-C-46[48]), primer – MIL-PRF-23377K Type I, paint – A/C Green[49], MIL-DTL-64159B Type II[50], pencil eraser, and pressure sensitive tapes – NSN’s:7510-00-550-7124, 7510-00-550-7129, 7510-00-550-7126, or 7510-00-550-7125.

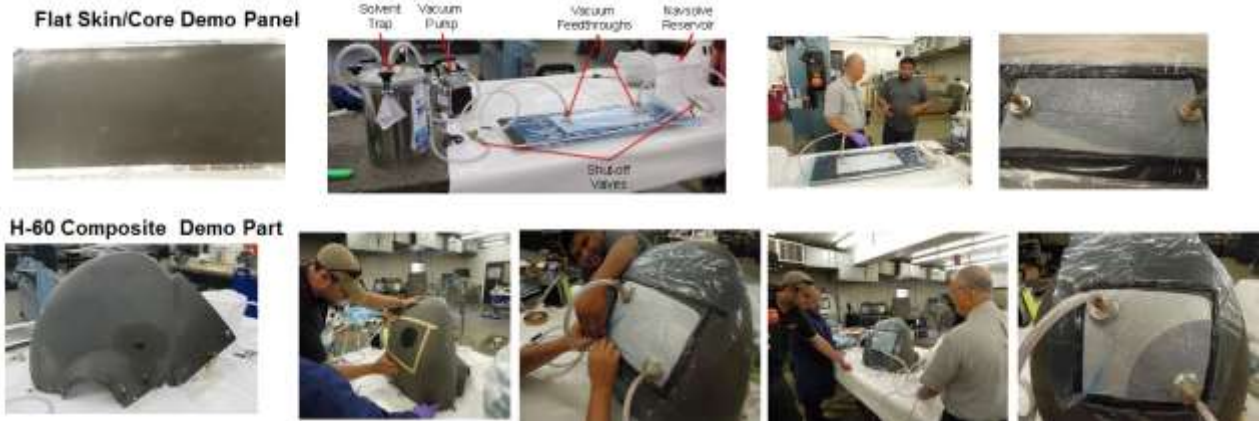


Figure 43. TASMG Vacuum Cleaning Demonstrations

For the demonstration, first three equal sections of the UH-60 cargo door were outlined to be cleaned with acetone, NAVSOLVE™, and MIL-PRF-32295B Type III (see Figure 57). Section 1 was cleaned with acetone, Section 2 was cleaned with NAVSOLVE™, and Section 3 was cleaned with MIL-PRF-32295B Type III. Next Section 1 was sanded with dry abrasive paper (P-P-101[51]). Then Section 1 was wiped four separate times with cloths (CCC-C-46) moistened with acetone. To verify cleanliness of Section 1, the area was flushed with water and inspected for breaks in the water film. If any breaks occurred in the water film, the previous wipe cleaning step was repeated. The number of times the step was repeated was documented.

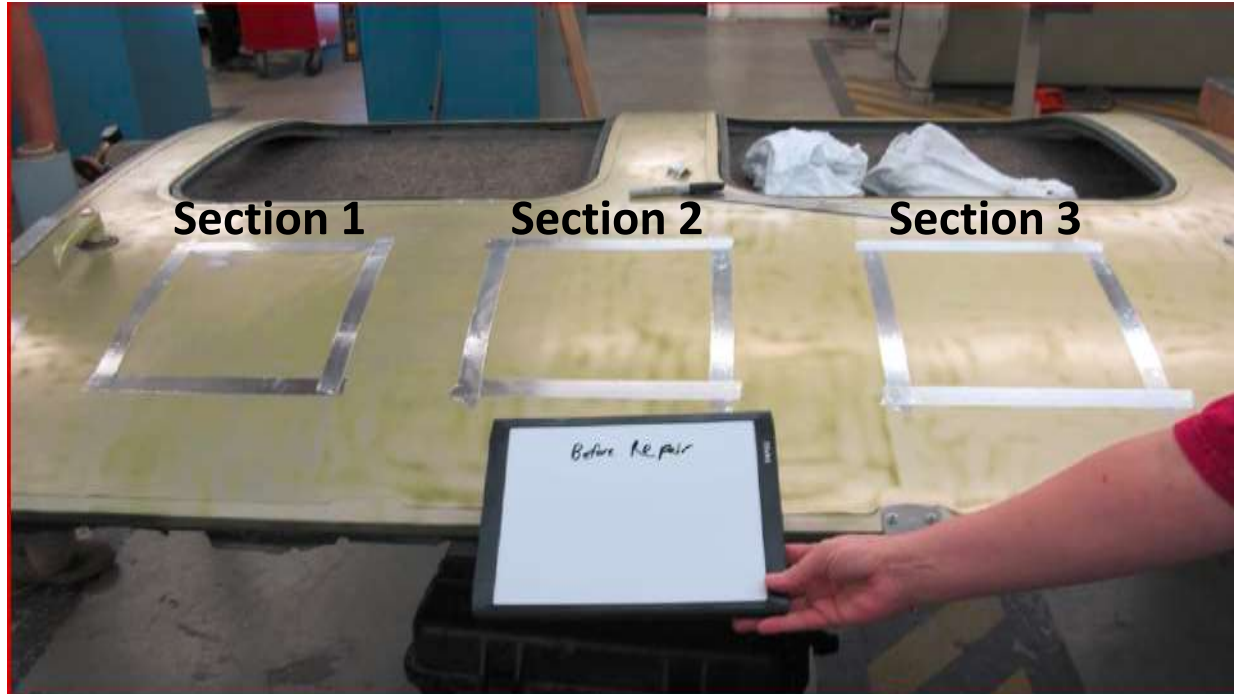


Figure 57. Outlined areas of UH-60 cargo door

Section 2 was sanded with dry abrasive paper (P-P-101). Then Section 2 was wiped four separate times with cloths (CCC-C-46) moistened with NAVSOLVE™ and then allowed to dry for 5

minutes. To verify cleanliness of Section 2, the area was flushed with water and inspected for breaks in the water film (see Figure 58). If any breaks occurred in the water film, the previous NAVSOLVE™ wipe cleaning steps was repeated. The number of times the wipe cleaning step was repeated was documented. Finally, Section 3 was sanded and then cleaned with cloths (CCC-C-46) moistened with MIL-PRF-32295B Type III and cleanliness verified using the same steps as Sections 1 and 2.



Figure 58. Section 2 (NAVSOLVE™): (a) hand wipe cleaning followed by (b) water break test

The cleaning results found the Section 2 area cleaned with NAVSOLVE™ took fifteen minutes to dry compared to twenty seconds for the Section 1 area cleaned with acetone. Section 2 also required two cleaning cycles before reaching a water break free surface compared with one cleaning cycle for the Section 1 area cleaned with acetone. TASM-G is not authorized for compressed air drying of parts to decrease drying time.

Next, the panel was repainted and the integrity of the primer/paint layers to the part surface verified via tape adhesion test TM 1-1500-345-23; 4-16B. In preparation for the paint adhesion tests, the masked off areas of the UH-60 Cargo Door were surface treated, primed, and painted. The paint was cured for seven days and then the non-destructive adhesion test was performed on four areas of Section 1, Section 2, and Section 3. To perform the paint adhesion test, a length of tape was firmly pressed onto the paint surface, rubbing out all air bubbles under the tape using a pencil eraser. Approximately ten seconds was allowed for the test area to return to room temperature (see Figure 59). Next, the free end of the tape, at a rapid speed, was stripped from the paint surface by pulling the tape back upon itself at 180° (in such a manner that the tape is folded back on itself during the procedure). If bare spots were seen, then the paint adhesion had failed, indicating the cleaning step was not adequate. The tape adhesion test was performed on four areas of Sections 1, 2, and 3. In each Section no bare spots were observed where the paint might have been removed demonstrating NAVSOLVE™ cleaning efficiency was comparable to acetone (see Figure 60).

Results of the cleaning demonstrations were presented to base senior Army management and environmental POCs on the last day of the visit. Feedback on the results were all positive.

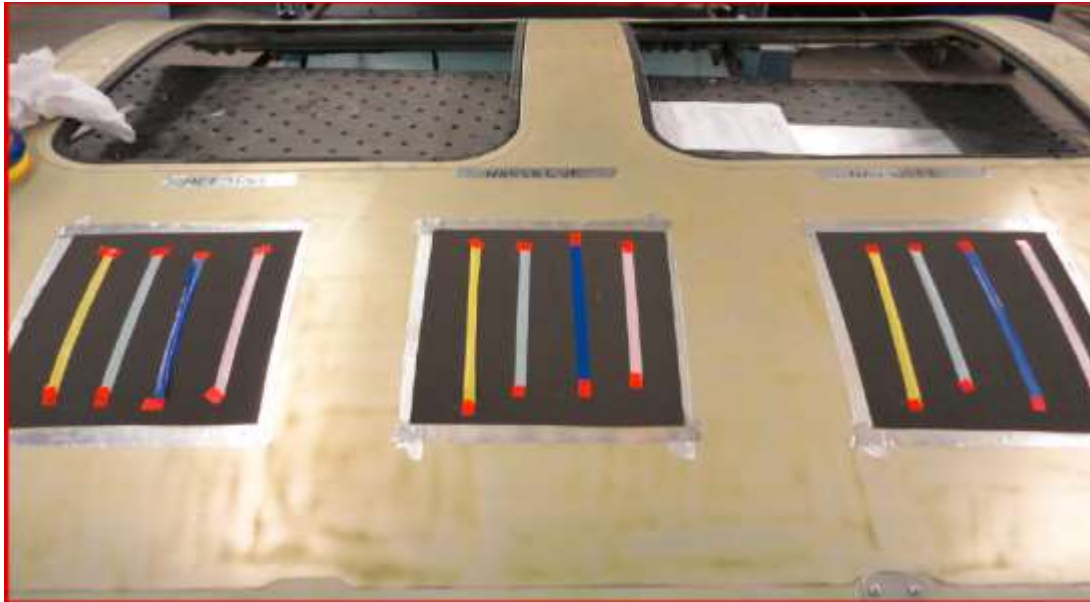


Figure 59. Pressure sensitive tape applied to Section 1, Section 2, and Section 3

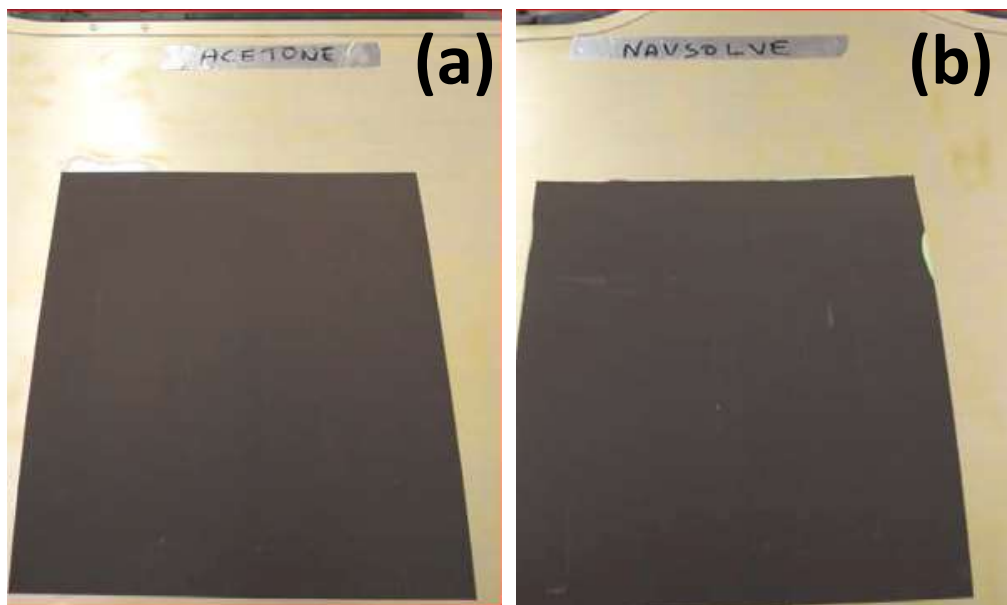


Figure 60. (a) Section (Acetone) and (b) Section 2 (NAVSOLVE™) after Adhesion Test; No bare spots

6.3.5 Camp Pendleton MCAS, CA

The NAVSOLVE™ Site Demonstration at Pendleton Marine Corps Base, CA occurred 29 October – 1 November, 2017. The demonstration was held in the Marine Aviation Logistics Squadron 39 (MALS-39), Marine Aircraft Group 39 (MAG-39) of the 3rd Marine Aircraft Wing. V-22 related components for the site demonstration were provided by the Marine Medium Tiltrotor (V-22) Squadron 164 (VMM-164). The demonstration started in the MALS-39 GSE W/C 940- SE

Component Repair Branch. As the branch is not approved to perform bonded composite repairs, the demonstrations were restricted to part cleaning examples. The V-22 components for degreasing/cleaning were two carbon fiber/polymer composite intercostal parts from the right hand nacelle (see Figure 61). Project PI's first demonstrated cleaning with NAVSOLVE™ on each side of the first part. For the second part the shop artisans performed the cleaning with the solvents and their feedback recorded on the reporting sheets provided. The cleaning exercise included wipe cleaning and the use of heavy duty spray bottles with adjustable nozzles (see Figure 62). The final cleaned parts are shown in Figure 63 and Figure 64.

