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

Joint Test Report S-95-SP-007-R1

for Validation of Alternatives to Lead-Containing Dry Film Lubricants for Antigalling/Antifretting, Antiseizing, and Assembly Aid Applications

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PREFACE

This report was prepared by Concurrent Technologies Corporation (*CTC*) through the National Defense Center for Environmental Excellence (NDCEE) under Contract Number DAAA21-93-C-0046. This report was prepared on behalf of, and under guidance provided by, the Joint Group on Pollution Prevention (JG-PP) through the Joint Acquisition Sustainment Pollution Prevention Activity (JASPPA) and the Propulsion Environmental Working Group (PEWG). The structure, format, and depth of technical content of the report were determined by the JASPPA, PEWG, government contractors, and other government technical representatives in response to the specific needs of this project.

This Joint Test Report (JTR) documents the results of the first three phases of testing of candidate alternative dry film lubricants. The results of the fourth testing phase will be documented in a subsequent JTR.

We wish to thank the participants involved in the creation of this document for their invaluable contributions.

EXECUTIVE SUMMARY

The Propulsion Environmental Working Group (PEWG) is a tri-service forum established to help resolve environmental issues common to aircraft engine users and manufacturers. Rolls-Royce Allison (formerly Allison Engine Company), AlliedSignal Engines, General Electric Aircraft Engines, and Pratt & Whitney-United Technologies Corporation participate in PEWG. These four manufacturers apply dry film lubricants (DFLs) to components of aircraft engines to prevent galling, fretting, and seizing at temperatures up to 1400°F. DFLs also aid in assembly of engines by providing lubrication and protecting against nicks and scratches. These DFLs are applied to a wide variety of metal substrates. Many of the DFLs currently used by the PEWG participants contain lead or other materials that cause environmental or health concerns.

The Joint Group on Pollution Prevention (JG-PP) and PEWG pursued a joint project to identify and validate more environmentally friendly alternatives to current DFLs. Target hazardous materials in current DFLs include lead, volatile organic compounds (VOCs), antimony, cadmium, and carcinogenic chemicals. A joint group led by JG-PP and PEWG defined critical requirements for alternative DFLs and tests to validate alternative DFLs. These tests are documented in the *Joint Test Protocol (JP-P-1-1) for Validation of Alternatives to Lead-Containing Dry Film Lubricants for Antigalling/Antifretting, Antiseizing, and Assembly Aid Applications*, dated October 1, 1997, hereafter referred to as JTP. The requirements in the JTP were identified for a number of general application categories, defined below:

- **LG** - low temperature antigalling/antifretting applications (up to 850°F), DFL used to protect part surfaces against sliding and oscillating wear
- **HG** - high temperature antigalling/antifretting applications (850°F to 1400°F), DFL used to protect part surfaces against sliding and oscillating wear
- **LS** - low temperature antiseizing applications (up to 850°F), DFL applied to threaded fasteners at assembly to facilitate subsequent disassembly
- **HS** - high temperature antiseizing applications (850°F to 1400°F), DFL applied to threaded fasteners at assembly to facilitate subsequent disassembly
- **AD** - short-term assembly aid applications, DFL used during assembly to prevent seizing and protect parts from nicks and scratches, DFLs for this application are usually applied by aerosol spray and are allowed to briefly air dry prior to assembly.

Selected alternative DFLs were subjected to tests described in the JTP. Prior to testing, the project participants decided not to pursue validation of any candidates for the AD application category. The project participants also planned to divide the testing into four successive phases, and eliminate some DFLs after each phase. This phased test approach was intended to minimize the cost of validating suitable alternatives. This Joint Test Report (JTR) documents the results of the first three phases of that testing.

Nine candidate DFLs were initially tested for compliance with the requirements defined for LG, LS, HG, and HS application categories. Three candidate DFLs were eliminated after the first phase of testing. Three more were eliminated after the second phase of testing. No candidate

DFLs were eliminated after the third phase of testing, leaving three candidate DFLs for testing in the fourth phase. The three candidate DFLs that are recommended for testing in the fourth testing phase are Tiolube 614-T9B from Tiodize Co., Inc.; and Everlube 812 and Everlube 10030 from E/M Corporation.

In the fourth testing phase, Tiolube 614-T9B will be tested for compliance with the requirements of the LS, HG, and HS application categories. Everlube 812 will be tested for compliance with the requirements of the LG application category. Everlube 10030 will be tested for compliance with the requirements of the HG and HS application categories. The results of the fourth testing phase will be documented in a subsequent JTR.

Users of this JTR should remember that the tests and acceptance criteria in the JTR were defined by the participants in this project for their specific needs. The DFLs that were eliminated during this testing are all suitable for a number of different uses and situations not covered by this testing. Specific interactions between substrates used for this testing and the DFLs tested should not be used to predict the interactions between these DFLs and other substrates.

1. INTRODUCTION

This project is being conducted under the auspices of the Joint Group on Pollution Prevention (JG-PP) and the Propulsion Environmental Working Group (PEWG). The goal of this project is to eliminate the use in aircraft engines of dry film lubricants (DFLs) containing lead.

Joint Group on Pollution Prevention (JG-PP): The Joint Logistics Commanders (JLC) chartered the Joint Group on Acquisition Pollution Prevention (JG-APP) to coordinate joint service activities affecting pollution prevention issues identified during a weapon system's acquisition process. JG-APP has become the JG-PP to accommodate an expanded focus to address sustainment needs.

The JLC and Headquarters National Aeronautics and Space Administration (NASA) co-chartered JG-PP to coordinate joint service/agency activities affecting pollution prevention issues identified during system and component acquisition and sustainment processes. The primary objectives of the JG-PP are to:

- Reduce or eliminate the use of hazardous materials (HazMats) and hazardous processes at manufacturing, remanufacturing, and sustainment locations
- Avoid duplication of efforts in actions required to reduce or eliminate HazMats through joint service cooperation and technology sharing.

JG-PP projects typically involve an original equipment manufacturer (OEM) producing multiple defense systems for more than one of the Services, as well as at least one depot servicing one or more of the defense systems. JG-PP technical representatives for each project begin by selecting a target HazMat that is used in the production or sustainment processes and may cause environmental and/or worker health concerns. Project participants then identify alternative technologies for evaluation.

The Propulsion Environmental Working Group (PEWG): The PEWG is a tri-service forum established in 1991 by the Air Force Propulsion Product Group Manager (PPGM) and the Joint Propulsion Coordinating Committee (JPCC) to resolve common environmental issues and facilitate technical interchange between System Program Offices (SPOs), Development System Offices (DSOs), engine contractors, engine users/customers, the Air Force PPGM and tri-service team members. It serves as the hazardous material management subcommittee of the JPCC. Its goal is to integrate pollution prevention into the systems engineering process by facilitating the identification, tracking, elimination, substitution, and minimization of hazardous materials on all programs supported by team members. It is intended to assist Integrated Product Teams (IPTs) and engine programs in managing environmental and hazardous material related issues. The OEMs involved with the PEWG project to eliminate the use of lead-containing dry film lubricants in engines are Rolls-Royce Allison (formerly

Allison Engine Company), AlliedSignal Engines, General Electric Aircraft Engines (GEAE), and Pratt & Whitney-United Technologies Corporation (P&W-UTC).

The *Joint Test Protocol (JP-P-1-1) for Validation of Alternatives to Lead-Containing Dry Film Lubricants for Antigalling/Antifretting, Antiseizing, and Assembly Aid Applications*, dated October 1, 1997 (hereafter referred to as JTP), contains tests necessary to qualify alternatives to lead-containing DFLs for use in aircraft engines. The tests defined in the JTP were derived from engineering, performance, and operational impact (supportability) requirements defined by a consensus of government and industry participants (technical representatives). The requirements in this JTP were identified by multiple contractors for a number of application categories. A candidate alternative may fail to meet one or more of these requirements but still be suitable for specific applications.

This Joint Test Report (JTR) documents the results of the testing specified in Sections 3.1 through 3.17 of the noted JTP. The JTR will be made available as a reference for future pollution prevention efforts by other DoD and commercial users.

Table 1 summarizes the target HazMat, process/material, application, current specifications, affected programs, and affected parts/substrates.

Table 1. Target HazMat Summary

Target HazMat	Lead contained in DFLs Secondary target HazMats: volatile organic compounds (VOCs), antimony, cadmium, and carcinogenic chemicals
Current Process/ Material	DFLs (sometimes referred to as solid film lubricants)
Applications	Lubricants for aiding assembly and subsequent disassembly of mated parts (antiseizing) and/or for antigalling/antifretting
Current Specifications	MIL-F-7179, MIL-L-23398, MIL-L-45983, MIL-L-46010, MIL-L-46147, MIL-L-81329, AMS 2525, AMS 3084, AS 1701, A50TF9, A50TF79, A50TF147, A50TF150, A50TF159, A50TF170, A50TF171, A50TF174, A50TF192, A50TF279, EMS 5248, EMS 5402, EMS 27605, EMS 27608, EMS 27610, EMS 27615, EMS 27628, EPS 11705, EPS 11706, EPS 11708, EPS 11709, EPS 11710, EPS 11712, EPS 11715, EPS 11718, EPS 11720, F50TF42, F50TF58/70, F50TF88, GM6078M, PWA 586
Affected Programs*	F100 in F-15 and F-16; F101 in B-1B; F103 in KC-10; F110 in F-14 and F-16; F117 in C-17; F118 in B-2 and U-2; F119 in F-22; F404/F414 in F/A-18 and F-117A; LM1600; LM2500 in AOE-6, CG-47, DD-963, DD-993, DDG-51, and FFG-7; LM6000; J52 in A-4, A-6, and EA-6; T53 in UH-1H and AH-1S; T55 in CH-47 and MH-47; T56 in C-130, E-2, and P-3; T406 in V-22 and C-130J; T700 in UH-60 and AH-64; T800 in Cheyenne; TF30 in F-14 and EF-111; TF34 in A-10 and OA-10; TF39 in C-5; TF40 in LCAC
Affected Parts/ Substrates	• Threaded fasteners, compressor and turbine discs and blade roots • Aluminum: 2024 • Cobalt: Haynes 188, MP159 • Magnesium: AMS 4375 • Nickel: Hastelloy X, Inconel 718, Waspaloy • Steel: A-286, AISI 4340, Greek Ascoloy, AM-355 • Titanium: Ti-6Al-4V, Ti-8-1-1

* This table reflects families of engines; various models are included that are used on a number of platforms.

2. TESTING REQUIREMENTS

A joint group led by JG-PP and the PEWG chairman, consisting of technical representatives from Rolls-Royce Allison, AlliedSignal Engines, GEAE, and P&W-UTC; the affected Department of Defense (DoD) Program Managers; representatives of the Sustainment Community; and other government technical representatives reached consensus on the contents of the JTP. The JTP contains tests necessary to qualify alternatives to lead-containing DFLs for use in aircraft engines. The tests defined in the JTP were derived from engineering, performance, and operational impact (supportability) requirements defined by a consensus of government and industry participants (technical representatives).