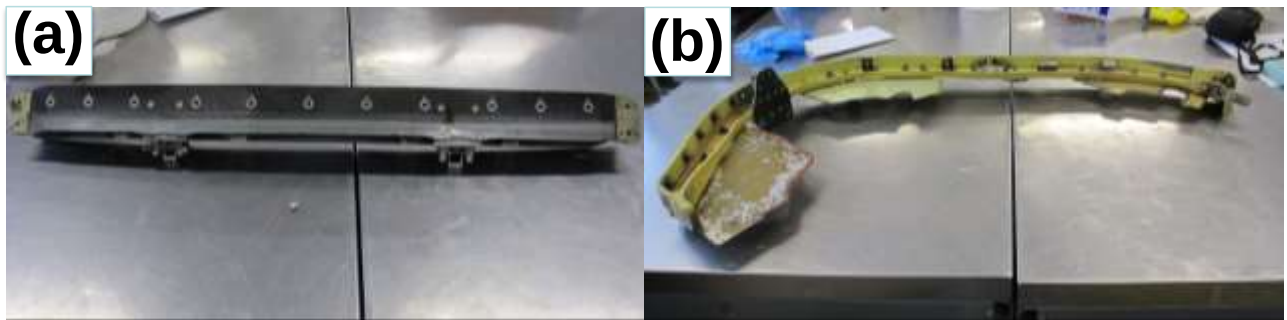


Figure 61. V-22 cleaning demonstration parts, (a) unprimed and (b) primed



Figure 62. Cleaning trials on V-22 demonstration composite part



Figure 63. Final NAVSOLVE™ cleaned unpainted V-22 composite demonstration part



Figure 64. Final primed V-22 composite demonstration part cleaned with NAVSOLVE™

The second demonstration was on the flight-line and entailed degreasing/cleaning of the central rotor hub of a V-22 blade assembly. The shop floor artisan conducted the cleaning demonstration with NAVSOLVE™ for the bottom portion of the hub (Figure 65). The shop artisan performed the cleaning with the cleaner and their feedback were positive and supportive.

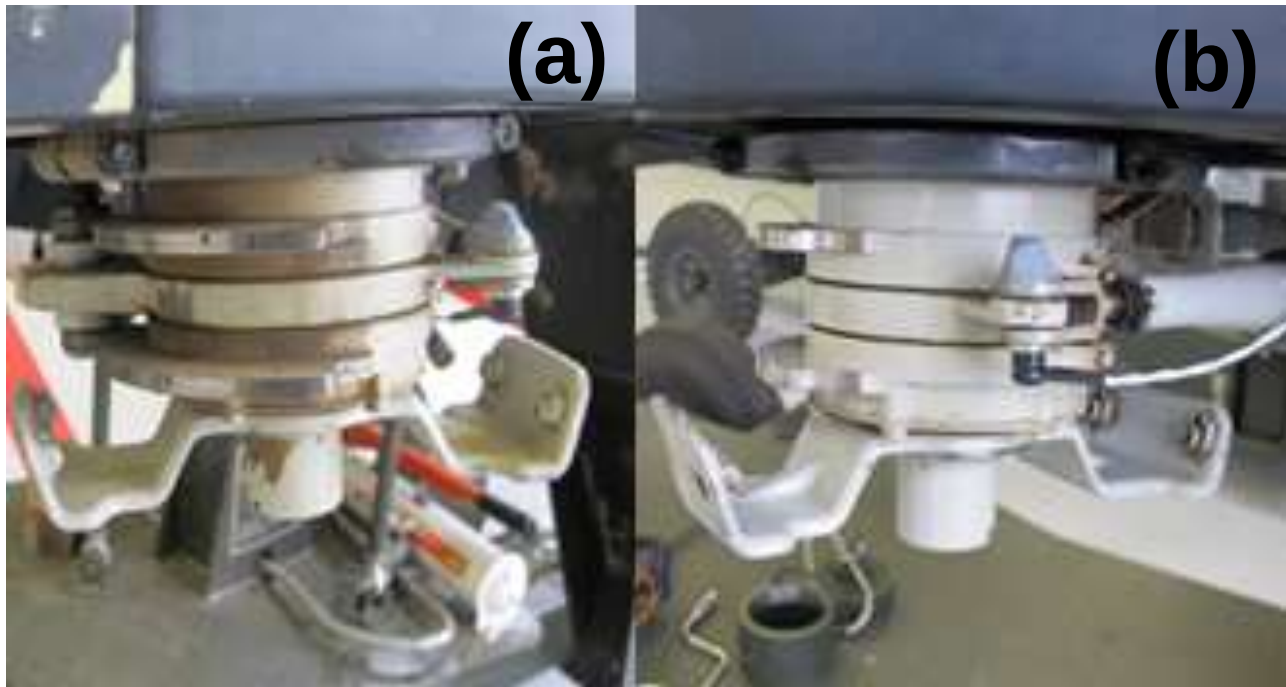


Figure 65. Final primed V-22 composite demonstration part cleaned with NAVSOLVE™

6.3.6 Naval Air Station Lemoore, CA

The NAVSOLVE™ site demonstration at Naval Air Station Lemoore, CA occurred 11-12 December, 2017. The demonstrations were held in the Commander Strike Fighter Wing, Pacific (CSFWP) and Fleet Readiness Center West. The first cleaning demonstration was on a small F/A-18 composite part with heavy grease contamination, see Figure 66. The cleaning demonstration was successful. The second demonstration was on the F/A flight line and entailed cleaning the interior of an open bay of an F/A-18, see Figure 67. When using the cleaner called out in the



Figure 66. Cleaning demonstration with NAVSOLVE™ on F/A-18 part contaminated with heavy grease

manual, the support technicians had to rotate out every minute due to the strong odor emitted by the standard cleaner. When cleaning the bay with NAVSOLVE™ this rotation step was not necessary.

Results of the cleaning demonstrations were presented to the F/A-18 CSFWP leads and hazmat coordinator. Feedback on the demonstration results were all positive. The leads stated, though, that before approving use of NAVSOLVE™, it would need to be demonstrated that the cleaner does not affect LO (low observable) coatings.



Figure 67. Cleaning demonstration with NAVSOLVE™ of F/A-18 bay on flight-line

6.4 PERFORMANCE OBJECTIVES SUMMARY - DEMONSTRATIONS

Table 16 and Table 17 summarize the results of the demonstrations both for cleaning and for composite repair.

Table 16. Performance Objectives – Part Cleaning Demonstration Results

Demonstration	Test Method	Data Requirements	Success Criteria	Results
Hill AFB F-35 BMI Panel Cleaning for Repaint	Water break	T.O. 1-1-8	Pass water break inspection	Passed
	PATTI	ASTM D4541	Failure at primer interface	Passed
	Paint Adhesion Tape Test	ASTM D3359	No peel or removal of paint	Passed
TASMG H-60 Part Cleaning for Repaint	Paint Adhesion Tape Test	TM 1-1500-345-23; 4-16B	No peel or removal of paint	Passed
Lemoore F/A-18 Door Cleaning	Feedback from shop floor Marine	N/A	No additional training required	Passed
Pendleton MCAS Composite Intercostal & Rotor Hub Cleaning	Feedback from shop floor Serviceman	N/A	No additional training required	Passed
Hill AFB F-35 Door Cleaning	Water break	T.O. 1-1-8	Pass water break inspection	Passed

Table 17. Performance Objectives – Bonded Repair Demonstration Results

Demonstration	Test Method	Data Requirements	Success Criteria	Results
Redstone H-47 Blade Bonded Repair	PATTI	ASTM D4541	Honeycomb core failure	Passed
	Tap Test	TM 1-1500-345-11; Section 7	Pass tap test	Passed
FRC-SE UAV Wing Repair	PATTI	ASTM D4541	Honeycomb core failure	Passed
NAVSOLVE™ ease of use vs current shop cleaners	Feedback from shop floor artisans	N/A	No additional training required	Passed

7 COST ASSESSMENT

The primary goal of the program was to implement a more environmentally safe solvent for cleaning composite parts, however, savings are realized through reduced repair and maintenance costs and costs of disposal of hazardous waste associated with current solvents. The transitioned technology will provide a more efficient, cost effective, and environmentally compliant means for cleaning composite aircraft components.

7.1 COST ANALYSIS & COMPARISON

The cost analysis for transitioning the NAVSOLVE™ cleaner is based on several cost factors which include initial implementation costs, operation and maintenance costs, and indirect environmental related costs. With respect to implementation (i.e. startup) costs, they will be minimal, as current depot equipment, operators, and procedures will be used. The NAVSOLVE™ cleaner is only replacing the existing hazardous solvents. NAVSOLVE™ costs more than the current solvents but the difference is not significant. This material cost difference could affect operational costs depending on the number of vacuum rinse cycles required to effectively remove fluid contamination from the part. As such, the amount of cleaner used for the demonstrations was tracked to support final technology cost assessment.

NAVSOLVE™ also has a lower vapor pressure than the solvents currently used which results in a longer drying time from a surface. This property might also impact the overall time to complete a repair which would also impact operational cost. During the demonstrations, overall repair times using NAVSOLVE™ were tracked and compared to average times for similar procedures using current hazardous solvents as well as to requirements identified in aircraft or general series manuals. The cost of the new cleaner in the area of compliance and environmental management will be minimal due to being free of hazardous air pollutants (HAP).

7.1.1 ROI Analysis

As the cost of NAVSOLVE™ is greater than that of current noncompliant solvents (i.e. MIBK,

MEK, hexane) the overall cost savings is based on reduction in the scrap rate of expensive composite parts. Though cost savings will initially be attained on the fielded V-22 and F/A-18's which incorporate a high percentage of structural composite parts, the ultimate ROI for waste and cost reductions will be realized on the F-35. Although not widely fielded yet, the improved cleaning procedure would affect the 2,443 F-35's the DoD is slated to purchase and support over a 40-year lifecycle. There are also no additional hazmat waste disposal costs with using NAVSOLVE™ ; it can be discarded with base standard waste streams. So the impact of this cost and waste reduction to the DoD Operations and Maintenance (O&M) budget over the lifetime of these aircraft is significant.

Overall, estimated savings for the Navy and DoD are based on the cost of startup operations (including LPS updates) and maintenance costs, as-well-as potential re-cycling costs. The cost avoidance of replacing high-VOC and hazardous cleaners with a low-VOC and HAP-free product will ultimately reduce the maintenance costs of aircraft and weapon systems. In addition to cost savings, the new technology will meet the current environmental regulations regarding VOC emissions and thus avoid the cost of non-compliance penalties.

8 IMPLEMENTATION ISSUES

The transitioned technology will provide an efficient and environmentally compliant means to clean composite aircraft components. No additional equipment or materials are required at the sites for implementation of NAVSOLVE™. No scale up issues restrict transition of NAVSOLVE™ to the composite shops in the Services' aircraft maintenance facilities. The cleaner has been qualified to both MIL-PRF-32295B and the new MIL-PRF-32597 specifications. NAVSOLVE™ is commercially available from two vendors: Armick Chemicals in Grand Rapids, MI and Ecolink in Tucker, GA

The field test sites in the program are key customers for transition and will be the first DoD users. The primary stakeholders are the Fleet Support Teams for the respective aircraft model (F-35, V-33, F/A-18, H-53K, H-60) and the maintenance sites. Hill AFB is currently planned as the depot for both the Air Force's F-35A and Navy's F-35C carrier version. The ultimate ROI for waste and cost reductions will be realized on the F-35. The technology would impact the 2,443 F-35's the DoD is to purchase and support over a forty-year lifecycle.

Future efforts to implement NAVSOLVE™ in fleet composite maintenance and repair activities will require update of associated local process specifications, Tech Orders, and/or process documentation at each respective facility. A first step for the NAVY is update of the General Composite Repair Manual (NAVAIR 01-1A-21) approving use of NAVSOLVE™ for certain procedures. The custodian for NAVAIR 01-1A-21 is NAVAIR FRC South-West in San Diego. Both Air Force and NAVAIR stakeholders for fixed wing fighter aircraft (ex. F-22, F35) indicated NAVSOLVE™ also must be qualified for use on low observable materials before use on these specific aircraft components. A DLA funded effort completed this qualification.

There are several stakeholders for this project relative to the three demonstration sites. For the V-

22 repair demonstration at Camp Pendleton, the primary stakeholder is the V-22 Fleet Support Team (FST) that includes the Senior Structures Engineer (AIR 4.3.3.1), the Strength and Analysis Technical Team (AIR 4.3.3.5). For the demonstration at FRC-South-East (Jacksonville), the primary stakeholders are the F/A-18 FST and the Environmental/Hazmat Group (AIR 6.5.3). For the demonstration at Hill AFB the primary stakeholders are the F-22 and F-35 Depot Maintenance support management teams. The additional stakeholders consist of users, program managers, process owners, process custodians, and any other personnel that are required to change the process documentation.

The tests performed during the course of this project were the result of coordinated input from many stakeholders including program office air worthiness POC's, base and program HAZMAT coordinators, material SME's, and depot maintenance and repair engineers and artisans. The final implementation of the NAVSOLVE™ cleaner requires stakeholder authorizations through various site/platform specific specifications (i.e. Local Process Specifications) and general NAVAIR technical specifications and manuals (i.e. MIL-PRF-32295B, NAVAIR 01-1A-509 Manual, NAVAIR 01-1A-21 Repair Manual).

During the course of the effort the consensus of NAVAIR AIR 4.3.4.2. and the stakeholders was that instead of revising MIL-PRF-32295B specification to include cleaning of composite aircraft parts a new cleaning specification specific to composite materials would be implemented. The program plan initially proposed updating MIL-PRF-32295B to include cleaners for composite materials to document the NAVSOLVE™ qualification results. As MIL-PRF-32295B is focused on cleaners for metal parts, the project identified a DoD wide requirement for a cleaner specification exclusive to fiber reinforced PMCs as composite mechanical tests to support qualification are fundamentally different from that of metallic materials. To support this need the project also established a new MIL specification, MIL-PRF-32597- "Cleaner, Polymer and Polymer Matrix Composite (PMC) Material, Non-Aqueous, HAP-Free" approving NAVSOLVE™ for use on aircraft composites. MIL-PRF-32597 is provided in Appendix B.

The decision on implementation of the new cleaner for composites will be based on performance, cost savings, safety, product's availability, compatibility, and shelf life. If the new alternative meets the accepted criteria, the implementation will take place by issuing a NAVAIR authorization letter. Following the authorization letter, the final draft will be submitted to the technical point of contact (POC) (i.e. custodian) for new NAVAIR specifications (AIR 4.1.2 Specs and Standards, Lakehurst, NJ). Following acceptance of NAVAIR's draft, they will coordinate concurrence from the Air Force and Army technical representatives. If all the representatives agree, the new specification will be issued.

The procedure to update the NAVAIR 01-1A-509 Manual (Cleaning and Corrosion Control for Aircraft) is as follows. NAVAIR AIR 4.3.4.2 will submit a request to the technical POC for the 509 Manual (Ms. Louis Nicoloff, FRC-SW, CA) to add the cleaning product (NAVSOLVE™) to additional sections of the manual (beyond engine components under which it is currently listed) including "Exterior Components, Painted" Section. In addition, NAVAIR will submit the following documents to the technical POC for the manual: the new composite cleaner specification, authorization letter, Environmental Security Technology Certification Program (ESTCP) final report on the demonstration/validation for the new product, the qualification mechanical testing

results for NAVSOLVE™ on composites, the National Stock Number (NSN), and the Qualified Products List (QPL) or Qualified Products Database (QPD). The technical POC reviews the documentations to determine if it applies to a wide range of aircraft, and can be used in most localities where Navy personnel are stationed (for general series manuals). If the technical POC for the manual accepts NAVAIR's request, concurrence from the Air Force and Army technical representatives will be required for Tri-Service manuals such as the -509. If all the representatives agree, the change is reviewed to see how much of the manual it affects. For changes with minimal effects, an Interim Rapid Action Change (IRAC) incorporating the change can be issued. For changes that affect many pages, funds must be requested from the publications POC to do a change or revision in the following fiscal year. Once funding is received, the new process/material is incorporated in the next change/revision of the manual.

9 REFERENCES

- 1) MIL-PRF-83282, "Cleaner, Non-Aqueous, Low VOC, HAP Free", 19 April 2010.
- 2) MIL-PRF-33295A, "Cleaner, Non-Aqueous, Low VOC, HAP Free", 19 April 2010.
- 3) H. Tripathi and E. S. Arafat, "DSCR Partners with the Navy for New Green Aircraft Cleaner", DLA Today, February 10, 2010.
- 4) H. Tripathi and E. S. Arafat, "Environmental-Preferred Alternatives to MIL-PRF-680 / P-D-680 Cleaner", HTIS Bulletin, Vol. 20, No. 2, Page 1-2, March - April, 2010.
- 5) H. Tripathi and E. S. Arafat, "Partnership Allows for Greener and Cleaner Military Services", Environmental Update, Spring 2010.
- 6) E. S. Arafat, "Non-HAP and Non-VOC Replacement for P-D-680 Solvent", DLA Report - Project No. SC04000700487; May 20, 2010.
- 7) E. S. Arafat, "Development of Non-Aqueous Low-VOC Cleaner as Alternative to MIL-PRF-680/P-D-680 Cleaners", DoD Corrosion Conf., La Quinta, CA, Aug. 2011.
- 8) U. S. Patent No. 7,897,558 B1 (March 1, 2011) - "Siloxane Solvent Compositions", E. S. Arafat.
- 9) U. S. Patent No. 8,273,698 B2, (September 25, 2012) - "Siloxane Compositions Comprising an Alkylated CycloSiloxane and Linear Alkylated Siloxane Mixture", El Sayed Arafat.
- 10) NAVAIR 01-1A-509-2: Technical Manual: Cleaning and Corrosion Control, Volume II- Aircraft
- 11) SMP-0021M1: General Cleaning
- 12) SMP-0021M5: "Removal of Oil and Grease from Composite Laminate"
- 13) SRP-1012 Rev B: Honeycomb Core Structure-Composite Face Sheet and Core Damage
- 14) LPS 751B: Adhesive Bonding Local Process Specification
- 15) T.O. 1-1-690: General Advanced Composite Repair Process
- 16) TM 1-1500-345-23: Technical Manual: Painting and Marking of Army Aircraft
- 17) LPS-NI-MATL1115 B: Moisture/Fluid Removal from Carbon/Epoxy Parts
- 18) NAVAIR 01-1A-21: General Composite Repair
- 19) T.O. 1-1-8: Technical Manual: Application and Removal of Organic Coatings, Aerospace and Non-Aerospace Equipment
- 20) Executive Order 13514: Federal Leadership in Environmental, Energy, and Economic Performance, October 5, 2009
- 21) Toxicity of Decamethylpentasiloxane (D5), Dow Corning, Internal Publication.
- 22) Research on the Safety of D4, Silicones Environmental, Health and Safety Council of North America (SEHSC), September 2006.
- 23) SEHSC Statement: Government of Canada's Chemical Management Program Final Screening Assessments for D4, D5 and D6, January 30, 2009.
- 24) Health Hazard Assessment (HHA) for Navsolve Cleaner, Navy and Marine Corps Public Health Center, Industrial Hygiene HHA, Portsmouth, VA, September 27, 2010.
- 25) Material Safety Data Sheet (MSDS) for Dow Corning Fluid 244 (Octamethylcyclotetra siloxane (D4)), 5, 18, 2010.
- 26) Material Safety Data Sheet (MSDS) for Dow Corning Fluid 245 (Decamethylcyclopenta siloxane (D5)), 6/2/2008.
- 27) DLA Final Report, "Field Test & Implementation of NAVSOLVE™ as an Alternative to MIL-PRF680 Solvent", 12 Sept 2013
- 28) 219BAR-10-010 Final Report: Development of Environmentally Friendly Cleaners for

Removal of Hydraulic Fluid from Composites

- 29) ASTM D2344: Standard Test Method for Short-Beam Strength of Polymer Matrix Composite Materials and Their Laminates
- 30) ASTM D7264: Standard Test Method for Flexural Properties of Polymer Matrix Composite Materials
- 31) ASTM C297: Standard Test Method for Flatwise Tensile Strength of Sandwich Constructions
- 32) ASTM D5229: Standard Test Method for Moisture Absorption Properties and Equilibrium Conditioning of Polymer Matrix Composite Materials
- 33) ASTM D3518: Standard Test Method for In-Plane Shear Response of Polymer Matrix Composite Materials by Tensile Test of a $\pm 45^\circ$ Laminate
- 34) ASTM D6484: Standard Test Method for Open-Hole Compressive Strength of Polymer Matrix
- 35) ASTM D3846: Standard Test Method for In-Plane Shear Strength of Reinforced Plastics
- 36) ASTM D5868: Standard Test Method for Lap Shear Adhesion for Fiber Reinforced Plastic (FRP) Bonding
- 37) SAE AS5127/1(Section 7.5): Aerospace Standard Test Methods for Aerospace Sealants Two-Component Synthetic Rubber Compounds/ Volume Swell
- 38) SAE AS5127/1 (Section 7.7) Aerospace Standard Test Methods for Aerospace Sealants Two-Component Synthetic Rubber Compounds/Tensile-Elongation
- 39) ASTM D2240: Standard Test Method for Rubber Property—Durometer Hardness
- 40) ASTM D1002: Standard Test Method for Apparent Shear Strength of Single-Lap-Joint Adhesively Bonded Metal Specimens by Tension Loading (Metal-to-Metal)
- 41) ASTM D4541: Standard Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers
- 42) ASTM D3359: Standard Test Methods for Measuring Adhesion by Tape Test
- 43) TM 1-1500-345-23; 4-16B: Painting and Marking of Army Aircraft;
- 44) TM 1-1500-345-11; Section 7: Aviation Unit Maintenance (AVUM) and Aviation Intermediate Maintenance (AVIM) Manual General Aircraft Maintenance Advanced Composite Material General Maintenance Practices Volume 11
- 45) LMA 2ZSA00064: Process Specification for Selected Repairs Identified in 2ZSA00064
- 46) NAVAIR 01-1A-16-1: Technical Manual Nondestructive Inspection Methods
- 47) ASTM D329: Standard Specification for Acetone
- 48) CCC-C-46: Cloth, Cleaning, Woven Fabric (30-SEP-1986)
- 49) MIL-PRF-23377K: Primer Coatings: Epoxy, High-Solids (07-JUN-2012)
- 50) MIL-DTL-64159B: Camouflage Coating, Water Dispersible Aliphatic Polyurethane, Chemical Agent Resistant
- 51) P-P-101: Paper, Abrasive
- 52) SAE AMS3819: Cloths, Cleaning For Aircraft Primary and Secondary Structural Surfaces

10 APPENDICES

Appendix A Points of Contact

Point of Contact	Organization	Phone/Fax/E-mail	Role in Project
Ray Meilunas	Materials Eng. Div. NAWCAD Patuxent River, MD	Phone: (301) 342-8064 raymond.meilunas@navy.mil	PI

Appendix B MIL - PRF - 3 2 5 9 7

NOT MEASUREMENT SENSITIVE

MIL-PRF-32597A

02 February 2018

PERFORMANCE SPECIFICATION

CLEANER, POLYMER AND POLYMER MATRIX COMPOSITE (PMC)

MATERIAL, NON-AQUEOUS, HAP-FREE

This specification is approved for use by all Departments and Agencies of the Department of Defense.

1. SCOPE

1.1 Scope. This specification covers a non-aqueous cleaner that is free of hazardous air pollutants (HAPs) and available in a low (no more than 25 grams per liter) volatile organic compound (VOC) and high VOC type for cleaning aircraft components (including structural metallic and fiber reinforced polymer matrix composite parts), ground support equipment, and other general cleaning applications (see 6.1).

1.2 Types. The cleaners are of the following types as specified (see 6.2).

Type I – Low-VOC (≤ 25 g/L)

Type II – High-VOC

Type III - VOC-Exempt (Bulk)

Type IIIA - VOC-Exempt, Aerosol

Type IIW - VOC-Exempt, Pre-saturated wipe

1.2.2 Classes. The classes are as follows:

Class 1 - Bulk container

Class 2 - Self-pressurized container

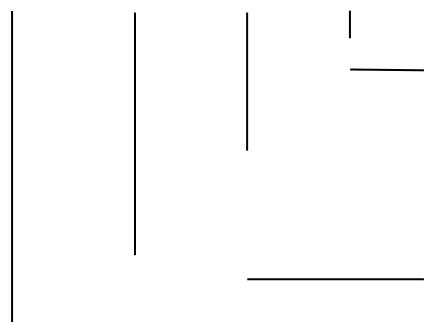
Comments, suggestions, or questions on this document should be addressed to: Commander, Naval Air Warfare Center Aircraft Division, (Code 4.1.2.2), Route 547, Mail Stop 120-3, Joint Base MDL, NJ 08733-5100 or emailed to michael.sikora@navy.mil. Since contact information can change, you may want to verify the currency of this address information using the ASSIST Online

AMSC N/A

FSC 6850

1.3 Part or Identifying number (PIN). The PINs to be used for cleaners acquired to this specification are created as follows:

M XXXXX - X X



Classes: Container: 1 = Bulk

2 = Self-pressurized

Types: VOC: 1 = Low VOC (≤ 25 g/L)

2 = High VOC

3 = Type III- VOC-Exempt (Bulk)

4 = Type IIIA- VOC Exempt, Aerosol

5 = Type IIIW- VOC Exempt, Pre-saturated wipe

Specification number

M prefix

2. APPLICABLE DOCUMENTS

2.1 General. The documents listed in this section are specified in sections 3 and 4 of this specification. This section does not include documents cited in other sections of this specification or recommended for additional information or as examples. While every effort has been made to ensure the completeness of this list, document users are cautioned that they must meet all specified requirements of documents cited in sections 3 and 4 of this specification, whether or not they are listed.

2.2 Government documents.

2.2.1 Specifications and standards. The following specifications and standards form a part of this document to the extent specified herein. Unless otherwise specified, the issues of these documents are those cited in the solicitation or contract.

DEPARTMENT OF DEFENSE SPECIFICATIONS

- MIL-PRF-10924 - Grease, Automotive and Artillery
- MIL-G-21164 - Grease, Molybdenum Disulfide, for Low and High Temperatures, NATO Code Number G-353
- MIL-DTL-81381/11 - Wire, Electric, Fluorocarbon/polyimide Insulated, Medium Weight, Silver Coated Copper Conductor, 600 Volts, 200 Deg. C, Nominal 8.4 or 15.4 Mil Wall
- MIL-PRF-81733 - Sealing And Coating Compound, Corrosion Inhibitive
- MIL-PRF-83282 - Hydraulic Fluid, Fire Resistant, Synthetic Hydrocarbon Base, Metric, NATO Code Number H-537

DEPARTMENT OF DEFENSE STANDARD

- MIL-STD-1916 - DoD Preferred Methods for Acceptance of Product

(Copies of these documents are available online at <http://quicksearch.dla.mil>.)

2.2.2 Other Government documents and publications. The following other Government documents and publications form a part of this document to the extent specified herein. Unless otherwise specified, the issues are those cited in the solicitation or contract.

CODE OF FEDERAL REGULATIONS (CFR)

- 40 CFR 82 - Protection of Stratospheric Ozone, Protection of Environment
- 40 CFR 401 - General Provisions, Protection of Environment

(Copies of these documents are available from <http://www.ecfr.gov>.)

SOUTH COAST AIR QUALITY MANAGEMENT DISTRICT (SCAQMD)

- SCAQMD Method 313 - Determination of Volatile Organic Compounds
(VOC) by Gas Chromatography/Mass Spectrometry
(GC/MS)

(Copies of this document are available online at <http://www.aqmd.gov>.)

2.3 Non-Government publications. The following documents form a part of this document to the extent specified herein. Unless otherwise specified, the issues of these documents are those cited in the solicitation or contract.