The requirements in the JTP were identified by the technical representatives for a number of general application categories. These categories are as follows:

- **LG** - low temperature antigalling/antifretting applications (up to 850°F), DFL used to protect part surfaces against sliding and oscillating wear
- **HG** - high temperature antigalling/antifretting applications (850°F to 1400°F), DFL used to protect part surfaces against sliding and oscillating wear
- **LS** - low temperature antiseizing applications (up to 850°F), DFL applied to threaded fasteners at assembly to facilitate subsequent disassembly
- **HS** - high temperature antiseizing applications (850°F to 1400°F), DFL applied to threaded fasteners at assembly to facilitate subsequent disassembly
- **AD** - short-term assembly aid applications, DFL used during assembly to prevent seizing and protect parts from nicks and scratches, DFLs for this application are usually applied by aerosol spray and are allowed to briefly air dry prior to assembly.

After the JTP was completed, the technical representatives decided not to test any AD-category DFLs.

Table 2 summarizes the requirements defined by the technical representatives for validating alternatives to lead-containing DFLs and documented in the JTP. This summary includes acceptance criteria and the references, if any, used in developing the tests.

Table 2. Engineering and Performance Test Requirements

Engineering Requirement	Test	JTP Section	Application Categories	Acceptance Criteria	References
Corrosion Protection	Aluminum Corrosion Resistance [a]	3.1 [a]	AD	No discoloration, pitting, white deposits, or other evidence of corrosion greater than that observed on uncoated control specimens	ASTM D2649 - 83
Chemical Content	Chromium Content	3.2	LG, HG, LS, HS, AD	Chromium content below 100 ppm	ASTM D3718 - 85a
Film Properties	Cured Film Thickness Uniformity	3.3	LG, HG, LS, HS	No more than one thickness measurement per panel below 0.0003 inch (0.3 mil) and no more than one thickness measurement per panel above 0.0008 inch (0.8 mil)	ASTM E376 - 89 ASTM B244 - 79 ASTM D1400 - 87 ASTM B499 - 88 ASTM D1186 - 87
Film Properties (adhesion)	Dry Tape Adhesion	3.4	LG, HG, LS, HS, AD	No exposure of underlying substrate	ASTM D2510 - 83
Compatibility with Substrate, Thermal Stability	Elevated Temperature Material Compatibility	3.5	LG, HG, LS, HS	No substrate degradation exceeding by 0.0002 inches or more the degradation observed on the uncoated control specimens	*none*
Corrosion Protection	Fastener Corrosion	3.6	HS	No evidence of substrate corrosion greater than that of the uncoated control assemblies	*none*

[a] This test is only applicable to AD-category DFLs. After the JTP was completed, the project participants decided not to test any AD-category DFLs. For this reason, the test results reported in this JTR do not include any results from Aluminum Corrosion Resistance testing.

(Table 2 continued on next page)

Table 2. Engineering and Performance Test Requirements (continued)

Engineering Requirement	Test	JTP Section	Application Categories	Acceptance Criteria	References
Chemical Resistance, Film Properties (adhesion)	Fluid Resistance	3.7	LG, HG, LS, HS	No lifting, softening, blistering, cracking, peeling, significant discoloration, or loss of adhesion	ASTM D2510 - 83 ASTM D1141 - 90 ASTM D1193 - 91 MIL-A-8243D MIL-H-87257 MIL-L-23699E MIL-T-5624R MIL-T-83133D VV-D-1078B
Chemical Content	Lead and Cadmium Content	3.8	LG, HG, LS, HS, AD	No more than 100 ppm lead or cadmium	ASTM D3335 - 85a
Wear Resistance, Lubricity	Reciprocating Sliding Wear	3.9	LG, HG	Residual film of lubricant with smooth or slightly striated wear pattern remaining on shoe specimen; no DFL flaking, base metal wear, or other signs of degradation Coefficient of Kinetic Friction: LG: less than 0.12 HG: less than 0.15	ASTM G115 - 93
Corrosion Protection	Salt Spray (Fog) Corrosion Resistance	3.10	LG	No more than three (3) corrosion spots per specimen and no corrosion spots larger than 1.0 millimeter diameter	ASTM B117 - 94 ASTM D165 - 92
Chemical Resistance, Film Properties (adhesion)	Solvent Rub	3.11	LG, HG, LS, HS	No separation of lubricant film or exposure of substrate	*none*

(Table 2 continued on next page)

Table 2. Engineering and Performance Test Requirements (continued)

Engineering Requirement	Test	JTP Section	Application Categories	Acceptance Criteria	References
Corrosion Protection	Stress Corrosion	3.12	LG, LS, AD	No cracking of substrate	ASTM F945 - 85
Corrosion Protection	Sulfurous Acid Salt Spray	3.13	LG, AD	No pitting, staining, or other visible evidence of corrosion	ASTM D1141 - 90 FED-STD-791C (Method 5331.1)
Thermal Stability, Film Properties (adhesion)	Thermal Shock Stability	3.14	LG, HG, LS, HS	No flaking, cracking, softening, lifting, or loss of adhesion greater than that observed for the control (lead containing DFL)	ASTM D2511 - 83 ASTM D2510 - 83
Thermal Stability	Thermal Stability by Simultaneous Differential Thermal Analysis-Thermogravimetric Analysis (SDT)	3.15	LG, HG, LS, HS	This test is intended to provide baseline information on the temperature limits of a DFL. The temperature limits will define and categorize the DFL as low temperature (up to 850°F) or high temperature (between 850°F and 1400°F). The *useful temperature limit* will be defined as the temperature above 400°F at which there is a substantial change (increase or decrease) in the mass of the cured DFL sample.	*None*

(Table 2 continued on next page)

Table 2. Engineering and Performance Test Requirements (continued)

Engineering Requirement	Test	JTP Section	Application Categories	Acceptance Criteria	References
Antiseizing, Thermal Stability	Torque-Tension Evaluation	3.16	LS, HS	*See test description, starting on Page 53 of the JTP.*	*none*
Chemical Content	Volatile Organic Compound Content	3.17	LG, HG, LS, HS, AD	VOC content no greater than 500 g/L for DFLs supplied as bulk liquid and VOC content no greater than 880 g/L for DFLs supplied in aerosol cans	ASTM D1475 - 90 ASTM D2369 - 92 ASTM D3792 - 91 ASTM D3960 - 92 ASTM D4017 - 90 ASTM D4457 - 85

The testing was performed in four sequential phases, with the phases defined by the technical representatives. After the completion of each phase, the technical representatives jointly selected which candidate DFLs were eliminated and which were tested further. This testing strategy is represented in Figure 1.

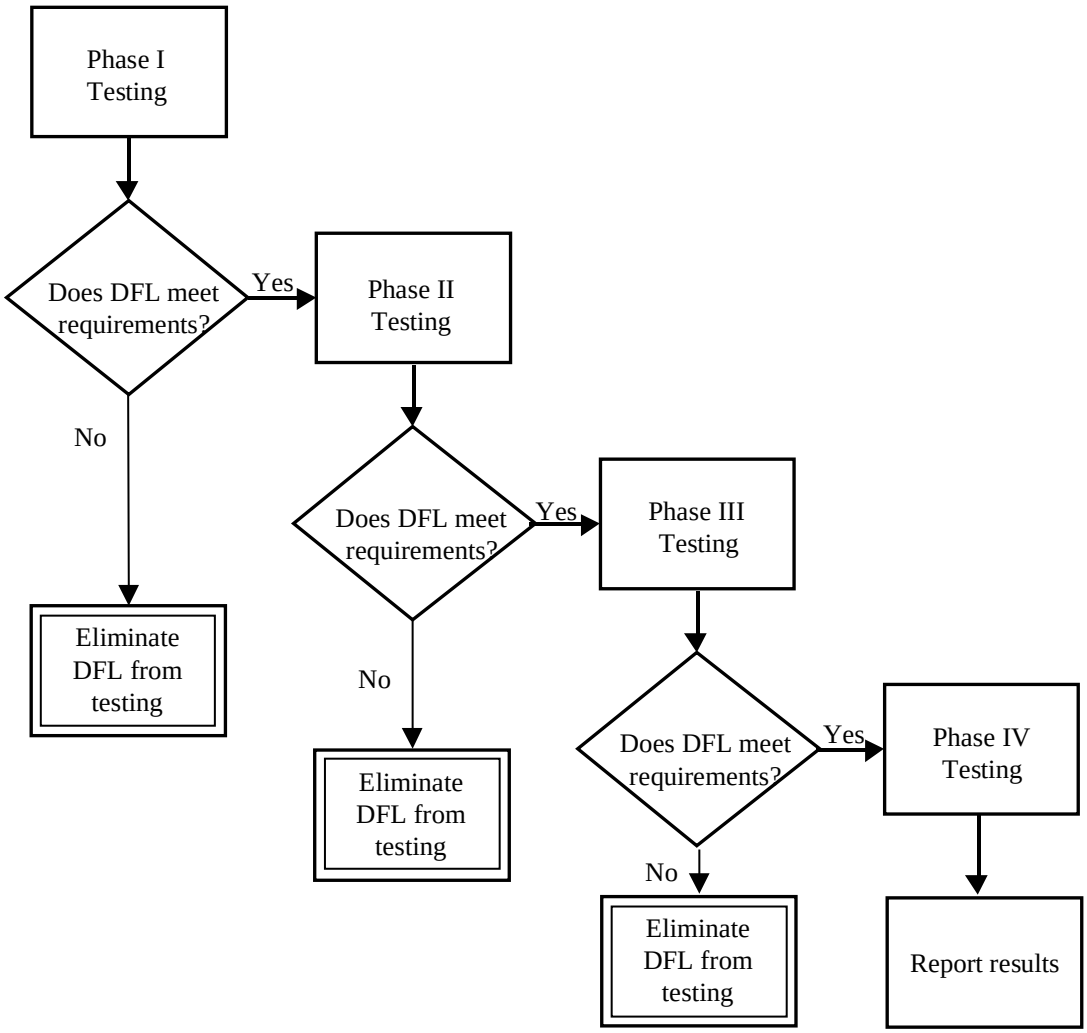

Figure 1. DFL Testing Strategy

The tests in each testing phase are listed in Table 3. Table 3 also shows the general relationships between DFL application categories and the tests performed. Note that one test, Aluminum Compatibility, was defined after the JTP was completed and is defined in Section 2.1 in this JTR. In addition, because the technical representatives decided not to test any AD-category candidate DFLs, the Aluminum Corrosion Resistance test (JTP Section 3.1) was not performed.

Table 3. Test Phases for Sequential Execution

Testing Phase	JTP Section	Test Name	Application Categories			
			LG	LS	HG	HS
Phase I	3.2	Chromium Content				
	3.3	Cured Film Thickness Uniformity				
	3.4	Dry Tape Adhesion				
	3.8	Lead and Cadmium Content				
	3.11	Solvent Rub				
	3.17	Volatile Organic Compound Content				
	JTR 2.1	Aluminum Compatibility (not in JTP, defined in Section 2.1 in this JTR)				
Phase II	3.5	Elevated Temperature Material Compatibility				
	3.7	Fluid Resistance				
	3.12	Stress Corrosion				
	3.14	Thermal Shock Stability				
	3.15	Thermal Stability by SDT				
Phase III	3.6	Fastener Corrosion				
	3.10	Salt Spray (Fog) Corrosion Resistance				
	3.13	Sulfurous Acid Salt Spray				
Phase IV	3.9.1	Reciprocating Sliding Wear – Fretting Wear				
	3.9.2	Reciprocating Sliding Wear – Galling Wear				
	3.16	Torque-Tension Evaluation				

The technical representatives decided on a number of modifications to the testing defined in the JTP. These modifications affect the substrates, applied thickness of DFLs, specimen counts, test conditions, and the lead-containing control DFLs. In addition, individual DFLs within an application category may not be subjected to all tests applicable to that category.