ASTM INTERNATIONAL

- ASTM C297/C297M- Standard Test Method for Flatwise Tensile Strength of Sandwich Constructions
- ASTM D56 - Standard Test Method for Flash Point by Tag Closed Cup Tester (DoD Adopted)
- ASTM D130 - Standard Test Method for Corrosiveness to Copper from Petroleum Products by Copper Strip Test (DoD Adopted)
- ASTM D891 - Standard Test Methods for Specific Gravity, Apparent, of Liquid Industrial Chemicals (DoD Adopted)
- ASTM D1002 - Standard Test Method for Apparent Shear Strength of Single-Lap-Joint Adhesively Bonded Metal Specimens by Tension Loading (Metal-to-Metal)

ASTM D1296	-	Standard Test Method for Odor of Volatile Solvents and Diluents (DoD Adopted)
ASTM D1353	-	Standard Test Method for Nonvolatile Matter in Volatile Solvents for Use in Paint, Varnish, Lacquer, and Related Products (DoD Adopted)
ASTM D1613	-	Standard Test Method for Acidity in Volatile Solvents and Chemical Intermediates Used in Paint, Varnish, Lacquer, and Related Products (DoD Adopted)
ASTM D2240	-	Standard Test Method for Rubber Property-Durometer Hardness (DoD Adopted)
ASTM D2344/ ASTM D2344M	-	Standard Test Method for Short-Beam Strength of Polymer Matrix Composite Materials and Their Laminates
ASTM D2879	-	Standard Test Method for Vapor Pressure-Temperature Relationship and Initial Decomposition Temperature of Liquids by Isoteniscope (DoD Adopted)
ASTM D3518/ ASTM D3518M	-	Standard Test Method for In-Plane Shear Response of Polymer Matrix Composite Materials by Tensile Test of a $\pm 45^\circ$ Laminate
ASTM D3755	-	Standard Test Method for Dielectric Breakdown Voltage and Dielectric Strength of Solid Electric Insulating Materials Under Direct-Voltage Stress
ASTM D5229/ ASTM D5229M	-	Standard Test Method for Moisture Absorption Properties and Equilibrium Conditioning of Polymer Matrix Composite Materials
ASTM D5868	-	Standard Test Method for Lap Shear Adhesion for Fiber Reinforced Plastics (FRP) Bonding
ASTM D6484/D6484M	-	Standard Test Method for Open-Hole Compressive Strength of Polymer Matrix Composite Laminates
ASTM D7264	-	Standard Test Method for Flexural Properties of Polymer Matrix Composite Materials
ASTM F483	-	Standard Test Method for Total Immersion Corrosion Test for Aircraft Maintenance Chemicals (DoD Adopted)
ASTM F484	-	Standard Test Method for Stress Crazeing of Acrylic Plastics

		in Contact with Liquid or Semi-liquid Compounds (DoD Adopted)
ASTM F485	-	Standard Test Method for Effects of Cleaners on Unpainted Aircraft Surfaces
ASTM F502	-	Standard Test Method for Effects of Cleaning and Chemical Maintenance Materials on Painted Aircraft Surfaces (DoD Adopted)
ASTM F519	-	Standard Test Method for Mechanical Hydrogen Embrittlement Evaluation of Plating/Coating Processes and Service Environments (DoD adopted)
ASTM F945	-	Standard Test Method for Stress-Corrosion of Titanium Alloys by Aircraft Engine Cleaning Materials (DoD Adopted)
ASTM F1110	-	Standard Test Method for Sandwich Corrosion Test (DoD Adopted)
ASTM F1111	-	Standard Test Method for Corrosion of Low-Embrittling Cadmium Plate by Aircraft Maintenance Chemicals (DoD Adopted)

(Copies of these documents are available from www.astm.org.)

SAE INTERNATIONAL

SAE AMS 4377	Magnesium Alloy, Sheet and Plate, 3.0Al-1.0 Zn-0.20Mn (AZ31B-H24), Cold Rolled, Partially Annealed (DoD Adopted)
SAE AMS 4911	Titanium Alloy, Sheet, Strip, and Plate 6Al-4V Annealed (DoD Adopted)
SAE AMS 5040	Steel, Sheet and Strip 0.15 Carbon, Maximum Deep Forming Grade (DoD Adopted)
SAE AMS-M-3171	Magnesium Alloy, Processes for Pretreatment and Prevention of Corrosion on (DoD Adopted)
SAE AMS-P-83310	Plastic Sheet, Polycarbonate, Transparent (DoD Adopted)
SAE AMS-QQ-A-250/4	Aluminum Alloy 2024, Plate And Sheet (DoD Adopted)
SAE AMS-QQ-A-250/12	Aluminum Alloy 7075, Plate and Sheet (DoD Adopted)
SAE AMS-S-8802	Sealing Compound, Fuel Resistant, Integral Fuel Tanks and Fuel Cell Cavities

(Copies of these documents are available from www.sae.org.)

2.4 Order of precedence. Unless otherwise noted herein or in the contract, in the event of a conflict between the text of this document and the references cited herein (except for related specification sheets), the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

3. REQUIREMENTS

3.1 Qualification. The cleaners furnished under this specification shall be products that are authorized by the qualifying activity for listing on the applicable qualified products list

before contract award (see 4.2 and 6.3).

3.2 Material. The cleaners supplied under this specification shall be homogenous liquids that are clear (without turbidity), stable, and free of haze and suspended matter.

3.2.1 Composition. The cleaners shall be of the same composition and specific gravity as that of the qualification sample. If the cleaner contains any halogenated solvent, adequate acid acceptance stabilizers shall also be present. Any change in the formulation of a qualified product shall require requalification.

3.2.2 Prohibited materials. The cleaners shall contain no known or suspected human carcinogens (see 6.8.1), no hazardous air pollutants (see 6.8.2), no toxic pollutants (see 40 CFR), no ozone depleting substances (see 40 CFR 82), or any other hazardous substances.

3.3 Toxicity. The cleaners supplied under this specification shall have no adverse effect on the health of personnel when all precautions are followed for its usage in accordance with the applicable Safety Data Sheet (SDS) (see 4.5.16 and 6.7).

3.4 Performance requirements. The cleaners shall meet the performance requirements listed in Table I. For Type IIIA (aerosol) and Type IIW (wipes), the bulk liquid from which the aerosols or wipes are produced, shall be tested, along with the aerosol cans or packaged wipes used for the examinations listed under 3.7.1 and 3.7.2.

TABLE I. Properties and test methods.

PROPERTY	REQUIREMENT			TEST METHOD
VOC content, grams/liter (maximum)	Type I ≤25	Type II No Limit	Type III Exempt	SCAQMD Method 313
Apparent specific gravity, 60/60 °F	No change from qualification sample			ASTM D891

Vapor pressure, mm Hg at 20 °C (maximum)	Type I 7	Type II 7	Type III No Limit	ASTM D2879
Flash point, °C (°F) (minimum)	60 (140)	60 (140)	No Limit	ASTM D56
Nonvolatile residue, mg/100ml, (maximum)	5			ASTM D1353
Acidity (weight %)	0.02			ASTM D1613
Miscibility with water	Immiscible			4.5.1
Drying time, minutes (maximum)	50	50	10	4.5.2
Low temperature stability	No freezing and no separation			4.5.3
Sandwich corrosion (maximum)	Rating of 1			ASTM F1110
Immersion corrosion, mg/cm ² /day (maximum) Aluminum, Titanium, Steel Magnesium	0.04 0.20			ASTM F483 and 4.5.4
Cadmium corrosion test, mg/cm ² /day (maximum)	0.20			ASTM F1111
Copper corrosion rating (maximum)	1b			ASTM D130 and 4.5.5
Effect on unpainted surfaces	No streaks or stains			ASTM F485
Hydrogen embrittlement	No failures in less than 150 hours when specimens are loaded to 45 percent of fracture strength and immersed in cleaner			ASTM F519 and 4.5.6

Titanium stress corrosion (examined with 500X magnification)	No cracking	ASTM F945 Method A
Effect on painted surfaces	No streaks, fading, blisters, or discoloration No softening >1 pencil hardness	ASTM F502

TABLE I. Properties and test methods – Continued.

PROPERTY	REQUIREMENT	TEST METHOD
Effect on plastics Acrylic, type A & C Polycarbonate, SAE AMS-P-83310	No crazing No crazing after 2 hrs at 2000 psi	ASTM F484
Effect on polyimide wire	No more insulation cracking than with distilled water and no subsequent dielectric breakdown or leakage	ASTM D3755 and 4.5.7
Effect on sealant	No change in Shore A hardness greater than ± 5 units	4.5.8
Effect on mechanical properties of fiber reinforced, polymer matrix composite	Data sets of baseline (unexposed) conditions and cleaner exposed conditions are not significantly different based on t-test or analysis of variance statistical methods	ASTM D2344/D2344M ASTM D7264 ASTM D3518/D3518M ASTM D6484/D6484
Effect on structural adhesive	Data sets of baseline (unexposed) conditions and cleaner exposed conditions are not significantly different based on t-test or analysis of variance statistical methods	ASTM D1002 ASTM D5868

Effect on structural honeycomb core	Data sets of baseline (unexposed) conditions and cleaner exposed conditions are not significantly different based on t-test or analysis of variance statistical methods			ASTM C297/C297M
Cleaning efficiency on MIL-PRF-83282 soil MIL-G-21164 soil MIL-PRF-10924 grease	Type I ≥ 95% ≥ 70% ≥ 85%	Type II ≥ 95% ≥ 70% ≥ 85%	Type III ≥ 85% ≥ 60% ≥ 75%	4.5.12
Odor	Non-offensive, low intensity, non-residual			ASTM D1296 and 4.5.13

3.5 Storage stability. The cleaners, after storage in the original, unopened container for not less than one year at a temperature of 90 ± 2 °F (34 ± 1 °C), shall meet all the requirements of this specification. In addition, the containers shall exhibit no corrosion, distortion, leakage, or other evidence of incompatibility.

3.6 Propellant (Class 2). The propellant shall have zero Ozone Depleting Potential (ODP) and shall deliver a uniform spray of usable product. A propellant shall conform to Environmental Protection Agency (EPA) regulations for aircraft maintenance use of aerosol products.

3.7 Dispenser.

3.7.1 Aerosol dispenser (Class 2).

3.7.1.1 Composition. When visually examined in accordance with 4.5.15.1, the dispenser shall be of the aerosol type and shall have an on/off finger controlled pressure type of dispensing device to produce the spray. When not in use, the dispensing device shall be protected against activation by a snug-fitting protective cap. This cap shall provide a clearance of 0.125 inch (3.2 mm) over the dispensing device. The valve on the aerosol shall be of a type to allow for 360 degree actuation. In other words, the product can be dispensed in both an upright and upside down orientation. A 5 inch (127mm) hollow cylindrical plastic extension designed to fit into the dispensing

device, for directing the spray into hard to reach places, shall be attached to the outside of the dispenser by tape, adhesive, or similar material.

3.7.1.2 Size. The dispenser shall be capable of containing 5 or 12 ounces (142 or 340 grams) of the cleaning compound (see 6.2), without exceeding 90 percent at 21 °C (70 °F) of the internal volume of the dispenser.

3.7.1.3 Leakage. When tested as specified in 4.5.15.2, the pressurized dispenser shall not leak nor become distorted.

3.7.1.4 Net contents. The average net contents per dispenser shall be not less than the amount specified for the size dispenser (see 6.2), when tested in accordance with 4.5.15.3.

3.7.1.5 Precautionary markings. Each dispenser shall contain precautionary information, marked directly on the surface of the dispenser with marking material which is not affected by the cleaning compound. The warning shall be as follows:

CAUTION: Contents under pressure.

Do not puncture.

Use with adequate ventilation.

Keep away from direct sunlight, radiators, hot water, and other heat.

Avoid prolonged or repeated breathing of vapors or contact with skin.

Do not take internally.

3.7.2 Pre-saturated wipes (Type IIIW).

3.7.2.1 Composition. No gauze or cheesecloth type material is acceptable. Each foil package shall contain 25 wipes saturated with 1200 ml of a qualified MIL-PRF-32295B Type III product. Wipe dimensions shall be 16" x 17" and be provided in an airtight flexible foil package with a tear strip for opening. The foil package shall be re-sealable with a press type seal or rubber band to prevent loss of

volatile and fluid components. The length of the foil package should be long enough to allow for adequate sealing of the unused portion after opening. Samples submitted for qualification shall be accompanied by written correspondence on company letterhead showing qualification to 3.7.2.1 and 3.7.2.2 Leakage. The flexible foil packages shall show no signs of leakage.

3.7.2.3 Precautionary markings. Each dispenser shall contain precautionary information, marked directly on the surface of the dispenser with marking material which is not affected by the cleaning compound. The warning shall be as follows:

CAUTION: Re-sealable foil packages should be stored at a temperature less than 120 °F (49 °C) and not exposed to direct sunlight for extended periods.

Do not store in enclosed areas with minimum ventilation and a possibility of exceeding the temperature limits.

Do not freeze.

Opened packages shall be used within 6 weeks.

4. VERIFICATION

4.1 Classification of inspections. The inspection requirements specified herein are classified as follows:

a. Qualification inspection (see 4.2).

b. Conformance inspection (see 4.3).

4.2 Qualification inspection. The qualification inspection (see 6.3) shall consist of all tests and examinations of this specification. Failure of any examination or test shall be cause for rejection.

4.3 Conformance inspection. Conformance inspection shall consist of the tests listed in Table II and the examinations listed in 4.3.2.

TABLE II. Conformance inspections.

TEST	REFERENCE
VOC	Table I
Apparent Specific Gravity	Table I
Vapor Pressure	Table I
Flash Point	Table I
Nonvolatile Residue	Table I
Acidity	Table I
Miscibility with Water	4.5.1
Drying Time	4.5.2
Low Temperature Stability	4.5.3
Sandwich Corrosion	Table I
Immersion Corrosion	4.5.4 & Table I
Cadmium Corrosion	Table I
Copper Corrosion	4.5.5 & Table I
Effect on Unpainted Surfaces	Table I
Hydrogen Embrittlement	4.5.6 & Table I
Titanium Stress Corrosion	Table I
Effect on Painted Surfaces	Table I
Effect on Plastics	Table I
Effect on Polyimide Wire	4.5.7 & Table I
Cleaning Efficiency	4.5.12
Odor	4.5.13 & Table I

Dispenser	4.5.15
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4.3.1 Sampling for conformance tests. Samples for conformance tests shall be selected from each lot in accordance with MIL-STD-1916, verification level I. Samples for tests shall consist of unopened containers of cleaner selected at random from each lot. Containers shall only be opened when being tested. Any failure shall be cause for rejection of the lot.

4.3.2 Visual inspection of filled containers. Samples for visual inspection shall be selected at random from each lot in accordance with MIL-STD-1916, verification level I. The lot size for this inspection shall be the number of containers fully prepared for delivery. The selected samples shall be examined for container fill, completion of item identification, and chemical warnings. Any failure shall be cause for rejection of the lot.