Two additional substrates were identified by the technical representatives for use in testing the candidate DFLs. The first of these new substrates is AL1d, defined as aluminum alloy 2024, phosphate coated in accordance with Method 4 (*Section 4.4*) of ASTM D1730-67 (reapproved 1993) (*Standard Practices for Preparation of Aluminum and Aluminum-Alloy Surfaces for Painting*, approved September 8, 1967), 3 inches by 6 inches by nominal thickness. The second new test substrate is ST10, defined as corrosion and heat resistant steel alloy AM-355 conforming to AMS 5547F (15.5Cr 4.5Ni 2.9Mo 0.10N, solution heat treated), 3 inches by 6 inches by nominal thickness.

Table 4 summarizes the major differences between the JTP and the tests performed. The test results in Section 4 of this JTR contain specific listings of the test substrates, DFLs, DFL film thickness, specimen counts, test conditions, and lead-containing control DFLs actually used for each test.

Table 4. General Modifications to Testing Defined in JTP

Testing Phase	JTP Section	Test Name	General Modifications from JTP
Phase I	3.2	Chromium Content	None
	3.3	Cured Film Thickness Uniformity	1. No AL1c or ST2b specimens 2. ST9b specimens used for some DFLs 3. ST10 specimens used for some DFLs 4. TI1a specimens used for some DFLs 5. TI1b specimens used for some DFLs 6. Some DFLs applied to film thickness of 0.1 mil to 0.2 mil, rather than 0.3 mil to 0.8 mil as specified in JTP.
	3.4	Dry Tape Adhesion	1. No AL1a or ST2b specimens 2. ST9b specimens used for some DFLs 3. ST10 specimens used for some DFLs 4. TI1a specimens used for some DFLs 5. TI1b specimens used for some DFLs 6. Some DFLs applied to film thickness of 0.1 mil to 0.2 mil, rather than 0.3 mil to 0.8 mil as specified in JTP 7. A lead-containing DFL is used as an experimental control.
	3.8	Lead and Cadmium Content	None
	3.11	Solvent Rub	1. No AL1a or ST2b specimens 2. ST10 specimens used for some DFLs 3. TI1a specimens used for some DFLs.
	3.17	Volatile Organic Compound (VOC) Content	None
	JTR 2.1	Aluminum Compatibility	Not defined in JTP, defined in Section 2.1 in this JTR

(Table 4 continued on next page)

Table 4. General Modifications to Testing Defined in JTP (continued)

Testing Phase	JTP Section	Test Name	General Modifications from JTP
Phase II	3.5	Elevated Temperature Material Compatibility	1. AL1d specimens used for some DFLs 2. NI3 specimens used for some DFLs 3. ST9b specimens used for some DFLs 4. ST10 specimens used for some DFLs 5. TI1a specimens used for some DFLs 6. Some DFLs applied to film thickness of 1 mil to 2 mils, rather than 0.3 mil to 0.8 mil as specified in JTP 7. Some DFLs applied to film thickness of 0.2 mil to 1 mil, rather than 0.3 mil to 0.8 mil as specified in JTP.
	3.7	Fluid Resistance	1. No AL1a or ST2a specimens 2. AL1d specimens used for some DFLs 3. ST9b specimens used for some DFLs 4. ST10 specimens used for some DFLs 5. TI1a specimens used for some DFLs 6. Some DFLs applied to film thickness of 0.1 mil to 0.2 mil, rather than 0.3 mil to 0.8 mil as specified in JTP 7. A lead-containing DFL is used as an experimental control.
	3.12	Stress Corrosion	1. TI1b specimens used for some DFLs 2. Some DFLs applied to film thickness of 0.1 mil to 0.2 mil, rather than 0.3 mil to 0.8 mil as specified in JTP 3. Some trials performed in duplicate rather than triplicate.
	3.14	Thermal Shock Stability	1. No ST5 specimens 2. ST10 specimens used for some DFLs 3. Some DFLs applied to film thickness of 0.2 mil to 1 mil, rather than 0.3 mil to 0.8 mil as specified in JTP 4. Some DFLs applied to film thickness of 1 mil to 2 mils, rather than 0.3 mil to 0.8 mil as specified in JTP 5. Some trials performed in duplicate rather than triplicate.
	3.15	Thermal Stability by SDT	Not all DFLs subjected to this test

(Table 4 continued on next page)

Table 4. General Modifications to Testing Defined in JTP (continued)

Testing Phase	JTP Section	Test Name	General Modifications from JTP
Phase III	3.6	Fastener Corrosion	1. Only 0.5 inch diameter nut/bolt combinations used 2. No NI2a nut/CO2 bolt combination used 3. DFLs applied to film thickness of 0.1 mil to 0.2 mil.
	3.10	Salt Spray (Fog) Corrosion Resistance	1. ST9b specimens used for some DFLs 2. ST10 specimens used for some DFLs 3. Some DFLs applied to film thickness of 1 mil to 2 mils, rather than 0.3 mil to 0.8 mil as specified in JTP 4. Some trials performed in duplicate rather than triplicate 5. A lead-containing DFL is used as an experimental control.
	3.13	Sulfurous Acid Salt Spray	1. No ST1 specimens 2. ST9b specimens used for some DFLs 3. ST10 specimens used for some DFLs 4. Some DFLs applied to film thickness of 1 mil to 2 mils, rather than 0.3 mil to 0.8 mil as specified in JTP 5. Some trials performed in duplicate rather than triplicate 6. A lead-containing DFL is used as an experimental control 7. A specially-fitted salt-spray chamber and rectangular panels are used to achieve cycles of misting with synthetic sea water followed by drying.

(Table 4 continued on next page)

Table 4. General Modifications to Testing Defined in JTP (continued)

Testing Phase	JTP Section	Test Name	General Modifications from JTP
Phase IV	3.9.1	Reciprocating Sliding Wear – Fretting Wear	1. No NI2a, NI3, ST5, or ST9b specimens 2. ST10 specimens used for some DFLs 3. No trials at 1000°F or 1200°F will be performed 4. A lead-containing DFL will be "tested" exactly like a candidate DFL as an experimental control.
	3.9.2	Reciprocating Sliding Wear – Galling Wear	1. No NI2a, ST5, or ST9b specimens 2. TI1a specimens used for some DFLs 3. ST10 specimens used for some DFLs 4. Some DFLs applied to film thickness of 0.2 mil to 1 mil, rather than 0.7 mil to 0.9 mil as specified in JTP 5. Some DFLs applied to film thickness of 1 mil to 2 mils, rather than 0.9 mil to 1.1 mils as specified in JTP 6. Some trials performed to total test duration of 700 cycles 7. Some trials performed to total test duration of 5,000 cycles 8. Some trials performed at 900°F ± 25°F 9. No trials at 1000°F or 1200°F will be performed 10. Trials of a lead-containing DFL will be more extensive than those specified in the JTP.
	3.16	Torque-Tension Evaluation	1. TI1a nuts, bolts, and block fixtures used for some DFLs 2. TI1a nuts and block fixtures with NI3 bolts used for some DFLs 3. NI3 nuts and block fixtures with TI1a bolts used for some DFLs 4. Some DFLs applied to film thickness of 0.1 mil to 0.2 mil 5. Some trials performed at 950°F ± 25°F 6. Some trials performed at 1100°F ± 25°F 7. No trials at 1000°F or 1200°F will be performed.

2.1 Aluminum Compatibility

Test Description

This test allows assessment of aluminum substrate degradation promoted by a candidate DFL at an elevated temperature. This test is intended only for a DFL that requires curing above 400°F (the maximum use temperature of aluminum).

Apply candidate DFL to a 1-inch by 0.5-inch by 0.550-inch (minimum) thick ST3 test specimen as recommended by the DFL manufacturer, to a thickness of 0.3 mil to 0.8 mil, and cure according to the manufacturer's directions. Verify the film thickness by measurement at three separate locations on the specimen. Visually examine the ST3 specimen under normal work lighting and 3X magnification, to verify that the applied DFL is a smooth film of uniform color, with no cracks, sags, runs, scratches, pinholes, blisters, nodules, or chipping.

Clamp an uncoated 1-inch by 0.5-inch by 0.050-inch (minimum) thick AL1c test specimen to the DFL-coated surface of the ST3 specimen. Place the clamped specimens and another uncoated 1-inch by 0.5-inch by 0.050-inch (minimum) thick AL1c test specimen in an oven. Heat the test specimens to 400°F for 9 hours (according to the time and temperature specified in Table 4). Remove the test specimens from the oven and allow the panels to cool to room temperature. Unclamp the composite test specimen and examine the AL1c specimens visually and metallographically (at 500X magnification in cross section), comparing the two AL1c specimens.

Table 5. Test Methodology for Aluminum Compatibility Test

Parameters	Heat in oven for 9 hours $\pm$ 1 hour at 400°F $\pm$ 5°F
Number and Type of Specimens per Candidate DFL	1 of ST3 (DFL-coated) clamped to 1 of AL1c (uncoated)
Experimental Control Specimens	1 of AL1c, uncoated
Acceptance Criteria	No degradation of the aluminum substrate in contact with candidate DFL greater than degradation of experimental control specimen

3. ALTERNATIVES TESTED

Table 6 lists the nine candidate alternative DFLs that were chosen to be tested during Phase I and designates the two lead-containing experimental control DFLs that were used for the testing. Table 6 also identifies the DFL application categories for which each candidate alternative DFL was considered. The correspondence between DFL application categories as referenced to tests and as referenced to candidate DFLs is not exact; the tests to which each DFL were subjected are specified in the test results in Section 4.

Table 6. Potential Alternative DFLs (for Phase I Testing)

Product	DFL Code	Manufacturer	Cure Temperature	Application Categories			
				LG	LS	HG	HS
Alseal 333	A	Coatings for Industry, Inc.	250°F				
Alseal 360	B	Coatings for Industry, Inc.	500°F				
E/M -1380B [a]	C	E/M Corporation	500°F				
Everlube 10030 [a]	C'	E/M Corporation	500°F				
Everlube 812	D	E/M Corporation	400°F				
Surf-Kote LOB-1800G Class A	E	Hohman Plating & Mfg., Inc.	300°F				
Tiolube 29	F	Tiodize Co., Inc.	400°F				
Tiolube 614-T9B	G	Tiodize Co., Inc.	950°F				
X-204 Solid Film Lubricant	H	Fel-Pro Chemical Products L.P.	350 to 500°F				
Experimental Control DFL	J	N.A.	N.A.				
Experimental Control DFL	K	N.A.	N.A.				

N.A. = Not Available

[a] E/M 1380B and Everlube 10030 are different designations for the same dry film lubricant; E/M 1380B designates the DFL as applied by the manufacturer, and Everlube 10030 designates the lubricant as supplied for application by *CTC* for this testing. E/M 1380B was only tested in Phase I.

Some general information about the technical and environmental, safety, and occupational health characteristics of these nine candidate DFLs may be found in the *Potential Alternatives Report (JP-A-1-1) for Alternatives to Lead-Containing Dry Film Lubricants for Antigalling/Antifretting, Antiseizing, and Assembly Aid Applications*, dated August 25, 1998 (hereafter referred to as PAR). It should be noted that the list of

DFLs in Table 6, and the identification of specific DFLs with application categories, is not identical to the list of DFLs selected for testing and documented in the PAR. The DFLs in Table 6 in this JTR were selected by the project participants based on further refinement of the participants' requirements after the PAR was complete.

4. TEST RESULTS

Table 7 summarizes the substrates used for testing.

Table 7. Test Specimen Codes and Substrate Descriptions

Test Specimen Code	Substrate Description
AL1c	Aluminum alloy 2024-T3, bare, conforming to AMS 4037M (4.4Cu 1.5Mg 0.60Mn, solution heat treated), not anodized, 1” x 0.5” x 0.050” (minimum) thick specimens, for Elevated Temperature Material Compatibility test (JTP Section 3.5)
AL1d	Aluminum alloy 2024, phosphate coated in accordance with Method 4 (*Section 4.4*) of ASTM D1730-67 (reapproved 1993) (*Standard Practices for Preparation of Aluminum and Aluminum-Alloy Surfaces for Painting*, approved September 8, 1967), • 1” x 0.5” x 0.050” (minimum) thick specimens for Elevated Temperature Material Compatibility test (JTP Section 3.5) • 3 inches by 6 inches by nominal thickness, for Fluid Resistance test (JTP Section 3.7)
CO1	Corrosion and heat resistant cobalt alloy Haynes 188 conforming to AMS 5608C (40Co 22Cr 22Ni 14.5W 0.07La, solution heat treated), 1” x 0.5” x 0.062” (minimum) thick specimens, for Elevated Temperature Material Compatibility test (JTP Section 3.5)
CO2	Corrosion and heat resistant cobalt alloy MP159, solution heat treated, 1” x 0.5” x 0.050” (minimum) thick specimens conforming to AMS 5843C, for Elevated Temperature Material Compatibility test (JTP Section 3.5)
MG	Magnesium alloy conforming to AMS 4375J (3.0Al 1.0Zn 0.20Mn, annealed and recrystallized), 1” x 0.5” x 0.032” (minimum) thick specimens, for Elevated Temperature Material Compatibility test (JTP Section 3.5)
NI1	Corrosion and heat resistant nickel alloy Hastelloy X conforming to AMS 5536L (47.5Ni 22Cr 1.5Co 9.0Mo 0.60W 18.5Fe, solution heat treated), 1” x 0.5” x 0.035” (minimum) thick specimens, for Elevated Temperature Material Compatibility test (JTP Section 3.5)

(Table 7 continued on next page)

Table 7. Test Specimen Codes and Substrate Descriptions (continued)

Test Specimen Code	Substrate Description
NI2a	Corrosion and heat resistant nickel alloy Waspaloy; solution, stabilization, and precipitation heat treated • 1" x 0.5" x 0.050" (minimum) thick specimens conforming to AMS 5709F, for Elevated Temperature Material Compatibility test (JTP Section 3.5) • 3" x 6" x 0.050" (minimum) thick panels conforming to AMS 5709F, for Thermal Shock Stability test (JTP Section 3.14) • Self-locking nuts conforming to AS 7253, for Fastener Corrosion test (JTP Section 3.6) and Torque-Tension Evaluation (JTP Section 3.16), of the following diameters: ➢ 0.250 inch ➢ 0.500 inch • Bolts conforming to AS 7471, for Fastener Corrosion test (JTP Section 3.6) and Torque-Tension Evaluation (JTP Section 3.16), of the following diameters: ➢ 0.250 inch ➢ 0.500 inch • Blocks conforming to AMS 5709F, of dimensions suitable for Torque-Tension Evaluation (JTP Section 3.16)
NI2b	Corrosion and heat resistant nickel alloy Waspaloy conforming to AMS 5544G (57Ni 19.5Cr 13.5Co 4.2Mo 3.0Ti 1.4Al 0.05Zr 0.006B, consumable electrode vacuum induction melted, annealed), 1" x 0.5" x 0.050" (minimum) thick specimens, for Elevated Temperature Material Compatibility test (JTP Section 3.5)

(Table 7 continued on next page)

Table 7. Test Specimen Codes and Substrate Descriptions (continued)

Test Specimen Code	Substrate Description
NI3	Corrosion and heat resistant nickel alloy Inconel 718, 1775°F solution heat treated • Self-locking nuts conforming to AMS 5662J, for Fastener Corrosion test (JTP Section 3.6) and Torque-Tension Evaluation (JTP Section 3.16), of the following diameters: ➢ 0.250 inch ➢ 0.500 inch • Bolts conforming to AS 7467, for Fastener Corrosion test (JTP Section 3.6) and Torque-Tension Evaluation (JTP Section 3.16), of the following diameters: ➢ 0.250 inch ➢ 0.500 inch • Shoe and block specimens conforming to AMS 5662J, for Reciprocating Sliding Wear (Galling Wear) test (JTP Section 3.9.2) • Blocks conforming to AMS 5662J, of dimensions suitable for Torque-Tension Evaluation (JTP Section 3.16)
ST3	Low alloy steel AISI 4340 conforming to AMS 6359F (0.80Cr 1.8Ni 0.25Mo 0.38-0.43C), 1” x 0.5” x 0.550” (minimum) thick specimens, for Elevated Temperature Material Compatibility test (JTP Section 3.5)
ST4	Corrosion and heat resistant steel alloy Greek Ascoloy conforming to AMS 5508E (13Cr 2.0Ni 3.0W, annealed), 1” x 0.5” x 0.050” (minimum) thick specimens, for Elevated Temperature Material Compatibility test (JTP Section 3.5)
ST9a	Corrosion and heat resistant precipitation hardenable iron alloy A-286 conforming to AMS 5858B, 1800°F solution heat treated, 1” x 0.5” x 0.050” (minimum) thick panels, for Elevated Temperature Material Compatibility test (JTP Section 3.5)

(Table 7 continued on next page)

Table 7. Test Specimen Codes and Substrate Descriptions (continued)

Test Specimen Code	Substrate Description
ST9b	Corrosion and heat resistant precipitation hardenable iron alloy A-286, solution and precipitation heat treated • 3" x 6" x 0.050" (minimum) thick panels for Cured Film Thickness Uniformity test (JTP Section 3.3), Dry Tape Adhesion test (JTP Section 3.4), Fluid Resistance test (JTP Section 3.7), Salt Spray (Fog) Corrosion Resistance test (JTP Section 3.10), and Sulfurous Acid Salt Spray (JTP Section 3.13) • 1" x 0.5" x 0.050" (minimum) thick specimens, for Elevated Temperature Material Compatibility test (JTP Section 3.5) • Self-locking nuts conforming to AS 7250, for Fastener Corrosion test (JTP Section 3.6) and Torque-Tension Evaluation (JTP Section 3.16), of the following diameters: ➢ 0.250 inch ➢ 0.500 inch • Bolts conforming to AS 7477A, for Fastener Corrosion test (JTP Section 3.6), of the following diameters: ➢ 0.500 inch
ST10	Corrosion and heat resistant steel alloy AM-355 conforming to AMS 5547F (15.5Cr 4.5Ni 2.9Mo 0.10N, solution heat treated), • 3 inches by 6 inches by nominal thickness, for Cured Film Thickness Uniformity test (JTP Section 3.3), Dry Tape Adhesion test (JTP Section 3.4), Fluid Resistance test (JTP Section 3.7), Salt Spray (Fog) Corrosion Resistance test (JTP Section 3.10), Solvent Rub test (JTP Section 3.11), Sulfurous Acid Salt Spray (JTP Section 3.13), and Thermal Shock Stability test (JTP Section 3.14) • 1" x 0.5" x 0.050" (minimum) thick specimens, for Elevated Temperature Material Compatibility test (JTP Section 3.5) • Shoe and block specimens for Reciprocating Sliding Wear (Fretting Wear and Galling Wear) test (JTP Sections 3.9.1 and 3.9.2)

(Table 7 continued on next page)

Table 7. Test Specimen Codes and Substrate Descriptions (continued)

Test Specimen Code	Substrate Description
TI1a	Titanium alloy Ti-6Al-4V, annealed • 3 inches by 6 inches by nominal thickness, for Cured Film Thickness Uniformity test (JTP Section 3.3), Dry Tape Adhesion test (JTP Section 3.4), Fluid Resistance test (JTP Section 3.7), and Solvent Rub test (JTP Section 3.11) • 1" x 0.5" x 0.050" (minimum) thick specimens, for Elevated Temperature Material Compatibility test (JTP Section 3.5) • Shoe and block specimens conforming to AMS 4967G (heat treatable), for Reciprocating Sliding Wear test (JTP Section 3.9) • 5.6" x 0.5" x 0.050" thick specimens conforming to AMS 4911H, for Stress Corrosion test (JTP Section 3.12) • Self-locking nuts for Torque-Tension Evaluation (JTP Section 3.16), of the following diameters: ➢ 0.250 inch ➢ 0.500 inch • Bolts conforming to AS 7460, for Torque-Tension Evaluation (JTP Section 3.16), of the following diameters: ➢ 0.250 inch ➢ 0.500 inch • Blocks conforming to AMS 4967G, of dimensions suitable for Torque-Tension Evaluation (JTP Section 3.16) • Shoe and block specimens for Reciprocating Sliding Wear (Fretting Wear and Galling Wear) test (JTP Sections 3.9.1 and 3.9.2)
TI1b	Titanium alloy Ti-6Al-4V, annealed, shot peened with CS110 steel shot to intensity level of 3 to 5A in accordance with AMS 2430L • 3 inches by 6 inches by nominal thickness, for Cured Film Thickness Uniformity test (JTP Section 3.3), Dry Tape Adhesion test (JTP Section 3.4), and Thermal Shock Stability test (JTP Section 3.14) • Shoe and block specimens conforming to AMS 4967G, for Reciprocating Sliding Wear test (JTP Section 3.9) • 3" x 6" x 0.050" (minimum) thick panels, conforming to AMS 4911H, for Thermal Shock Stability test (JTP Section 3.14)
TI2	Titanium alloy Ti-8-1-1 conforming to AMS 4916F (8Al 1Mo 1V, duplex annealed), 5.6" x 0.5" x 0.050" specimens, for Stress Corrosion test (JTP Section 3.12)

4.1. Phase I Test Results

The Phase I tests were performed at *CTC* in fall of 1998. The results of the Phase I tests are summarized in Table 8, and the individual results for each candidate DFL are reported in Tables 9 through 18.

Table 8. Phase I Testing Results - Summary

DFL Code	Test (JTP Section)						
	3.2	3.3	3.4	3.8	3.11	3.17	JTR 2.1
A	Pass	Fail	Fail	Pass	Fail	Pass	NT
B	Pass	Pass	Pass	Pass	Pass	Pass	NT
C	Pass	Pass	Pass	Fail [a]	NT	NT	NT
C'	Pass	Pass	Pass	Pass	NT	Pass	NT
D	Pass	Pass	Pass	Pass	Pass	Pass	NT
E	(Fail)/ Pass [b]	Fail	Pass	Pass	Pass	Pass	NT
F	Pass	Fail	Fail	Fail	Fail	Pass	NT
G	(Fail)/ Pass [b]	Pass	Pass	Pass	Pass	NT	Pass
H	Pass	Pass	Pass	Pass	NT	Pass	NT
J	NT	NT	Pass	NT	NT	NT	NT
K	NT	NT	NT	NT	NT	NT	NT

NT = Not Tested

[a] This DFL was carried on to Phase II testing because the failing value in lead content was very close to the acceptance limit.

[b] After an initial failure, the participants realized that the failing value in chrome content may have been caused by contamination from chrome-containing substrate material. The chrome measurements were performed again, using samples removed from titanium test panels, with passing results.