4.4 Inspection conditions. Unless otherwise specified in the test method or paragraph, laboratory test conditions for all inspections and tests in this specification shall be 72 ± 4 °F (22 ± 2 °C) and a relative humidity of 50 ± 20 percent.

4.5 Test methods. The tests of this specification shall be conducted in accordance with Table I and 4.5.1 through 4.5.16.

4.5.1 Miscibility with water. Twenty milliliters of the cleaner and 20 milliliters of distilled water shall be added to a 50 milliliter graduated cylinder and thoroughly shaken for 10 seconds. The mixture shall then be centrifuged (1000 rpm for 2 minutes) in a 50 milliliter graduated tube. The cleaner shall be considered immiscible if two clear phases separate cleanly with no volume change of either phase.

4.5.2 Drying time. To a pre-weighed aluminum weighing dish (all weights shall be to the nearest 0.0001 gram) 500 mg (+/- 10 mg) of cleaner shall be added. The weighing dish shall be 57 ± 1 mm in diameter and no more than 1.5 grams in weight. The dish shall then be reweighed and immediately placed in a forced draft oven at 120 ± 2 °F (49 ± 1 °C). After 50 minutes, the dish shall be removed from the oven, cooled for 30 seconds by placing it on a clean metallic surface, and then immediately reweighed. If the cleaner remaining is no more than 0.1 percent of the original weight of

cleaner used, the drying time shall be considered to be no more than 50 minutes.

4.5.3 Low temperature stability. Fifty milliliters of the cleaner shall be added to a test tube of suitable size and placed in a 0 ± 2 °F (-18 ± 1 °C) cold box for 24 hours. The tube shall be removed, immediately examined for any evidence of freezing, and allowed to return to room temperature, after which it shall be inverted five times and examined for separation.

4.5.4 Immersion corrosion. The immersion corrosion test shall be conducted in accordance with ASTM F483 (using the 7-day duration) on test panels constructed of the following materials:

- a. Aluminum alloy 2024 (T3 temper), conforming to SAE AMS-QQ-A-250/4
- b. Aluminum alloy 7075 (T6 temper), conforming to SAE AMS-QQ-A-250/12
- c. Titanium alloy (6Al-4V), conforming to SAE AMS4911
- d. Carbon steel (1020), conforming to SAE AMS5040
- e. Magnesium alloy (AZ31B-H24), conforming to SAE AMS4377, chrome pickled to SAE AMS-M-3171, type VI

4.5.5 Copper corrosion. The copper corrosion test shall be conducted in accordance with ASTM D130 using a 24-hour soak in cleaner at 100 ± 2 °F (38 ± 1 °C).

4.5.6 Hydrogen embrittlement.

4.5.6.1 Preparation of test specimens. Hydrogen embrittlement characteristics shall be determined in accordance with ASTM F519, using cadmium-plated AISI4340, type 1a specimens. Four specimens shall be tested as follows. Plating shall be applied using treatment B and shall cover the notch and surfaces within 0.5 inch (13mm) of the notch; threaded surfaces shall not be plated. Plated specimens shall be baked in accordance with ASTM F519.

4.5.6.2 Test procedure. Each specimen shall be stressed by applying a load equivalent to 45 percent of notch fracture strength. The notch shall be immersed in the cleaner for the duration of the test. Discontinue the test if no fractures occur after 150 hours of immersion. If a failure occurs in

one of four specimens tested, a second set of 4 specimens shall be evaluated. A minimum of 7 out of 8 specimens shall meet the 150 hour duration.

4.5.7 Effect on polyimide insulated wire. Approximately 24 inch (61cm) of wire conforming to MIL-DTL-81381/11 shall be formed into a coil. Place the coil in a 4 ounce (118ml) wide-mouth jar. Add to the jar sufficient cleaner to completely cover the coil of wire. Cap the jar and store it at room temperature for 14 days. Concurrently, perform this procedure using distilled water for comparison. At the end of the storage period, remove both coils and rinse thoroughly with tap water at room temperature. Suspend each coil and allow it to drain until completely dry. Each wire shall then be uncoiled and wrapped tightly on a 0.125 inch (3.2mm) mandrel noting the appearance of any cracks in the insulation. Each wire shall then be unwrapped and rewrapped in the opposite direction, again noting appearance of cracks. If the test wire shows no more cracks than the comparison wire, it shall be immersed in a 5 percent by weight sodium chloride solution and subjected to a one minute dielectric test of 2,500 volts (root mean square) without breakdown or leakage in accordance with ASTM D3755.

4.5.8 Effect on sealants. The effect of the cleaner on polysulfide and polythioether sealants shall be determined as specified in 4.5.8.1 and 4.5.8.2.

4.5.8.1 Preparation of test specimens. Sealants in accordance with AMS-S-8802, Type II, Class B and MIL-PRF-81733 Type II, Class 2, Grade B shall be mixed as specified by their respective manufacturers and processed to form sheets 0.125 inch (3.2mm) thick. Sealants shall be cured for 14 days at $77 \pm 5^{\circ}\text{F}$ ($25 \pm 3^{\circ}\text{C}$) at 50 percent humidity. These conditions shall be considered standard conditions. The sealing compound may be given an accelerated cure for 48 hours, minimum at standard conditions followed by 24 hours, minimum at 140°F (60°C). The cured sealants are the sheet stock from which the specimens for each sealant shall be cut.

4.5.8.2 Test procedure. The Shore A hardness of each sealant specimen shall be measured as specified in ASTM D2240 (stacking two specimens of the same sealant to make a 1/4 inch thickness) before exposing it to the cleaner. Two specimens of each sealant shall be immersed in cleaner at room temperature. After 30 minutes, specimens shall be removed, wiped dry and tested (as above) within 30 minutes for Shore A hardness.

4.5.9 Effect on mechanical properties of fiber reinforced polymer matrix composites. The effect of the cleaner on the mechanical properties of fiber reinforced polymer matrix composites shall

be determined as specified in 4.5.9.1, 4.5.9.2, 4.5.9.3, 4.5.9.4. and 4.5.9.5.

4.5.9.1 Preparation of test specimens. Polymer matrix composite specimens for use in assessing the effects of the cleaner on mechanical properties shall be as described below:

- a. For 4.5.9.2 a unidirectional laminate (minimum 16 plies total thickness) of unidirectional IM7/977-3 prepreg processed in an autoclave in accordance with material supplier recommendations.
- b. For 4.5.9.4 a laminate of unidirectional IM7/977-3 prepreg stacked in accordance with ASTM D3518/D3518M Section 8.2.1 and processed in an autoclave in accordance with material supplier recommendations.
- c. For 4.5.9.3 and 4.5.9.5 a balanced, quasi-isotropic laminate of unidirectional IM7/977-3 prepreg processed in an autoclave in accordance with material supplier recommendations. The minimum total thickness as specified in the respective ASTM test method.

4.5.9.2 Effect on short beam shear properties. A minimum of twenty Short Beam Shear test specimens shall be fabricated from the polymer matrix composite in accordance with ASTM D2344/D2344M. Test specimens shall be dried in accordance with ASTM D5229/D5229M, Procedure D. Ten dried specimens of the polymer matrix composite shall be immersed in the cleaner at room temperature for 14 days. After 14 days, specimens shall be removed from the cleaner, dried, and tested in accordance with ASTM D2344/D2344M. Test results shall be compared to the short beam shear properties of the ten, baseline (unexposed) specimens using t-test or analysis of variance (ANOVA) statistical methods.

4.5.9.3 Effect on flexure properties. A minimum of ten flexure test specimens shall be fabricated from the polymer matrix composite in accordance with ASTM D7264. Test specimens shall be dried in accordance with ASTM D5229/D5229M, Procedure D. Five dried specimens of the polymer matrix composite shall be immersed in the cleaner at room temperature for 14 days. After 14 days, specimens shall be removed from the cleaner, dried and tested in accordance with ASTM D7264. Test results shall be compared to the flexure properties of the five, baseline (unexposed) specimens using t-test or analysis of variance (ANOVA) statistical methods.

4.5.9.4 Effect on in plane shear ($\pm 45^\circ$ tension) properties. A minimum of ten $\pm 45^\circ$ tension test specimens shall be fabricated from the polymer matrix composite in accordance with ASTM

D3518/D3518M. Test specimens shall be dried in accordance with ASTM D5229/ASTM D5229M, Procedure D. Five dried specimens of the polymer matrix composite shall be immersed in the cleaner at room temperature for 14 days. After 14 days, specimens shall be removed from the cleaner, dried and tested in accordance with ASTM D3518/D3518M, Test results shall be compared to the in plane shear properties of the five baseline (unexposed) specimens using t-test or analysis of variance (ANOVA) statistical methods.

4.5.9.5 Effect on open hole compression properties. A minimum of ten open hole compression test specimens shall be fabricated from the polymer matrix composite in accordance with ASTM D6484/D6484M. Test specimens shall be dried in accordance with ASTM D5229/ D5229M, Procedure D. Five dried specimens of the polymer matrix composite shall be immersed in the cleaner at room temperature for 14 days. After 14 days, specimens shall be removed from the cleaner, dried, and tested in accordance with ASTM D6484/D6484M. Test results shall be compared to the open hole compression properties of the five baseline (unexposed) specimens using t-test or analysis of variance (ANOVA) statistical methods.

4.5.10 Effect on polymer based structural adhesives (paste and film). The effect of the cleaner on the mechanical properties of structural adhesives shall be determined as specified in 4.5.10.1. The test specimens shall be two balanced, quasi-isotropic laminates (minimum 16 plies total thickness) of unidirectional IM7/977-3 prepreg processed in an autoclave in accordance with material supplier recommendations bonded with 9394 structural adhesive, with the bonding accomplished in accordance with material supplier recommendations.

4.5.10.1 Effect on single lap shear properties. A minimum of ten single lap shear test specimens shall be fabricated from the structural adhesive. The specimens shall be fabricated using materials described in 4.5.10.1 in accordance with ASTM D5868. Test specimens shall be dried in accordance with ASTM D5229/D5229M, Procedure D. Five dried specimens of the adhesive shall be immersed in the cleaner at room temperature for 14 days. After 14 days, specimens shall be removed from the cleaner, dried, and tested in accordance with ASTM D5868. Test results shall be compared to the lap shear properties of the five baseline (unexposed) specimens using t-test or analysis of variance (ANOVA) statistical methods.

4.5.11 Effect on polymer based structural honeycomb core. The effect of the cleaner on the mechanical properties of structural honeycomb core shall be determined as specified in

4.5.11.1. The test specimens shall be a honeycomb sandwich comprising:

- a. an aramid honeycomb core of 1 inch nominal thickness minimum, with minimum cell size of 0.125 inch nominal and minimum nominal density of 3.0 lb per cubic foot;
- b. two facesheets of balanced, quasi-isotropic laminates (minimum 5 plies total thickness) of unidirectional IM7/977-3 prepreg processed in an autoclave in accordance with material supplier recommendations;
- c. facesheets and core bonded with FM300 structural adhesive, with the bonding accomplished in accordance with material supplier recommendations.

4.5.11.1 Effect flatwise tensile properties of polymer based structural honeycomb core. A minimum of ten flatwise tensile test specimens shall be fabricated from the structural honeycomb core described in 4.5.11 in accordance with ASTM C297/C297M. The test specimens shall be dried in accordance with ASTM D5229/D5229M, Procedure D. Five dried specimens of the core shall be immersed in the cleaner at room temperature for 14 days. After 14 days, specimens shall be removed from the cleaner, dried, and tested in accordance with ASTM C297/C297M. Test results shall be compared to the flatwise tensile properties of the five baseline (unexposed) specimens using t-test or analysis of variance (ANOVA) statistical methods.

4.5.12 Cleaning efficiency.

4.5.12.1 Preparation of test specimens. Stainless steel coupons 1 by 2 by 0.05 inch (25 by 50 by 1.3 mm) shall be polished with 240 grit aluminum oxide abrasive paper or cloth and solvent wiped with isopropyl alcohol. Coupons shall be weighed (weight = W_1), coated on one side with 20 - 25 mg of soil, then reweighed (weight = W_2). Soils to be tested shall be as follows:

- a. MIL-G-21164 (with 10 percent by weight carbon black blended in using a grease working machine to achieve a smooth consistency)
- b. MIL-PRF-83282 (with 10 percent by weight carbon black blended in using a spatula)
- c. MIL-PRF-10924 grease without additions

4.5.12.2 Test procedure. Fresh solvent shall be used for each soil tested. Each test coupon shall be cyclically immersed and withdrawn from a 150ml beaker containing 100ml of the cleaner at a rate of 20 cycles per minute for 5 minutes. Each coupon shall then be dried for 10 minutes at 140 ± 4 °F (60 ± 2 °C), cooled to room temperature, and reweighed (weight = W_3).

Cleaning efficiency for the cleaner shall be calculated as follows for each coupon:

$$\% \text{ Cleaning efficiency} = (W_2 - W_3) / (W_2 - W_1) \times 100$$

The test result for each soil shall be the average of three coupon cleaning efficiencies.

4.5.13 Odor evaluation. Odor shall be assessed by a three person panel in an odor-free area. No reference sample shall be used. Each assessor shall determine whether the odor is too offensive or intense to be used in the workplace and whether a residual odor exists after drying. The result shall be a consensus of the panel.

4.5.14 Storage stability. The cleaner, after storage in its original unopened container for not less than one year, shall be subjected to the tests necessary to meet the requirements specified in 3.5.

4.5.15 Aerosol dispenser.

4.5.15.1 Composition. The dispenser shall be visually examined to determine conformance to 3.7.1.

4.5.15.2 Leakage. Using a filled pressurized dispenser, the solvent shall be sprayed five times for three seconds with a two second pause between sprays. The dispenser shall then be submerged completely in water maintained at 54 ± 1 °C (130 ± 2 °F) for five minutes. The emission of bubbles indicates leakage. At the end of the five minutes, the dispenser shall be removed from the water and examined for conformance to 3.7.3.