Table 9. Phase I Test Results: Alseal 333 (DFL Code A)

Test Name/ JTP Section	Substrate	Results per Trial	Pass/ Fail
Chromium Content/3.2	None	Trial 1 – 45 ppm; Trial 2 – 35 ppm Average – 40 ppm	Pass
Cured Film Thickness Uniformity/ 3.3	ST10, TI1a, TI1b	*ST10 panels – target 0.3 – 0.8 mil* Panel 1 – 0.62, 0.69, 0.72, 0.75, 0.85, 0.88, 0.89, 0.92, 1.06, 1.33 mils Panel 2 – 0.59, 0.71, 0.72, 0.77, 0.81, 0.83, 0.83, 0.84, 0.84, 1.07 mils Panel 3 – 0.63, 0.68, 0.72, 0.73, 0.78, 0.79, 0.81, 0.83, 0.85, 1.26 mils	 Fail Fail Fail

(Table 9 continued on next page)

Table 9. Phase I Test Results: Alseal 333 (DFL Code A) (continued)

Test Name/ JTP Section	Substrate	Results per Trial	Pass/ Fail
Cured Film Thickness Uniformity/ 3.3 (continued)	ST10, TI1a, TI1b	*TI1a panels – target 0.3 – 0.8 mil* Panel 1 – 0.32, 0.35, 0.36, 0.37, 0.42, 0.45, 0.52, 1.01, 1.40, 1.50 mils Panel 2 – 0.39, 0.43, 0.46, 0.48, 0.51, 0.52, 0.54, 0.59, 0.76, 0.88 mil Panel 3 – 0.41, 0.44, 0.5, 0.54, 0.55, 0.56, 0.58, 0.70, 0.87, 0.88 mil	 Fail Pass Fail
		TI1b panels – target 0.3 – 0.8 mil Panel 1 – 0.42, 0.45, 0.50, 0.57, 0.60, 0.72, 0.72, 0.76, 0.79, 1.06 mils Panel 2 – 0.28, 0.42, 0.48, 0.48, 0.51, 0.61, 0.74, 0.77, 0.89, 1.24 mils Panel 3 – 0.42, 0.48, 0.51, 0.55, 0.64, 0.68, 0.76, 0.78, 0.86, 0.88 mil	 Pass Fail Fail
		Overall	**Fail**
Dry Tape Adhesion/3.4	ST10, TI1a, TI1b	3 ST10 panels, each 100% removal 3 TI1a panels; ~35%, 100%, and ~70% removal 3 TI1b panels; ~40%, <5%, and ~10% removal	 Fail
Lead and Cadmium Content/3.8	None	*Cadmium Content* Trial 1 – <1 ppm; Trial 2 – <1 ppm Average – <1 ppm	 Pass
		Lead Content Trial 1 – 9.9 ppm; Trial 2 – 3.5 ppm Average – 6.7 ppm	 Pass
Solvent Rub/3.11	ST10, TI1a	*Methyl ethyl ketone* 3 ST10 panels, each discolored 3 TI1a panels, each discolored Overall	 Pass
		Acetone 3 ST10 panels, each slightly “burned” 3 TI1a panels, each slightly “burned” Overall	 Pass

(Table 9 continued on next page)

Table 9. Phase I Test Results: Alseal 333 (DFL Code A) (continued)

Test Name/ JTP Section	Substrate	Results per Trial	Pass/ Fail
Solvent Rub/3.11 (continued)	ST10, TI1a	*PD 680B Type II* 3 ST10 panels, each stained, one also burnished 3 TI1a panels, each stained, one with some coating removed Overall	Pass
		Isopropyl alcohol 3 ST10 panels, each stained 3 TI1a panels, one stained, two with substrate showing (failures) Overall	Fail
VOC Content/ 3.17	None	Trial 1 – <1.0 g/L; Trial 2 – <1.0 g/L Average – <1.0 g/L	Pass
Aluminum Compatibility/ JTR 2.1	N.A.	Not tested by decision of participants	NT

N.A. – Not Applicable
NT – Not Tested

Table 10. Phase I Test Results: Alseal 360 (DFL Code B)

Test Name/ JTP Section	Substrate	Results per Trial	Pass/ Fail
Chromium Content/3.2	None	Trial 1 – 13 ppm; Trial 2 – 16 ppm Average – 15 ppm	Pass
Cured Film Thickness Uniformity/ 3.3	ST9b, ST10, TI1a, TI1b	*ST9b panels – target 0.3 – 0.8 mil* Panel 1 – 0.30, 0.30, 0.30, 0.30, 0.31, 0.31, 0.31, 0.31, 0.33, 0.33 mil Panel 2 – 0.30, 0.31, 0.31, 0.31, 0.31, 0.31, 0.31, 0.32, 0.32, 0.33 mil Panel 3 – 0.31, 0.32, 0.33, 0.35, 0.35, 0.37, 0.37, 0.39, 0.40, 0.40 mil	Pass Pass Pass

(Table 10 continued on next page)

Table 10. Phase I Test Results: Alseal 360 (DFL Code B) (continued)

Test Name/ JTP Section	Substrate	Results per Trial	Pass/ Fail
Cured Film Thickness Uniformity/ 3.3 (continued)	ST9b, ST10, TI1a, TI1b	*ST10 panels – target 0.3 – 0.8 mil* Panel 1 – 0.40, 0.55, 0.55, 0.55, 0.65, 0.65, 0.70, 0.70, 0.80, 0.80 mil Panel 2 – 0.45, 0.60, 0.60, 0.65, 0.70, 0.70, 0.75, 0.75, 0.75, 0.75 mil Panel 3 – 0.35, 0.40, 0.40, 0.45, 0.50, 0.50, 0.60, 0.60, 0.60, 0.70 mil	Pass Pass Pass
		TI1a panels – target 0.3 – 0.8 mil Panel 1 – 0.27, 0.34, 0.34, 0.39, 0.40, 0.42, 0.48, 0.51, 0.55, 0.62 mil Panel 2 – 0.42, 0.44, 0.44, 0.46, 0.46, 0.47, 0.47, 0.52, 0.53, 0.53 mil Panel 3 – 0.48, 0.50, 0.50, 0.53, 0.56, 0.56, 0.63, 0.64, 0.65, 0.69 mil	Pass Pass Pass
		TI1b panels – target 0.3 – 0.8 mil Panel 1 – 0.39, 0.40, 0.41, 0.46, 0.48, 0.49, 0.49, 0.51, 0.56, 0.56 mil Panel 2 – 0.49, 0.56, 0.57, 0.64, 0.70, 0.72, 0.72, 0.74, 0.74, 0.79 mil Panel 3 – 0.55, 0.57, 0.61, 0.63, 0.65, 0.66, 0.66, 0.66, 0.67, 0.79 mil	Pass Pass Pass
		Overall	**Pass**
Dry Tape Adhesion/3.4	ST9b, ST10, TI1a, TI1b	3 ST9b panels, each no removal 3 ST10 panels, each no removal 3 TI1a panels, each no removal 3 TI1b panels, each no removal	Pass
Lead and Cadmium Content/3.8	None	*Cadmium Content* Trial 1 – <1 ppm; Trial 2 – <1 ppm Average – <1 ppm	Pass
		Lead Content Trial 1 – 2.6 ppm; Trial 2 – 3.4 ppm Average – 3.0 ppm	Pass

(Table 10 continued on next page)

Table 10. Phase I Test Results: Alseal 360 (DFL Code B) (continued)

Test Name/ JTP Section	Substrate	Results per Trial	Pass/ Fail
Solvent Rub/3.11	ST10, TI1a	*Methyl ethyl ketone* 3 ST10 panels, two discolored and one burnished, each with some coating removed 3 TI1a panels, each discolored with some coating removed Overall	Pass
		Acetone 3 ST10 panels, each burnished and stained 3 TI1a panels, each deeply "burned" and slightly discolored Overall	Pass
		PD 680B Type II 3 ST10 panels, each slightly "burned" and slightly discolored 3 TI1a panels, each "burned" and slightly discolored Overall	Pass
		Isopropyl alcohol 3 ST10 panels, each burnished 3 TI1a panels, each burnished Overall	Pass
VOC Content/ 3.17	None	Trial 1 – <1.0 g/L; Trial 2 – <1.0 g/L Average – <1.0 g/L	Pass
Aluminum Compatibility/ JTR 2.1	N.A.	Not tested by decision of participants	NT

N.A. – Not Applicable
NT – Not Tested

Table 11. Phase I Test Results: E/M-1380B (DFL Code C)

Test Name/ JTP Section	Substrate	Results per Trial	Pass/ Fail
Chromium Content/3.2	None	Trial 1 – 83 ppm; Trial 2 – 88 ppm Average – 86 ppm	Pass
Cured Film Thickness Uniformity/ 3.3	ST9b	*ST9b panels – target 0.1 – 0.2 mil* Panel 1 – 0.10, 0.11, 0.12, 0.12, 0.12, 0.13, 0.13, 0.13, 0.14, 0.18 mil Panel 2 – 0.10, 0.11, 0.12, 0.12, 0.12, 0.13, 0.13, 0.14, 0.15, 0.17 mil Panel 3 – 0.11, 0.11, 0.12, 0.12, 0.12, 0.13, 0.13, 0.13, 0.14, 0.17 mil	Pass Pass Pass
		Overall	**Pass**
Dry Tape Adhesion/3.4	ST9b	3 ST9b panels, each no removal	Pass
Lead and Cadmium Content/3.8	None	*Cadmium Content* Trial 1 – <1 ppm; Trial 2 – <1 ppm Average – <1 ppm	Pass
		Lead Content Trial 1 – 96 ppm; Trial 2 – 106 ppm Average – 101 ppm	Fail
Solvent Rub/3.11	N.A.	Not tested by decision of participants	NT
VOC Content/ 3.17	None	N.A. [a]	NT
Aluminum Compatibility/ JTR 2.1	N.A.	Not tested by decision of participants	NT

N.A. – Not Applicable
NT – Not Tested
[a] This dry film lubricant was applied by the manufacturer. Results of testing the liquid form of the lubricant, Everlube 10030, are in Table 12.

Table 12. Phase I Test Results: Everlube 10030 (DFL Code C')

Test Name/ JTP Section	Substrate	Results per Trial	Pass/ Fail
Chromium Content/3.2	None	Trial 1 – 23 ppm; Trial 2 – 13 ppm Average – 18 ppm	Pass
Cured Film Thickness Uniformity/ 3.3	ST9b	*ST9b panels – target 0.1 – 0.2 mil* Panel 1 – 0.10, 0.11, 0.12, 0.12, 0.12, 0.13, 0.13, 0.13, 0.14, 0.18 mil Panel 2 – 0.10, 0.11, 0.12, 0.12, 0.12, 0.13, 0.13, 0.14, 0.15, 0.17 mil Panel 3 – 0.11, 0.11, 0.12, 0.12, 0.12, 0.13, 0.13, 0.13, 0.14, 0.17 mil	Pass Pass Pass
		Overall	**Pass**
Dry Tape Adhesion/3.4	ST9b	3 ST9b panels, each no removal	Pass
Lead and Cadmium Content/3.8	None	*Cadmium Content* Trial 1 – <1 ppm; Trial 2 – <1 ppm Average – <1 ppm	Pass
		Lead Content Trial 1 – 21 ppm; Trial 2 – 24 ppm Average – 23 ppm	Pass
Solvent Rub/3.11	N.A.	Not tested by decision of participants	NT
VOC Content/ 3.17	None	Trial 1 – <1 g/L; Trial 2 – <1 g/L Average – <1 g/L	Pass
Aluminum Compatibility/ JTR 2.1	N.A.	Not tested by decision of participants	NT

N.A. – Not Applicable
NT – Not Tested

Table 13. Phase I Test Results: Everlube 812 (DFL Code D)

Test Name/ JTP Section	Substrate	Results per Trial	Pass/ Fail
Chromium Content/3.2	None	Trial 1 – 13 ppm; Trial 2 – 23 ppm Average – 18 ppm	Pass
Cured Film Thickness Uniformity/ 3.3	ST10, TI1a, TI1b	*ST10 panels – target 0.3 – 0.8 mil* Panel 1 – 0.50, 0.55, 0.55, 0.65, 0.65, 0.65, 0.65, 0.75, 0.75, 0.75 mil Panel 2 – 0.55, 0.55, 0.60, 0.60, 0.70, 0.70, 0.75, 0.80, 0.80, 0.80 mil Panel 3 – 0.35, 0.50, 0.55, 0.55, 0.60, 0.60, 0.65, 0.65, 0.75, 0.80 mil	Pass Pass Pass
		TI1a panels – target 0.3 – 0.8 mil Panel 1 – 0.63, 0.64, 0.65, 0.68, 0.68, 0.69, 0.69, 0.70, 0.71, 0.72 mil Panel 2 – 0.53, 0.54, 0.58, 0.58, 0.58, 0.60, 0.61, 0.61, 0.65, 0.67 mil Panel 3 – 0.48, 0.51, 0.57, 0.58, 0.60, 0.62, 0.65, 0.65, 0.67, 0.68 mil	Pass Pass Pass
		TI1b panels – target 0.3 – 0.8 mil Panel 1 – 0.48, 0.50, 0.52, 0.55, 0.57, 0.58, 0.58, 0.60, 0.60, 0.64 mil Panel 2 – 0.39, 0.45, 0.46, 0.46, 0.48, 0.49, 0.54, 0.55, 0.57, 0.58 mil Panel 3 – 0.42, 0.42, 0.43, 0.46, 0.47, 0.47, 0.53, 0.55, 0.57, 0.60 mil	Pass Pass Pass
		Overall	**Pass**
Dry Tape Adhesion/3.4	ST10, TI1a, TI1b	3 ST10 panels, each no removal 3 TI1a panels, each no removal 3 TI1b panels, each no removal	Pass
Lead and Cadmium Content/3.8	None	*Cadmium Content* Trial 1 – <1 ppm; Trial 2 – <1 ppm Average – <1 ppm	Pass
		Lead Content Trial 1 – 37 ppm; Trial 2 – 65 ppm Average – 51 ppm	Pass
Solvent Rub/3.11	ST10, TI1a	*Methyl ethyl ketone* 3 ST10 panels, each discolored and with some coating removed 3 TI1a panels, each discolored and deeply "burned" Overall	Pass

(Table 13 continued on next page)

Table 13. Phase I Test Results: Everlube 812 (DFL Code D) (continued)

Test Name/ JTP Section	Substrate	Results per Trial	Pass/ Fail
Solvent Rub/3.11 (continued)	ST10, TI1a	*Acetone* 3 ST10 panels, each burnished and stained 3 TI1a panels, each burnished and stained Overall	Pass
		PD 680B Type II 3 ST10 panels, each discolored and deeply "burned" 3 TI1a panels, each slightly discolored and slightly "burned" Overall	Pass
		Isopropyl alcohol 3 ST10 panels, each burnished 3 TI1a panels, each burnished Overall	Pass
VOC Content/ 3.17	None	Trial 1 – <1 g/L; Trial 2 – 160 g/L [a] Average – 80 g/L	Pass
Aluminum Compatibility/ JTR 2.1	N.A.	Not tested by decision of participants	NT

N.A. – Not Applicable
NT – Not Tested
[a] The "detection" of VOCs in this waterborne DFL may be attributed to uncertainties in the ASTM method used for the measurements and calculations. Specifically, calculation of VOC content requires subtraction of "percent water" from "percent total volatiles." Because this is a waterborne DFL, "percent water" and "percent total volatiles" should be equal, meaning that small uncertainties in each of these measurements become magnified during the calculations.

Table 14. Phase I Test Results: Surf-Kote LOB-1800G Class A (DFL Code E)

Test Name/ JTP Section	Substrate	Results per Trial	Pass/ Fail
Chromium Content/3.2	None	Trial 1 – 106 ppm; Trial 2 – 140 ppm Average – 123 ppm	Fail
		Trial 3 – 47.3 ppm; Trial 4 – 58.8 ppm Average – 53.1 ppm	Pass
Cured Film Thickness Uniformity/ 3.3	ST9b, ST10, TI1a, TI1b	*ST9b panels – target 0.1 – 0.2 mil* Panel 1 – 0.11, 0.12, 0.13, 0.14, 0.15, 0.15, 0.16, 0.17, 0.19, 0.20 mil Panel 2 – 0.11, 0.11, 0.11, 0.15, 0.15, 0.17, 0.17, 0.18, 0.18, 0.19 mil Panel 3 – 0.11, 0.12, 0.12, 0.13, 0.15, 0.15, 0.17, 0.17, 0.17, 0.18 mil	Pass Pass Pass
		ST10 panels – target 0.3 – 0.8 mil Panel 1 – 0.66, 0.70, 0.72, 0.75, 0.76, 0.81, 0.84, 0.85, 0.88, 0.89 mil Panel 2 – 0.77, 0.83, 0.85, 0.87, 0.89, 0.89, 0.90, 0.90, 0.92, 1.01 mil Panel 3 – 0.83, 0.89, 1.04, 1.05, 1.05, 1.06, 1.07, 1.11, 1.18, 1.21 mil	Fail Fail Fail
		TI1a panels – target 0.3 – 0.8 mil Panel 1 – 0.31, 0.31, 0.32, 0.32, 0.36, 0.36, 0.37, 0.37, 0.38, 0.40 mil Panel 2 – 0.30, 0.30, 0.31, 0.33, 0.33, 0.33, 0.35, 0.35, 0.39, 0.50 mil Panel 3 – 0.30, 0.30, 0.30, 0.30, 0.31, 0.31, 0.31, 0.33, 0.33, 0.34 mil	Pass Pass Pass
		TI1b panels – target 0.3 – 0.8 mil Panel 1 – 0.30, 0.30, 0.30, 0.31, 0.31, 0.31, 0.32, 0.32, 0.35, 0.38 mil Panel 2 – 0.50, 0.51, 0.58, 0.58, 0.63, 0.63, 0.66, 0.67, 0.68, 0.74 mil Panel 3 – 0.51, 0.58, 0.60, 0.61, 0.64, 0.67, 0.71, 0.74, 0.78, 0.96 mil	Pass Pass Pass
		Overall	**Fail**
Dry Tape Adhesion/3.4	ST9b, ST10, TI1a, TI1b	3 ST9b panels, two with slight increase in coating porosity, one no removal 3 ST10 panels, each no removal 3 TI1a panels, each no removal 3 TI1b panels, each no removal	Pass

(Table 14 continued on next page)

Table 14. Phase I Test Results: Surf-Kote LOB-1800G Class A (DFL Code E) (continued)

Test Name/ JTP Section	Substrate	Results per Trial	Pass/ Fail
Lead and Cadmium Content/3.8	None	*Cadmium Content* Trial 1 – <1 ppm; Trial 2 – <1 ppm Average – <1 ppm	Pass
		Lead Content Trial 1 – 2.0 ppm; Trial 2 – 2.5 ppm Average – 2.3 ppm	Pass
Solvent Rub/3.11	ST10, TI1a	*Methyl ethyl ketone* 3 ST10 panels, each discolored and deeply "burned" 3 TI1a panels, each discolored Overall	Pass
		Acetone 3 ST10 panels, each burnished and stained 3 TI1a panels, each burnished and stained Overall	Pass
		PD 680B Type II 3 ST10 panels, each slightly discolored and slightly "burned" 3 TI1a panels, each slightly discolored and slightly "burned" Overall	Pass
		Isopropyl alcohol 3 ST10 panels, each burnished 3 TI1a panels, each burnished Overall	Pass
VOC Content/ 3.17	None	Trial 1 – <1.0 g/L; Trial 2 – <1.0 g/L Average – <1.0 g/L	Pass
Aluminum Compatibility/ JTR 2.1	N.A.	Not tested by decision of participants	NT

N.A. – Not Applicable
NT – Not Tested

Table 15. Phase I Test Results: Tiolube 29 (DFL Code F)

Test Name/ JTP Section	Substrate	Results per Trial	Pass/ Fail
Chromium Content/3.2	None	Trial 1 – 14 ppm; Trial 2 – 15 ppm Average – 14 ppm	Pass
Cured Film Thickness Uniformity/ 3.3	ST9b, ST10, TI1a, TI1b	*ST9b panels – target 0.1 – 0.2 mil* Panel 1 – 0.07, 0.09, 0.09, 0.09, 0.10, 0.10, 0.11, 0.12, 0.13, 0.13 mil Panel 2 – 0.05, 0.07, 0.08, 0.09, 0.10, 0.10, 0.10, 0.12, 0.12, 0.14 mil Panel 3 – 0.07, 0.08, 0.10, 0.11, 0.11, 0.11, 0.12, 0.12, 0.12, 0.12 mil	Fail Fail Fail
		ST10 panels – target 0.3 – 0.8 mil Panel 1 – 0.79, 0.81, 0.82, 1.05, 1.27, 1.28, 1.30, 1.45, 1.46, 1.62 mils Panel 2 – 0.50, 0.67, 0.85, 1.00, 1.02, 1.12, 1.19, 1.30, 1.34, 1.37 mils Panel 3 – 0.76, 1.10, 1.47, 1.51, 1.62, 1.64, 1.65, 1.74, 1.84, 1.95 mils	Fail Fail Fail
		TI1a panels – target 0.3 – 0.8 mil Panel 1 – 0.34, 0.61, 0.64, 0.64, 0.71, 0.71, 0.92, 1.14, 1.33, 1.38 mils Panel 2 – 0.20, 0.43, 0.60, 0.64, 0.66, 0.68, 0.72, 0.74, 0.78, 0.96 mil Panel 3 – 0.22, 0.52, 0.61, 0.71, 0.72, 0.73, 0.77, 1.22, 1.45, 1.81 mil	Fail Fail Fail
		TI1b panels – target 0.3 – 0.8 mil Panel 1 – 0.78, 0.90, 0.97, 1.03, 1.07, 1.07, 1.08, 1.10, 1.10, 1.11 mils Panel 2 – 0.68, 0.77, 0.83, 0.86, 0.94, 0.95, 0.99, 1.11, 1.15, 1.26 mils Panel 3 – 0.82, 1.03, 1.09, 1.12, 1.18, 1.20, 1.23, 1.27, 1.28, 1.35 mils	Fail Fail Fail
		Overall	**Fail**
Dry Tape Adhesion/3.4	ST9b, ST10, TI1a, TI1b	3 ST9b panels, each 100% removal 3 ST10 panels, each 100% removal 3 TI1a panels, each 100% removal 3 TI1b panels, each 100% removal	Fail

(Table 15 continued on next page)

Table 15. Phase I Test Results: Tiolube 29 (DFL Code F) (continued)