4.5.15.3 Net contents. The net weight of the dispenser shall be determined by the difference between the gross weight and the tare weight. Results shall be in conformance with 3.7.4.

4.5.15.4 Pre-saturated wipes (Type IIIW).

4.5.15.4.1 Composition. All pre-saturated wipes shall be free of visible contamination and show no signs of degradation, discoloration, fiber deterioration or any odor not consistent with the

bulk Type I product. Wipes shall conform to SAE AMS-S-3819, Class II, Grade A and be composed of a nonwoven material consisting of 100 percent Rayon or Lyocell. The dispenser shall be visually examined to determine conformance to 3.7.2.1.

4.5.16 Health/hazard assessment (HHA). The cleaner shall be evaluated by the Navy and Marine Corps Public Health Center (NMCPHC), using the administrative HHA (see 6.7.2).

5. PACKAGING

5.1 Packaging. For acquisition purposes, the packaging requirements shall be as specified in the contract or order (see 6.2). When packaging of materiel is to be performed by DoD or in-house contractor personnel, these personnel need to contact the responsible packaging activity to ascertain packaging requirements. Packaging requirements are maintained by the Inventory Control Point's packaging activities within the Military Service or Defense Agency, or within the military service's system commands. Packaging data retrieval is available from the managing Military Department's or Defense Agency's automated packaging files, CD-ROM products, or by contacting the responsible packaging activity.

6. NOTES

(This section contains information of a general or explanatory nature which may be helpful, but is not mandatory.)

6.1 Intended use. The materials covered by this specification are non-aqueous cleaners that are free of hazardous air pollutants and available in a low VOC (no more than 25 grams per liter) and high VOC types. The cleaners are intended for cleaning metallic, polymeric, and fiber reinforced polymer matrix composite materials and the adhesives and cores used in fabrication of advanced PMC-based aircraft structure. The cleaners are suitable for cleaning light soils, such as oils and hydraulic fluids, and heavy soils such as greases. Type IIIW is intended for wipe cleaning applications. Types I, II and III products are suitable for cleaning both metallic and fiber reinforced polymer matrix composite materials. Type III cleaners are exempt from aerospace National Emission Standards for Hazardous Air Pollutants (NESHAPs) and have similar performance properties to Type I cleaners. Uses include cleaning of aircraft components and ground support equipment. The cleaner may be suitable for other cleaning applications.

6.2 Acquisition requirements. Acquisition documents should specify the following:

- a. Title, number, and date of this specification.
- b. Type required (see 1.2).
- c. Quantity.
- d. Packaging requirements (see 5.1).

6.3 Qualification. With respect to products requiring qualification, awards will be made only for products which are, at the time of award of contract, qualified for inclusion in Qualified Products List QPL-32597, whether or not such products have actually been so listed by that date. The attention of the contractors is called to these requirements, and manufacturers are urged to arrange to have the products that they propose to offer to the Federal Government tested for qualification in order that they may be eligible to be awarded contracts or orders for the products covered by this specification. Information pertaining to qualification of products may be obtained from the Commander, Naval Air Warfare Center Aircraft Division, Code 4.3.4.2, Building 2188, Patuxent River, MD 20670-1908. An online listing of products qualified to

this specification may be found in the Qualified Products Database (QPD) at <https://assist.dla.mil>.

6.3.1 Storage stability, inspection, and other information. In addition to the qualification test samples, the qualifying activity will request the manufacturer to submit to the qualification activity: (a) a certified test report showing that the material conforms to the requirements of this specification; (b) one copy of the SDS (see 6.7.1); (c) certification that the manufacturer's material meets the VOC requirement (see Table I).

6.3.1.1 Qualification inspection sample identification. Qualification inspection samples are to be forwarded to the laboratory designated in the letter of authorization from the qualifying activity (see 6.3) and identified as follows:

QUALIFICATION TEST SAMPLES

Specification MIL-PRF-32597, Type and Class (as applicable)

CLEANER, POLYMER AND POLYMER MATRIX COMPOSITE (PMC)

MATERIAL, NON-AQUEOUS, HAP-FREE

Manufacturer's name and product number

Submitted by (name and date) for qualification testing in accordance with authorization
(reference authorizing letter)

6.4 Retention of qualification. To retain qualification approval of products listed on the Qualified Products List (QPL), the manufacturer will be required to verify by certification to the qualifying activity that its product(s) comply with the requirements of this specification. Unless otherwise specified by the qualifying activity, the time of periodic verification by certification is in two-year intervals from the date of original qualification. The certification action is initiated by the qualifying activity.

6.5 Conformance rejection and retest. Failure in any conformance inspection will result in the rejection of the batch from which it was obtained and constitutes justification for removal from the qualified products list. Rejected material cannot be resubmitted for acceptance without written approval from the qualifying activity (see 6.3). The application for resubmission will contain all

details concerning previous rejections and measures taken to correct these deficiencies.

6.6 Lot and batch formation. A lot consists of all of the cleaners manufactured at one time from one batch, forming part of one contract or order, and submitted for acceptance. A batch consists of all cleaners manufactured during one continuous operation.

6.7 Toxicity.

6.7.1 Safety Data Sheet (SDS). An SDS must be prepared and submitted in accordance with FED-STD-313 (obtain from <https://assist.dla.mil>). The SDS must also meet the requirements of 29 CFR 1910.1200. The 29 CFR 1910.1200 requires that the SDS for each hazardous chemical used in an operation must be readily available to personnel using the material. Questions pertinent to the effect(s) of these cleaners on the health of personnel using them should be referred by the procuring activity to the appropriate medical service, who will act as its adviser. Contracting officers will identify the activities requiring copies of the SDS.

6.7.2 Health/hazard assessment (HHA). The qualifying activity will request the Navy and Marine Corps Public Health Center (NMCPHC) to perform an HHA on the cleaner furnished. Prior to listing on the Qualified Products List, the results of the NMCPHC HHA must be deemed acceptable by the qualifying activity. The HHA is a review of the product based on information submitted by the manufacturer, to assess health hazards associated with the handling, application, and use of the product. Information on the HHA process can be found at

<http://www.med.navy.mil/sites/nmcphc/industrial-hygiene/Pages/health-hazard-assessment.aspx> (BUMEDINST 6270.8A provides additional information/guidance pertaining to this process).

Sufficient data to permit an HHA of the product is to be provided by the manufacturer to the Commanding Officer, Navy & Marine Corps Public Health Center, 620 John Paul Jones Circle, Suite 1100, Portsmouth, VA 20378-2103.

6.8 Definitions.

6.8.1 Carcinogens. The Occupational Safety and Health Administration (OSHA) definition of carcinogens is those chemicals / processes appearing in lists 1, 2A, and 2B of the International Agency for Research on Cancer (IARC) 1/; substances known to be carcinogenic and occupational exposures associated with a technological process known to be carcinogenic by the National Toxicology Program (NTP) Report on Carcinogens (latest annual report) 2/; and OSHA regulated carcinogens.

1/ Copies of these volumes may be found in medical libraries or through the World Health Organization, 1211 Geneva 27, Switzerland.

2/ Copies may be obtained from the Public Health Service, National Toxicology Program, Public Information Office, P.O. Box 12233, MD B2-04, Research Triangle Park, NC 27709.

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6.8.2 Hazardous Air Pollutant (HAP). HAP is defined as any substance listed under Section 112 of the Clean Air Act or its modifications. The text of the Clean Air Act, listed pollutants and modifications are kept by the Environmental Protection Agency (EPA) and are accessible through the website: <http://www.epa.gov>.

6.8.3 Volatile organic compound (VOC). VOC is defined in 40 CFR Part 51.100.

6.9 Subject term (key word) listing.

Cleaning

Cleaning compound

Cleaning efficiency

Miscibility

Soil

Solvent

CONCLUDING MATERIAL

Custodians:

Army – AT

Navy – AS

Air Force – 68

DLA – GS

Preparing activity:

Navy – AS

(Project 6850-2018-002)

NOTE: The activities listed above were interested in this document as of the date of this document. Since organizations and responsibilities can change, you should verify the currency of the information above using the ASSIST Online database at <https://assist.dla.mil>.

The Health and Safety Plan for the demonstration will follow the guidelines contained in EM 385-1-1 Safety and Health Requirements Manual. Applicable sections of EM 385-1-1 will be reviewed by members of the demonstration team prior to conducting the demonstrations. The Health Hazard Assessment for NAVSOLVE™ was conducted by the Navy and Marine Corp Public Health Center (Portsmouth, VA) in 8 March 2011.

Personal Protective Clothing and Equipment

Eye Protection

Eye hazardous tasks are any tasks that expose the worker to a reasonable possibility of an eye injury from dust, shavings, other flying particles, liquid chemicals, acids or caustic liquids, chemical gases or vapors, molten metal, hazardous glare, or radiation.

1. Safety eyewear will be worn by all employees who enter eye hazard areas or perform eye hazardous tasks.
2. When an employee suffers an eye injury, the supervisor must state on the CA-1 and dispensary pass if safety eyewear was required for the job being performed and if the eyewear was being worn.
3. All safety glasses will be issued with side shields. Side shields must be used at all times. Tasks that involve chemicals or fine particles call for the use of chemical splash goggles, not safety glasses.
4. Safety eyewear shall be distinctly marked to facilitate identification of the manufacturer.
5. Photo grey lenses are not authorized; the tint change is relatively slow and inconsistent.
6. Any person having useful vision in only one eye will be furnished with and required to wear safety glasses while in a shop or field environment.
7. Contact lenses do not meet the requirements of eye protection. A person wearing contact lenses must use some form of eye protection when in a hazardous area.
8. No person wearing contact lenses will be allowed to work in areas where chemicals, fumes, vapors, dusts, particles or molten metals are present.
9. A face shield should be used in conjunction with eye protection to protect the face from chemicals, particles or other material such as banding steel.

Foot Protection

1. Employees shall wear protective footwear when working in areas where there is a danger of foot injuries due to falling and rolling objects or objects piercing the sole.
2. Sandals, canvas shoes, cloth shoes, or similar types will not be worn in shops or warehouse areas.
3. It is the employee's responsibility to select safety shoes that fit properly to preclude foot discomfort.
4. Personnel who work upon conductive flooring, conductive mats, or conductive runners where explosives or flammable vapors are present, must wear non-sparking, conductive footwear. Personnel from other departments or visitors who enter these areas and who walk on conductive flooring materials must also wear non-sparking conductive footwear. Leg stats are acceptable for visitors or transients and can be used in toxic chemical operations, as long as their basic footwear is of non-sparking construction. Under no circumstances will personnel

working on electrical equipment or facilities wear conductive-sole safety shoes or other conductive footwear.

5. For all operations involving explosives not susceptible to static spark of the energy that can be discharged from a person, spark-proof (nonspark-producing) shoes are required. Shoes with soles and heels of leather, rubber, or synthetic compositions (neolite, neoprene, and similar compositions) may be used provided the soles and heels contain nonexposed nails or holes. The shoes shall have a fully enclosed safety toecap. The soles and heels must be cleaned free from sand and dirt before entering a building containing explosives.
6. Conductive shoes, under emergency circumstances may be used as a substitute provided they are closely examined and tested after this use and electric current sources are guarded or shut off in the area of operation.

Respiratory Protection

In the control of those occupational diseases caused by breathing air contaminated with harmful dusts, fogs, fumes, mists, gases, smokes, sprays, or vapors, the primary objective shall be to prevent atmospheric contamination. This shall be best accomplished by accepted engineering control measures (i.e. enclosure or confinement of the operation, general and local ventilation and substitution of less toxic materials).

Respiratory protection will only be used as a means of controlling employee exposure to airborne environmental hazards under the following circumstances:

- a) When no engineering or work practice controls can be used to adequately control the hazard.
- b) *During intermittent or nonroutine operations.*
- c) During interim periods while engineering controls are being designed and installed to eliminate the hazard.
- d) During emergencies.

Hazardous Materials

Labeling

The precautionary label for any hazardous chemical will be based upon the hazard it possesses. Containers of hazardous chemicals will be labeled in accordance with ANSI 129.1 (American National Standard for Hazardous Industrial Chemicals-Precautionary Labeling) and 29 CFR 1910.1200. As a minimum, they will contain the following:

- a) Identity of hazardous chemical.
- b) Appropriate hazard warnings.
- c) Name/manufacturer, importer or other responsible party.
- d) Precautionary measures (first aid).

Precautionary labels will be affixed to containers of hazardous material to afford easy and quick recognition of associated hazards.

Vehicles transporting hazardous chemicals will have placards corresponding to the warning label on the container to alert persons to potential dangers associated with the hazardous chemicals contained in the vehicle, and the driver will be briefed concerning the hazardous material transported.

Responsibilities

Employees will be provided information and training on hazardous chemicals in their work areas at the time of their initial assignment and whenever a new hazardous chemical is introduced into their work area. Responsibilities will include, but are not limited to:

- a) Obtain Material Safety Data Sheets for hazardous chemicals when requested by the user, and forward a copy of the MSDS to the user as requested.
- b) Review Material Safety Data Sheets, Process Control Pamphlets, and local SOPs, become familiar with the hazards associated with the chemical being handled, and know first aid and emergency procedures.
- c) Follow proper storage and handling procedures.
- d) Report all leaks or spills of hazardous chemicals to the immediate supervisor.