Test Name/ JTP Section	Substrate	Results per Trial	Pass/ Fail
Lead and Cadmium Content/3.8	None	*Cadmium Content* Trial 1 – <1 ppm; Trial 2 – <1 ppm Average – <1 ppm	Pass
		Lead Content Trial 1 – 129 ppm; Trial 2 – 192 ppm Average – 161 ppm	Fail
Solvent Rub/3.11	ST10, TI1a	*Methyl ethyl ketone* 3 ST10 panels, each with substrate showing 3 TI1a panels, each with substrate showing Overall	Fail
		Acetone 3 ST10 panels, each with substrate showing 3 TI1a panels, each with substrate showing Overall	Fail
		PD 680B Type II 3 ST10 panels, each with substrate showing 3 TI1a panels, each with substrate showing Overall	Fail
		Isopropyl alcohol 3 ST10 panels, each with substrate showing 3 TI1a panels, each with substrate showing Overall	Fail
VOC Content/ 3.17	None	Trial 1 – <1.0 g/L; Trial 2 – <1.0 g/L Average – <1.0 g/L	Pass
Aluminum Compatibility/ JTR 2.1	N.A.	Not tested by decision of participants	NT

N.A. – Not Applicable
NT – Not Tested

Table 16. Phase I Test Results: Tiolube 614-T9B (DFL Code G)

Test Name/ JTP Section	Substrate	Results per Trial	Pass/ Fail
Chromium Content/3.2	None	Trial 1 – 550 ppm; Trial 2 – 407 ppm Average – 479 ppm	Fail
		Trial 3 – 29.9 ppm; Trial 4 – 33.1 ppm Average – 31.5 ppm	Pass
Cured Film Thickness Uniformity/ 3.3	ST10, TI1a, TI1b	*ST10 panels – target 0.3 – 0.8 mil*	
		Panel 1 [a] – 0.5, 0.6, 0.7 mil	Pass
		Panel 2 [a] – 0.4, 0.5, 0.5 mil	Pass
		Panel 3 [a] – 0.4, 0.4, 0.6 mil	Pass
		TI1a panels – target 0.3 – 0.8 mil	
		Panel 1 [a] – 0.3, 0.4, 0.5 mil	Pass
		Panel 2 [a] – 0.4, 0.6, 0.7 mil	Pass
		Panel 3 [a] – 0.5, 0.6, 0.7 mil	Pass
		TI1b panels – target 0.3 – 0.8 mil	
		Panel 1 [a] – 0.5, 0.6, 0.6 mil	Pass
		Panel 2 [a] – 0.6, 0.6, 0.7 mil	Pass
		Panel 3 [a] – 0.6, 0.7, 0.7 mil	Pass
		Overall	**Pass**
Dry Tape Adhesion/3.4	ST9b, ST10, TI1a, TI1b	3 ST9b panels, each no removal 3 ST10 panels, each no removal 3 TI1a panels, each no removal 3 TI1b panels, each no removal	Pass
Lead and Cadmium Content/3.8	None	*Cadmium Content* Trial 1 – 2.0 ppm; Trial 2 – 2.0 ppm Average – 2.1 ppm	Pass
		Lead Content Trial 1 – < 3.5 ppm; Trial 2 – < 3.5 ppm Average – < 3.5 ppm	Pass

(Table 16 continued on next page)

Table 16. Phase I Test Results: Tiolube 614-T9B (DFL Code G) (continued)

Test Name/ JTP Section	Substrate	Results per Trial	Pass/ Fail
Solvent Rub/3.11	ST10, TI1a	*Methyl ethyl ketone* 3 ST10 panels, two slightly "burned" and one "burned" 3 TI1a panels, one slightly "burned" and two "burned" Overall	Pass
		Acetone 3 ST10 panels, each discolored and slightly "burned" 3 TI1a panels, each discolored and slightly "burned" Overall	Pass
		PD 680B Type II 3 ST10 panels, two slightly "burned" and one heavily "burned" 3 TI1a panels, two slightly "burned" and one heavily "burned" Overall	Pass
		Isopropyl alcohol 3 ST10 panels, one slightly "burned" and two heavily "burned" 3 TI1a panels, one slightly "burned" and two deeply "burned" Overall	Pass
VOC Content/ 3.17	None	N.A. [b]	NT
Aluminum Compatibility/ JTR 2.1	ST3/AL1c	No degradation of either AL1c panel observed at 500X magnification	Pass

N.A. – Not Applicable
NT – Not Tested

[a] This film could not be measured with a nondestructive technique. Measurement of the thickness of this film was performed in accordance with ASTM D4138, using a Tooke gauge. Using this method, it was only possible to obtain three separate film thickness measurements per panel.

[b] This dry film lubricant was applied by the manufacturer, and the liquid form of the lubricant was not available for testing.

Table 17. Phase I Test Results: X-204 Solid Film Lubricant (DFL Code H)

Test Name/ JTP Section	Substrate	Results per Trial	Pass/ Fail
Chromium Content/3.2	None	Trial 1 – 4.2 ppm; Trial 2 – 6.4 ppm Average – 5.3 ppm	Pass
Cured Film Thickness Uniformity/ 3.3	ST9b	*ST9b panels – target 0.1 – 0.2 mil* Panel 1 – 0.10, 0.12, 0.13, 0.16, 0.17, 0.18, 0.18, 0.18, 0.18, 0.19 mil Panel 2 – 0.10, 0.11, 0.12, 0.13, 0.14, 0.15, 0.16, 0.18, 0.20, 0.20 mil Panel 3 – 0.09, 0.10, 0.11, 0.11, 0.11, 0.12, 0.12, 0.13, 0.13, 0.15 mil	 Pass Pass Pass
		ST9b panels – target 0.3 – 0.8 mil Panel 1 – 0.31, 0.33, 0.35, 0.36, 0.37, 0.38, 0.42, 0.42, 0.54, 0.55 mil Panel 2 – 0.31, 0.32, 0.42, 0.43, 0.43, 0.47, 0.51, 0.53, 0.60, 0.63 mil Panel 3 – 0.45, 0.51, 0.56, 0.58, 0.63, 0.63, 0.65, 0.65, 0.80, 0.93 mil	 Pass Pass Pass
		Overall	**Pass**
Dry Tape Adhesion/3.4	ST9b	3 ST9b (0.1 to 0.2 mil thickness) panels, each ~65% of tape with DFL attached, but no substrate exposure 3 ST9b (0.3 to 0.8 mil thickness) panels, each ~65% of tape with DFL attached, but no substrate exposure	 Pass
Lead and Cadmium Content/3.8	None	*Cadmium Content* Trial 1 – <1 ppm; Trial 2 – <1 ppm Average – <1 ppm	 Pass
		Lead Content Trial 1 – 7.7 ppm; Trial 2 – 9.6 ppm Average – 8.6 ppm	 Pass
Solvent Rub/3.11	N.A.	Not tested by decision of participants	NT
VOC Content/ 3.17	None	Trial 1 – 130 g/L; Trial 2 – 130 g/L Average – 130 g/L	 Pass
Aluminum Compatibility/ JTR 2.1	N.A.	Not tested by decision of participants	NT

N.A. – Not Applicable
NT – Not Tested

Table 18. Phase I Test Results: Experimental Control DFL (DFL Code J)

Test Name/ JTP Section	Substrate	Results per Trial	Pass/ Fail
Chromium Content/3.2	None	Not tested by decision of participants	NT
Cured Film Thickness Uniformity/ 3.3	N.A.	Not tested by decision of participants	NT
Dry Tape Adhesion/3.4	ST10, TI1a, TI1b	3 ST10 panels, two with no removal, one with trace 3 TI1a panels, two with no removal, one with trace removal 3 TI1b panels, each no removal	Pass
Lead and Cadmium Content/3.8	None	Not tested by decision of participants	NT
Solvent Rub/3.11	N.A.	Not tested by decision of participants	NT
VOC Content/ 3.17	None	Not tested by decision of participants	NT
Aluminum Compatibility/ JTR 2.1	N.A.	Not tested by decision of participants	NT

N.A. – Not Applicable
NT – Not Tested

4.2. Phase II Test Results

After reviewing the results of the Phase I testing, the project participants chose to eliminate DFLs A (Alseal 333) and F (Tiolube 29). DFL C (E/M 1380B) was eliminated from further testing because its composition is identical to that of DFL C' (Everlube 10030). All other candidate DFLs (B, C', D, E, G, and H) were tested in Phase II, along with the lead-containing experimental control DFLs (J and K).

The Phase II tests were performed at *CTC* in spring of 1999. The results of the Phase II tests are summarized in Table 19, and the individual results for each candidate DFL are reported in Tables 20 through 25. Tables 26 through 28 contain the results of evaluations of the experimental control specimens.

Table 19. Phase II Testing Results - Summary

DFL Code	Test (JTP Section)				
	3.5	3.7	3.12	3.14	3.15
B	Pass	Fail	Pass	Fail	N.A.
C'	Pass	Pass	Pass	Pass	N.A.
D	Pass	Pass	Pass	Pass	N.A.
E	Pass	Fail	Pass	Fail	N.A.
G	Pass	Pass	Pass	Pass	N.A.
H	Pass	Fail	Pass	Fail	N.A.
J	NT	Fail	Pass	Pass [a]	N.A.
K	NT	NT	Pass	NT	NT

[a] These experimental control specimens coated with lead-containing DFL are the standard against which the nonlead DFL-coated specimens are judged, therefore they "pass" by definition.
NT = Not Tested
N.A. = Not Applicable (this test was performed to provide useful data rather than to support a pass/fail decision)

Table 20. Phase II Test Results: Alseal 360 (DFL Code B)

Test Name/ JTP Section	Substrate	Results per Trial		Pass/ Fail
Elevated Temperature Material Compatibility/ 3.5	AL1c, NI2a, NI3, ST9b, ST10, TI1a	*400°F ± 5°F* 1 AL1c, 1 ST10, 1 TI1a	*For all:* No degradation observed at 500X magnification	Pass
		750°F ± 5°F 1 ST10, 1 TI1a		
		1050°F ± 5°F 1 ST9b		
		1600°F ± 5°F 1 NI2a, 1 NI3		
Fluid Resistance/3.7	AL1d, ST9b, ST10, TI1a	*Engine Oil* 3 AL1d panels, each with acceptable adhesion and minor discoloration, one with small blisters		Fail
		3 ST9b panels, each with acceptable adhesion and minor discoloration		Pass
		3 ST10 panels, each with acceptable adhesion and minor discoloration		Pass
		3 TI1a panels, each with acceptable adhesion, two with some discoloration, one with heavy discoloration		Fail

(Table 20 continued on next page)

Table 20. Phase II Test Results: Alseal 360 (DFL Code B) (continued)