APPENDIX C Health Hazard Assessment



DEPARTMENT OF THE NAVY
NAVY AND MARINE CORPS PUBLIC HEALTH CENTER
620 JOHN PAUL JONES CIRCLE SUITE 1100
PORTSMOUTH VA 23708-2103

6261
Ser IH46/ 000111
03 MAR 2011

From: Commanding Officer, Navy and Marine Corps Public Health Center

To: Commander, Naval Air Warfare Center Aircraft Division (E. S. Arafat), Building 2188, 48066 Shaw Road, Unit 5, Patuxent River, MD 20670-1908

Subj: HEALTH HAZARD ASSESSMENT FOR NAVSOLVE CLEANER

Ref: (a) NAVAIRWARCEN Aircraft Division ltr 4123 Ser 434200A/10.0055 of 27 Sep 10
(b) NAVMCPUBHLTHCENINST 6270.8B of 6 Apr 09
(c) Material Safety Data Sheet for NAVSOLVE Non-Aqueous Cleaner (Industrial and Operational Chemical Laboratory, NAVAIR, AIR 4.3.4.2) of 21 Dec 10
(d) MIL-PRF-32295A, Cleaner, Non-Aqueous, Low VOC, HAP-Free of 19 Apr 10
(e) PHONCON NAVAIRWARCEN E. Arafat/NAVMCPUBHLTHCEN A. Smith of 10 Dec 10
(f) MIL-PRF-680B, Degreasing Solvent of 26 Oct 06
(g) Electronic Correspondence NAVAIRWARCEN E. Arafat/NAVMCPUBHLTHCEN A. Smith of 22 Dec 10
(h) NAVAIRWARCEN Confidential Proprietary Information, NAVSOLVE Formulation of 28 Sep 10

Encl: (1) Health Hazard Assessment for NAVSOLVE Cleaner

1. Reference (a) requested that the Navy and Marine Corps Public Health Center (NAVMCPUBHLTHCEN) conduct a health hazard assessment (HHA) on the subject cleaner per the guidance in reference (b). Per references (a) and (c), NAVSOLVE is a non-aqueous cleaner that is being considered to satisfy the requirements of reference (d) for a Type I cleaner. According to reference (e), reference (d) replaces reference (f).

2. Reference (g) states that NAVSOLVE is still under development. Therefore, this HHA addresses only the formulation and information provided in references (c), (d) and (h). A new HHA will be required if there are any changes in the product

Subj: HEALTH HAZARD ASSESSMENT FOR NAVSOLVE CLEANER

formulation, use or performance specifications. Such changes could occur if the product is unsatisfactory during field testing.

3. Follow the health and safety recommendations in enclosure (1) to minimize personnel illness or injury. Per reference (c), NAVSOLVE consists of octamethylcyclotetrasiloxane (D4), decamethylcyclopentasiloxane (D5) and solvents, which can all cause eye and skin irritation. It is important to note that laboratory inhalation studies using D4 have shown adverse reproductive effects in female rats.

4. If you need additional information, please contact Ms. P. Krevonick at DSN 377-0754, commercial 757-953-0754 or e-mail Patricia.Krevonick@med.navy.mil.



D. D. Hagen
By direction

Copy to:
BUMED (M44)

Health Hazard Assessment for NAVSOLVE Cleaner

- Ref:
- (a) NAVAIRWARCEN Aircraft Division ltr 4123 Ser 434200A/10.0055 of 27 Sep 10
 - (b) Electronic Correspondence NAVAIRWARCEN E. Arafat/NAVMCPUBHLTHCEN A. Smith of 22 Dec 10
 - (c) Material Safety Data Sheet, NAVSOLVE Non-Aqueous Cleaner (Industrial and Operational Chemical Laboratory, NAVAIR, AIR 4.3.4.2) of 21 Dec 10
 - (d) NAVAIRWARCEN Confidential Proprietary Information, NAVSOLVE Formulation of 28 Sep 10
 - (e) Material Safety Data Sheet, Dow Corning Corporation, 245 Fluid (D5) of 02 Jun 08
 - (f) Material Safety Data Sheet, Dow Corning Corporation, 244 Fluid (D4) of 18 May 10
 - (g) Silicones Environmental, Health and Safety Council of North America. Science, Health and Safety for D4 and D5. Available at www.sehsc.com/d4.asp and [/d5.asp](http://www.sehsc.com/d5.asp). Accessed 22 Dec 10.
 - (h) Material Safety Data Sheets for Dow Corning Corporation proprietary solvents of 16 Aug 07 and 21 Jun 10
 - (i) Searches from MEDLINE Plus®, National Library of Medicine, Bethesda, MD (15 Dec 1)
 - (j) Burns-Naas, L. A., Meeks, R. G., Kolesar, G. B., Mast, R. W., Elwell, M. R., Hardisty, J. F. and Thevenaz, P. Inhalation Toxicology of Octamethylcyclotetrasiloxane (D4) Following a 3-Month Nose-Only Exposure in Fischer 344 Rats. International Journal of Toxicology, 21(1): 39-53. 2002.
 - (k) Siddiqui, W. H., Stump, D. G., Plotzke, K. P., Holson, J. F. and Meeks, R. G. A Two-Generation Reproductive Toxicity Study of Octamethylcyclotetrasiloxane (D₄) in Rats Exposed by Whole-Body Vapor Inhalation. Reproductive Toxicology, 23(2): 202-215. 2007.
 - (l) American Conference of Governmental Industrial Hygienists (ACGIH). Industrial Ventilation: A Manual of Recommended Practice for Design. Cincinnati, OH: ACGIH. 2010.
 - (m) OPNAVINST 5100.23G, Chapter 8

1. Scope. According to references (a) and (b), NAVSOLVE will be used in various types of automatic and manual parts washers (both standard and recycling) to clean engine parts, wheel bearings, wheel assemblies and break assemblies from aircraft

Enclosure (1)

and ground support equipment. Military, civil service and possibly contract personnel at the depot, intermediate and squadron levels will use the cleaner. The company planning to license NAVSOLVE will package it in one and five gallon containers and in fifty-five gallon drums. The bulk cleaner will be pumped or poured directly from the container to the parts washer, using approximately 20-25 gallons at room temperature.

2. Health Hazards. Per references (c) and (d), NAVSOLVE consists of 30-40% octamethylcyclotetrasiloxane (D4), 60-70% decamethylcyclopentasiloxane (D5) and solvents (2 proprietary solvents totaling less than 5% by weight).

a. Based on references (e) through (i), health hazards associated with using NAVSOLVE include mainly eye and skin irritation. The organic solvents can affect the central nervous system, causing headache, fatigue or confusion. Since the percentage of solvents is low, such effects are not expected unless NAVSOLVE is heated or aerosolized.

b. Reference (f) states that commercial uses of D4 products do not represent a human risk. However, laboratory inhalation studies using octamethylcyclotetrasiloxane have reported evidence of adverse reproductive effects in female study animals [e.g., references (j) and (k)].

3. Exposure Protection and Industrial Hygiene Control.

a. Wear chemical splash-proof goggles and nitrile gloves when handling NAVSOLVE to protect the eyes and skin. Employees should wash hands thoroughly before breaks and meals, at the end of the shift and any time there is substantial skin contact. Use NAVSOLVE only in well ventilated areas.

b. Until human risks have been fully evaluated for D4, use local exhaust ventilation over the parts washers that meets the requirements of reference (l). Ventilation should be tested during the scheduled industrial hygiene survey per reference (m).

4. Safety Precautions. Reference (c) states that NAVSOLVE is a combustible liquid with a flash point of 141 degrees Fahrenheit. As a precaution, do not use NAVSOLVE in parts washers that have heating capability. Per references (e) and (f), static electricity may ignite vapors. Avoid creating mists, and

provide grounding to prevent a possible fire hazard. Keep stored containers closed and away from heat, sparks and flames.

5. Emergency Contact. The Regional Poison Control Center can be contacted at 1-800-222-1222 regarding acute or chronic poisoning from ingredients discussed in the HHA.



Safety Data Sheet (SDS)

OSHA HazCom Standard 29 CFR 1910.1200(g) and GHS Rev 03.

Reviewed on 05/07/2015

1 Identification

· **Product identifier**

· **Trade name: NAVSOLVE®**

· **Product description**

NAVSOLVE® is a low VOC (<25 g/ml) degreaser qualified to MIL-PRF-32295A Type II

Product Name	Part No.	Packaging	National Stock Number
NAVSOLVE®	240-55	55 Gal Drum	6850-01-606-8358
NAVSOLVE®	240-15	15 Gal Drum	6850-01-606-3293
NAVSOLVE®	240-5	5 Gal Drum	6850-01-606-8357
NAVSOLVE®	240-1	4 x 1 Gal Case	6850-01-606-8356

· **Details of the supplier of the safety data sheet Manufacturer Supplier:**

Ecolink

2177 Flintstone Drive, Ste. A

Tucker, GA 30084

www.ecolink.com

800-886-8240 or 770-621-8240 (8-5 EST)

email: info@ecolink.com

· **Emergency telephone number:**

Inside the U.S.: 800-535-5053 (INFOTRAC, 24 HOURS)

Outside the U.S.: 352-323-3500 (INFOTRAC, 24 HOURS)

2 Hazard(s) identification

· **Classification of the substance or mixture**



GHS08 Health hazard

Repr. 2 H361 Suspected of damaging fertility or the unborn child.

Flam. Liq. 4 H227 Combustible liquid.

Eye Irrit. 28 H320 Causes eye irritation.

· **Label elements**

· **GHS label elements**

The product is classified and labeled according to the Globally Harmonized System (GHS).

· **Hazard pictograms**



GHS08

· **Signal word Warning**

(Contd. on page 2)

uS

Safety Data Sheet (SDS)

OSHA HazCom Standard 29 CFR 1910.1200(g) and GHS Rev 03.

Reviewed on 05/07/2015

Trade name: NAVSOLVE®

- **Hazard-determining components of labeling:**
Octamethylcyclotetrasiloxane
- **Hazard statements**
Combustible liquid.
Causes eye irritation.
Suspected of damaging fertility or the unborn child.
- **Precautionary statements**
Keep away from flames and hot surfaces. – No smoking.
Wear protective gloves, eye protection, face protection.
Wash thoroughly after handling.
Obtain special instructions before use.
Do not handle until all safety precautions have been read and understood.
If in eyes: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing. If eye irritation persists: Get medical advice/attention.
If exposed or concerned: Get medical advice/attention.
In case of fire: Use for extinction: CO₂, or dry chemical rated for Class B.
Store locked up.
Store in a well-ventilated place. Keep cool.
Dispose of contents/container in accordance with local, regional, national or international regulations.
- **Classification system: NFPA/HMIS Definitions: 0-Least, 1-Slight, 2-Moderate, 3-High, 4-Extreme**
- **NFPA ratings (scale 0 - 4)**


Health = 1
Fire = 2
Reactivity = 0
- **HMIS-ratings (scale 0 - 4)**


HEALTH 1 Health = *1
FIRE 2 Fire = 2
REACTIVITY 0 Reactivity = 0
- **Hazard(s) not otherwise classified (HNOC):** None known

3 Composition/information on ingredients

- **Chemical characterization:** Mixtures
- **Description:** Mixture of substances listed below with nonhazardous additions.
- **Dangerous Components:**

CAS: 541-02-6	Decamethylcyclopentasiloxane	40-60%
	Flam. Liq. 4, H227; Eye Irrit. 28, H320	
CAS: 556-67-2	Octamethylcyclotetrasiloxane	25-50%
RTECS: GZ 4397000	Flam. Liq. 3, H226; Repr. 2, H361; Aquatic Chronic 4, H413	
CAS: 29911-28-2	Dipropylene glycol, n-butyl ether	2-12%
	Skin Irrit. 2, H315; Eye Irrit. 28, H320	

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Safety Data Sheet (SDS)

OSHA HazCom Standard 29 CFR 1910.1200(g) and GHS Rev 03.

Reviewed on 05/07/2015

Trade name: NAVSOLVE®

CAS: 107-41-5 Hexylene Glycol <1.0%
RTECS: SA 0810000 Skin Irrit. 2, H315; Eye Irrit. 2, H319; Flam. Liq. 4, H227

4 First-aid measures

- **Description of first aid measures**
- **Inhalation:** Supply fresh air. If not breathing provide artificial respiration. Consult doctor if symptoms persist. In case of unconsciousness, place patient securely on side position for transportation.
- **Skin contact:** Wash areas with soap and water, remove contaminated clothing and shoes. If skin irritation occurs, consult a doctor.
- **Eye contact:** Remove contact lenses at once. Rinse opened eye, including under eyelids under running water for at least 15 minutes. If irritation persists, seek medical attention.
- **Swallowing:** Rinse out mouth and then drink plenty of water. Do not induce vomiting. If vomiting does occur, repeat fluid administration. If symptoms develop and/or persist, seek medical attention.
- **Information for doctor:** Treat symptomatically
- **Most important symptoms/effects, both acute and delayed:** Breathing difficulties. Symptoms of overexposure may be headache, dizziness, tiredness, nausea and vomiting
- **Indication of any immediate medical attention and special treatment needed**
No further relevant information available.

5 Fire-fighting measures

- **Suitable Extinguishing media:** For small (incipient) fires, use regular foam, water fog, carbon dioxide or dry chemical. For large fires apply water from afar away as possible using very large quantities (flooding) applied as a mist or spray; solid streams of water may be ineffective. Cool affected containers with flooding quantities of water.
- **Special hazards arising from the substance or mixture:** Combustible liquid. Vapors can travel to a source of ignition and flash back. Explosive mixtures may occur at temperatures at or above flashpoint. If incinerated product will release the following toxic fumes: Carbon Oxides and Silicon Oxides.
- **Advice for firefighters Protective equipment:**
As in any fire, wear self-contained breathing apparatus pressure-demand (NIOSH approved or equivalent), and full protective gear to prevent contact with skin and eyes.

6 Accidental release measures

- **Personal precautions, protective equipment and emergency procedures**
Ensure adequate ventilation, keep people at a distance and stay upwind.
Avoid contact with skin, eyes and clothing. Beware of vapors accumulating to form explosive concentrations, vapors can accumulate in low areas. Keep away from ignition sources

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Safety Data Sheet (SDS)

OSHA HazCom Standard 29 CFR 1910.1200(g) and GHS Rev 03.

Reviewed on 05/07/2015

Trade name: NAVSOLVE®

- *Environmental precautions: Do not allow to enter sewers/ surface or ground water.*
- *Methods and material for containment and cleaning up: Absorb with liquid-binding material (i.e. sand, diatomite, acid binders, universal binders, sawdust). Keep in suitable closed containers for disposal. Remove all sources of ignition, use spark proof tools and explosive proof equipment. Dispose contaminated material as waste according to section 13.*
- *Reference to other sections*
See Section 7 for information on safe handling.
See Section 8 for information on personal protection equipment.
See Section 13 for disposal information.

7 Handling and storage

- *Precautions for safe handling: Avoid contact with skin, eyes and clothing. Keep away from sources of ignition. Ensure good ventilation/exhaustion at the workplace. Open and handle receptacle with care. Prevent formation of mists/vapors. Take measures to prevent electrostatic charge. Keep receptacles tightly sealed.*
- *Information about protection against explosions and fires: Protect from heat, keep away from sparks and flame. Keep protective respiratory device available.*
- *Conditions for safe storage, including any incompatibilities: Store away from strong acids, strong bases, strong oxidizing agents and strong reducing agents.*
- *Requirements to be met by storerooms and receptacles: Store in a well ventilated place. Store in a cool, dry place away from sparks and flame. Do not store in direct sunlight.*

8 Exposure controls/personal protection

- *Control parameters*
All ventilation should be designed in accordance with OSHA standard (29 CFR 1910.94). Use mechanical (general) ventilation for storage areas. Use appropriate ventilation as required to keep Exposure Limits in Air below TLV & PEL limits.
- *Components with occupational exposure limits:*
The product does not contain any relevant quantities of materials with critical values that have to be monitored at the workplace.
- *Engineering Measures: Ensure adequate ventilation especially in confined areas, ensure eye wash stations and safety showers are close to work stations.*
- *Components with occupational exposure limits:*
107-41-5 Hexylene Glycol
TLV ACGIH: 25 ppm
ACGIH - American Conference of Governmental Industrial Hygienists
- *General protective and hygienic measures: The usual precautionary measures for handling chemicals should be followed. Keep away from foodstuffs, beverages. Immediately remove all soiled and contaminated clothing and wash before reuse. Wash hands before breaks and at the end of work. Store protective clothing separately. Avoid contact with the eyes. Avoid contact with the eyes and skin.*

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Trade name: NAVSOLVE®

- **Breathing equipment:** Not necessary if room is well-ventilated. Where risk assessment shows air-purifying respirators are appropriate use a full face respirator. Use respirators and components tested and approved under appropriate government standards such as NIOSH (US) or CEN (EU).
- **Protection of hands:** Handle with gloves. Gloves must be inspected prior to use. Use chemical resistant gloves.

- **Eye protection:**



Wear appropriate protective glasses with side shields or chemical safety goggles. All eye protection should meet OSHA eye and face protection in regulations 29 CFR 1910.133 or NIOSH (US) or EN 166 (EU)

- **Body protection:** Wear appropriate impervious clothing to prevent skin exposure

9 Physical and chemical properties

- Information on basic physical and chemical properties

- General Information

- Appearance:

Form:

Liquid

Color:

Colorless

- Odor:

Mild

- Odor threshold:

Not determined.

- pH-value:

Not determined.

- Change in condition

Melting point/Melting range:

Not determined.

Boiling point/Boiling range:

85 °C (185 °F)

- Flash point:

61 °C (142 °F)

- Flammability (solid, gaseous):

Not applicable.

- Ignition temperature:

Decomposition temperature:

Not determined.

- Auto igniting:
self-igniting.

Product is not

- Danger of explosion:

Not determined.

- Explosion limits:

Lower:

Not determined.

Upper:

Not determined.

- Vapor pressure @ 20 °C (68 °F):

<0.5 mm Hg

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OSHA HazCom Standard 29 CFR 1910.1200(g) and GHS Rev 03.

Reviewed on 05/07/2015

Trade name: NAVSOLVE®

- Density @ 20 °C (68 °F): 0.950-0.965 g/cm³ (7.92-8.05 lbs/gal)
- Relative density: Not determined.
- Vapor density: >1.0 (air=1)
- Evaporation rate @ 20 °C (68 °F): 0.04 (nBuAc=1)
- Solubility in / Miscibility with Water: Negligible
- Partition coefficient (n-octanol/water): Not determined.
- Viscosity:
 - Dynamic: Not determined.
 - Kinematic: Not determined.
- Solvent content: <25 g/l
- VOC content: <25 g/l
- Other information: No further relevant information available.

10 Stability and reactivity

- Chemical stability: Stable under recommended storage conditions.
- Possibility of hazardous reactions: No dangerous reactions known.
- Conditions to avoid: Elevated temperatures; decomposes with heat. Sources of ignition such as sparks, hot spots, welding, flames. Exposure to moist air or water.
- Incompatible materials: Strong acids, strong bases, strong oxidizing agents and strong reducing agents.
- Hazardous decomposition products: Carbon Oxides and Silicon Oxides.

11 Toxicological information

- Information on toxicological effects
- Acute toxicity:
- LD/LC50 values that are relevant for classification:
 - 29911-28-2 Dipropylene glycol n-butyl ether
 - Oral LD50 >3,700 mg/kg (rat)
 - Dermal LD50 >2,000 mg/kg (rabbit)
 - 107-41-5 Hexylene Glycol
 - Oral LD50 3,700 mg/kg (rat)
 - Dermal LD50 7,600 mg/kg (rabbit)
- Information on toxicological effects: The toxicity of this product is unknown.
- Acute toxicity:
- Primary irritant effect:
 - on the skin: No irritating effect.
 - on the eye: Irritating effect. Causes serious eye irritation.

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Trade name: NAVSOLVE®

Additional toxicological information:

The product shows the following dangers according to Internally approved calculation methods for preparations: Irritant

Carcinogenic categories

IARC (International Agency for Research on Cancer)

Group 1 - Carcinogenic to humans

Group 2A - Probably carcinogenic to humans

Group 2B - Possibly carcinogenic to humans

Group 3 - Not classifiable as to its carcinogenicity to humans

Group 4 - Probably not carcinogenic to humans

None of the ingredients are listed.

NTP (National Toxicology Program)

None of the ingredients are listed.

OSHA-Ca (Occupational Safety & Health Administration)

None of the ingredients are listed.

12 Ecological information

Aquatic

- Acute: 29911-28-2 Dipropylene glycol, n-butyl ether

Fish LC50 841 mg/l, 96 hours Guppy (Poecilia reticulata)

Crustacea EC50 >1000 mg/l, 48 hours Water flea (Daphnia magna)

- Persistence and degradability No further relevant information available.

- Behavior in environmental systems: An environmental hazard cannot be excluded in the event of unprofessional handling or disposal.

- Bio-accumulative potential No further relevant information available.

- Mobility in soil No further relevant information available.

Additional ecological information:

- General notes: Not known to be hazardous to water.

- Results of PBT and vPvB assessment:

- PBT: Not applicable.

- vPvB: Not applicable.

- Other adverse effects No further relevant information available.

13 Disposal considerations

Waste treatment methods

Recommendation:

Must not be disposed of together with household garbage. Do not allow product to reach sewage or any water system. NAVSOLV liquid is to be disposed of according to local, state, federal and international regulations. This combustible material may be burned in a chemical incinerator equipped with an afterburner and scrubber. Offer surplus and non-recyclable solutions to a licensed disposal company. Under RCRA, this material is not considered as hazardous.

- Un-cleaned packaging recommendation: Disposal must be made according to official regulations.

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Reviewed on 05/07/2015

Trade name: NAVSOLVE

14 Transport information

- UN-Number
DOT, ADR, ADN, IMDG, IATA Non-Regulated Material
- UN proper shipping name
DOT, ADR, ADN, IMDG, IATA Non-Regulated Material
- Transport hazard class(es)
DOT, ADR, ADN, IMDG, IATA Non-Regulated Material
- Class
- Packing group
DOT, ADR, IMDG, IATA Non-Regulated Material
- Environmental hazards: Not applicable.
- Special precautions for user Not applicable.
- Transport in bulk according to Annex II of MARPOL73178 and the IBC Code Not applicable.

15 Regulatory information

- Safety, health and environmental regulations/legislation specific for the substance or mixture
- Sara
 - Section 355 (extremely hazardous substances):
None of the ingredients are listed.
 - Section 313 (Specific toxic chemical listings):
None of the ingredients are listed.
- TSCA (Toxic Substances Control Act):
All ingredients are listed.
- California Proposition 65: This product contains no listed substance known to the State of California to cause cancer, birth defects or other reproductive harm at levels which would require a warning under the statute.
- State Right to Know: Components of this product are found on the following state lists. FL, MA, NJ, WI, RI, PA

CAS #107-41-5	Hexylene Glycol	Amount <1%
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- Chemicals known to cause cancer:
None of the ingredients listed.
- Chemicals known to cause reproductive toxicity for females:
None of the ingredients listed.
- Chemicals known to cause reproductive toxicity for males:
None of the ingredients listed.
- Chemicals known to cause developmental toxicity:
None of the ingredients listed.

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Trade name: NAVSOLVE®

- Carcinogenic categories
- EPA (Environmental Protection Agency)
None of the ingredients listed.
- TLV (Threshold Limit Value established by ACGIH)
None of the ingredients listed.
- NIOSH-Ca (National Institute for Occupational Safety and Health)
None of the ingredients listed.
- GHS label elements
The product is classified and labeled according to the Globally Harmonized System (GHS).
- Hazard pictograms



GHS08

- Signal word Warning
- Hazard-determining components of labeling: Octamethylcyclotetrasiloxane
- Hazard statements: Combustible liquid. Causes eye irritation.
Suspected of damaging fertility or the unborn child.

Precautionary statements

Keep away from flames and hot surfaces. - No smoking.
Wear protective gloves eye protection/face protection. Wash thoroughly after handling.
Obtain special instructions before use.
Do not handle until all safety precautions have been read and understood.
If in eyes: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing. If eye irritation persists: Get medical advice/attention.
If exposed or concerned: Get medical advice/attention.
In case of fire: Use for extinction: CO2, powder or water spray.
Store locked up.
Store in a well-ventilated place. Keep cool.
Dispose of contents/container in accordance with local, regional, national, international regulations

- Chemical safety assessment: A Chemical Safety Assessment has not been carried out.

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Safety Data Sheet (SDS)

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Reviewed on 05/07/2015

Trade name: NAVSOLVE®

16 Other Information

Ecolink, Inc. believes the information contained herein is accurate. However, Ecolink makes no warranty, expressed or implied, regarding the accuracy of this data or the results to be obtained by the use thereof. Ecolink, Inc. assumes no responsibility for injury from the use of the product described herein.

- Date of preparation / last revision 05/07/2015

- Abbreviations and acronyms:

ADR: The European Agreement concerning the International Carriage of Dangerous Goods by Road

ADN: The European Agreement concerning the International Carriage of Dangerous Goods by Inland Waterways

IMDG: International Maritime Code for Dangerous Goods

DOT: US Department of Transportation

IATA: International Air Transport Association

ACGIH: American Conference of Governmental Industrial Hygienists

EINECS: European Inventory of Existing Commercial Chemical Substances

ELINCS: European List of Notified Chemical Substances

CAS: Chemical Abstracts Service (division of the American Chemical Society)

NFPA: National Fire Protection Association (USA)

HMS: Hazardous Materials Identification System (USA)

VOC: Volatile Organic Compounds (USA, EU)

LC50: Lethal concentration, 50 percent

LD50: Lethal dose, 50 percent

Flam. Liq. 3: Flammable liquids, Hazard Category 3

Flam. Liq. 4: Flammable liquids, Hazard Category 4

Skin Irrit. 2: Skin corrosion/irritation, Hazard Category 2

Eye Irrit. 2: Serious eye damage/eye irritation, Hazard Category 2

Eye Irrit. 2B: Serious eye damage/eye irritation, Hazard Category 2B

Repr. 2: Reproductive toxicity, Hazard Category 2

Aquatic Chronic 4: Hazardous to the aquatic environment - Chronic Hazard, Category 4

SOS created by MSDS Authoring Services www.msdsauthoring.com (877) 204-9106

NAVSOLVE®**Low VOC Degreasing Solvent
Product Data Sheet**

PO Box 9
Tucker, GA 30084
800-886-8240 • 770-621-8240
www.ecolink.com
email: info@ecolink.com

Description

NAVSOLVE® is a low VOC (<25 gm/l) degreaser designed to replace P-D-680, Stoddard Solvent, and MIL-PRF-680 parts washer solvents. It conforms to MIL-PRF-32295A Type II. NAVSOLVE® is safe for use on ferrous and non-ferrous metals.

NAVSOLVE® is strong enough to remove grease, fuel oil, carbon and organic resins yet safe on most painted surfaces.

Benefits

- Excellent solvency for a wide range of soils
- Controlled evaporation
- Leaves no residue
- Low odor
- Low VOC – meets stringent air quality standards and is certified to the South Coast Air Quality Clean Air Solvent Certification program.
- Meets MIL-PRF-32295A Type II

Applications

Use undiluted. NAVSOLVE® works very well in a drum mounted parts washer or any immersion tank. (Not for use in high pressure enclosed cabinets.) You may also spray or wipe NAVSOLVE® on a surface to be cleaned. Oil, dirt and carbon will flow off surface. If additional cleaning is required, re-apply and agitate with rag or brush. To speed evaporation, use compressed air or wipe with a dry rag.

Safety and Handling Precautions

NAVSOLVE® is a combustible material that should never be used around open flames, (welding torches, for example). Always use with adequate ventilation. Rubber gloves are recommended. Place rags in a metal sealable container after use. Keep container closed. Avoid excessive contact with fumes or liquid. Consult MSDS.

Key Physical Characteristics

Property	Value
Appearance	Clear colorless liquid
Odor	Low
Flash Point, Tag Closed Cup	>60° C
Evaporation Rate (nBuAc=1)	<1
Specific Gravity	0.950-0.960
Vapor Pressure (mm Hg)	<0.5 @ 20°C
VOC Content	<25 grams/liter
Distillation Range	Approx. 185 - 205° C
Shelf Life	2 Years Minimum

Packaging

Product Name	Part No.	Packaging	National Stock No.
NAVSOLVE®	240-55	55 Gal Drum	6850-01-606-8358
NAVSOLVE®	240-15	15 Gal Drum	6850-01-606-3293
NAVSOLVE®	240-5	5 Gal Pail	6850-01-606-8357
NAVSOLVE®	240-1	4x1 Gal Case	6850-01-606-8356

Revision 3