Test Name/ JTP Section	Substrate	Results per Trial	Pass/ Fail
Fluid Resistance/3.7 (continued)	AL1d, ST9b, ST10, TI1a	*Anti-Icing Fluid*	
		3 AL1d panels, each with minor film removal but no substrate exposure	Pass
		3 ST9b panels, one with minor film removal but no substrate exposure, two with exposed substrate	Fail
		3 ST10 panels, each with minor film removal but no substrate exposure	Pass
		3 TI1a panels, each with minor film removal but no substrate exposure	Pass
		JP-5 Fuel	
		3 AL1d panels, each with acceptable adhesion and minor discoloration	Pass
		3 ST9b panels, each with acceptable adhesion and minor discoloration	Pass
		3 ST10 panels, each with minor discoloration and minor film removal but no substrate exposure	Pass
		3 TI1a panels, each with minor film removal but no substrate exposure	Pass
		JP-8 Fuel	
		3 AL1d panels, each with no film defects	Pass
		3 ST9b panels, each with no film defects	Pass
		3 ST10 panels, each with acceptable adhesion and minor discoloration	Pass
		3 TI1a panels, each with acceptable adhesion and minor discoloration	Pass
		Distilled H_2O	
		3 AL1d panels, each with exposed substrate	Fail
		3 ST9b panels, each with exposed substrate	Fail
		3 ST10 panels, each with minor film removal but no substrate exposure	Pass
		3 TI1a panels, two with minor film removal but no substrate exposure, one with exposed substrate	Fail

(Table 20 continued on next page)

Table 20. Phase II Test Results: Alseal 360 (DFL Code B) (continued)

Test Name/ JTP Section	Substrate	Results per Trial		Pass/ Fail
Fluid Resistance/3.7 (continued)	AL1d, ST9b, ST10, TI1a	*Skydrol*		
		3 AL1d panels, each with no film defects		Pass
		3 ST9b panels, each with no film defects		Pass
		3 ST10 panels, each with no film defects		Pass
		3 TI1a panels, each with no film defects		Pass
		Damping Fluid		
		3 AL1d panels, each with no film defects		Pass
		3 ST9b panels, each with no film defects		Pass
		3 ST10 panels, each with no film defects		Pass
		3 TI1a panels, each with no film defects		Pass
		Substitute Ocean Water		
		3 AL1d panels, one with minor film removal but no substrate exposure, two with exposed substrate		Fail
		3 ST9b panels, each with exposed substrate		Fail
		3 ST10 panels, two with minor film removal but no substrate exposure, one with exposed substrate		Fail
		3 TI1a panels, each with minor film removal but no substrate exposure		Fail
		Hydraulic Fluid		
		3 AL1d panels, each with no film defects		Pass
		3 ST9b panels, each with no film defects		Pass
		3 ST10 panels, each with no film defects		Pass
		3 TI1a panels, each with no film defects		Pass
		Overall		**Fail**
Stress Corrosion/ 3.12	TI1a, TI1b	3 TI1a panels, 2 TI1b panels	*For all*: No cracking observed at 500X magnification	Pass

(Table 20 continued on next page)

Table 20. Phase II Test Results: Alseal 360 (DFL Code B) (continued)

Test Name/ JTP Section	Substrate	Results per Trial	Pass/ Fail
Thermal Shock Stability/3.14	NI2a, ST10, TI1b	*600°F ± 10°F*	
		3 ST10 panels, each with small blisters on DFL and adhesion failure	Fail
		3 TI1b panels w/ DFL 0.3 to 0.8 mil thick, each with small blisters on DFL, two failing adhesion and one passing adhesion	Fail
		2 TI1b panels w/ DFL 1 to 2 mils thick, each with heavy blistering and adhesion failure	Fail
		900°F ± 10°F	
		3 ST10 panels, each with blistering and adhesion failure	Fail
		1200°F ± 25°F	
		2 NI2a panels, each with adhesion failure	Fail
		1400°F ± 25°F	
		2 NI2a panels, each with adhesion failure	Fail
		Overall	**Fail**
Thermal Stability by SDT/3.15	None	*Temperature ramp at 10°F/minute in air, stop at 900°F*	
		Mass change: Trial 1 –3.6% between 122°F and 939°F; Trial 2 –3.9% between 122°F and 903°F; Average –3.7%	N.A.
		Energy transfer between sample and atmosphere: None detectable	
		Temperature ramp at 10°F/minute in argon, stop at 900°F	
		Mass change: Trial 1 –0.64% between 212°F and 634°F; Trial 2 –0.74% between 212°F and 652°F; Average –0.69%	N.A.
		Energy transfer between sample and atmosphere: None detectable	

(Table 20 continued on next page)

Table 20. Phase II Test Results: Alseal 360 (DFL Code B) (continued)

Test Name/ JTP Section	Substrate	Results per Trial	Pass/ Fail
Thermal Stability by SDT/3.15 (continued)	None	*Temperature ramp at 50°F/minute in air, stop at 600°F and hold for 24 hours*	
		Mass change: Trial 1 –2.3% between 1 hour 36 minutes (1:36) and 9:36; Trial 2 –1.8% between 1:36 and 9:12; Average –2.0%	N.A.
		Energy transfer between sample and atmosphere: None detectable	
		Temperature ramp at 50°F/minute in argon, stop at 600°F and hold for 24 hours	
		Mass change: Trial 1 –1.9% between 1:36 and 10:24; Trial 2 –1.9% between 1:36 and 10:24; Average –1.9%	N.A.
		Energy transfer between sample and atmosphere: None detectable	
		Temperature ramp at 50°F/minute in air, stop at 900°F and hold for 24 hours	
		Mass change: Trial 1 –25% between 1:36 and 24:00; Trial 2 –30% between 1:36 and 24:00; Average –27%	N.A.
		Energy transfer between sample and atmosphere: None detectable	
		Temperature ramp at 50°F/minute in argon, stop at 900°F and hold for 24 hours	
		Mass change: Trial 1 –2.7% between 1:36 and 12:00; Trial 2 –4.3% between 1:36 and 22:00; Average –3.5%	N.A.
		Energy transfer between sample and atmosphere: None detectable	

N.A. – Not Applicable
NT – Not Tested

Table 21. Phase II Test Results: Everlube 10030 (DFL Code C')

Test Name/ JTP Section	Substrate	Results per Trial		Pass/ Fail
Elevated Temperature Material Compatibility/ 3.5	NI2a, NI3, ST9b	*1050°F ±5°F* 1 ST9b	*For all:* No degradation observed at 500X magnification	Pass
		1600°F ±5°F 1 NI2a, 1 NI3		
Fluid Resistance/3.7	AL1d, ST9b	*Engine Oil*		
		3 AL1d panels, each with no film defects		Pass
		3 ST9b panels, each with no film defects		Pass
		Anti-Icing Fluid		
		3 AL1d panels, each with minor film removal but no substrate exposure		Pass
		3 ST9b panels, each with minor film removal but no substrate exposure		Pass
		JP-5 Fuel		
		3 AL1d panels, each with no film defects		Pass
		3 ST9b panels, each with minor film removal but no substrate exposure		Pass
		JP-8 Fuel		
		3 AL1d panels, each with no film defects		Pass
		3 ST9b panels, each with minor film removal but no substrate exposure		Pass
		Distilled H_2O		
		3 AL1d panels, each with minor film removal but no substrate exposure		Pass
		3 ST9b panels, each with minor film removal but no substrate exposure		Pass
		Skydrol		
		3 AL1d panels, each with minor film removal but no substrate exposure		Pass
		3 ST9b panels, each with minor film removal but no substrate exposure		Pass
		Damping Fluid		
		3 AL1d panels, each with no film defects		Pass
		3 ST9b panels, each with minor film removal but no substrate exposure		Pass

(Table 21 continued on next page)

Table 21. Phase II Test Results: Everlube 10030 (DFL Code C') (continued)

Test Name/ JTP Section	Substrate	Results per Trial	Pass/ Fail
Fluid Resistance/3.7 (continued)	AL1d, ST9b	*Substitute Ocean Water*	
		3 AL1d panels, each with some powdery white residue but no film removal	Pass
		3 ST9b panels, each with minor discoloration and minor film removal but no substrate exposure	Pass
		Hydraulic Fluid	
		3 AL1d panels, each with no film defects	Pass
		3 ST9b panels, each with minor film removal but no substrate exposure	Pass
		Overall	**Pass**
Stress Corrosion/ 3.12	N.A.	Not tested by decision of participants	NT
Thermal Shock Stability/3.14	NI2a	*1200°F ± 25°F*	
		2 NI2a panels, each with minor film removal but no substrate exposure	Pass
		1400°F ± 25°F	
		2 NI2a panels, each with minor film removal but no substrate exposure	Pass
		Overall	**Pass**
Thermal Stability by SDT/3.15	N.A.	Not tested by decision of participants	NT

N.A. – Not Applicable
NT – Not Tested

Table 22. Phase II Test Results: Everlube 812 (DFL Code D)

Test Name/ JTP Section	Substrate	Results per Trial		Pass/ Fail
Elevated Temperature Material Compatibility/ 3.5	ST10, TI1a	*400°F ±5°F* 1 ST10, 1 TI1a *750°F ±5°F* 1 ST10, 1 TI1a	*For all:* No degradation observed at 500X magnification	Pass
Fluid Resistance/3.7	ST10, TI1a	*Engine Oil*		
		3 ST10 panels, each with acceptable adhesion and some discoloration probably caused by oil absorption; the panels were further heated to 375°F for 4 hours, then visually examined and subjected to a dry tape adhesion test, which they passed		Pass
		3 TI1a panels, each with acceptable adhesion and some discoloration probably caused by oil absorption; the panels were further heated to 375°F for 4 hours, then visually examined and subjected to a dry tape adhesion test, which they passed		Pass
		Anti-Icing Fluid		
		3 ST10 panels, each with minor film removal but no substrate exposure		Pass
		3 TI1a panels, each with minor film removal but no substrate exposure		Pass
		JP-5 Fuel		
		3 ST10 panels, each with minor discoloration and minor film removal but no substrate exposure		Pass
		3 TI1a panels, each with some discoloration; one with minor film removal but no substrate exposure, two with exposed substrate		Fail
		JP-8 Fuel		
		3 ST10 panels, each with minor film removal but no substrate exposure		Pass
		3 TI1a panels, each with minor film removal but no substrate exposure		Pass

(Table 22 continued on next page)

Table 22. Phase II Test Results: Everlube 812 (DFL Code D) (continued)

Test Name/ JTP Section	Substrate	Results per Trial	Pass/ Fail
Fluid Resistance/3.7 (continued)	ST10, TI1a	*Distilled H_2O*	
		3 ST10 panels, each with minor film removal but no substrate exposure	Pass
		3 TI1a panels, each with minor film removal but no substrate exposure	Pass
		Skydrol	
		3 ST10 panels, each with no film defects	Pass
		3 TI1a panels, each with minor film removal but no substrate exposure	Pass
		Damping Fluid	
		3 ST10 panels, each with no film defects	Pass
		3 TI1a panels, each with no film defects	Pass
		Substitute Ocean Water	
		3 ST10 panels, each with minor film removal but no substrate exposure	Pass
		3 TI1a panels, each with minor film removal but no substrate exposure	Pass
		Hydraulic Fluid	
		3 ST10 panels, each with minor film removal but no substrate exposure	Pass
		3 TI1a panels, each with minor film removal but no substrate exposure	Pass
		Overall	**Pass** [a]
Stress Corrosion/ 3.12	TI1a	3 TI1a panels, no cracking observed at 500X magnification	Pass
Thermal Shock Stability/3.14	ST10, TI1b	*600°F ± 10°F*	
		3 ST10 panels, each with no film defects	Pass
		3 TI1b panels, each with no film defects	Pass
		900°F ± 10°F	
		3 ST10 panels, each with no film defects	Pass
		Overall	**Pass**

(Table 22 continued on next page)

Table 22. Phase II Test Results: Everlube 812 (DFL Code D) (continued)

Test Name/ JTP Section	Substrate	Results per Trial	Pass/ Fail
Thermal Stability by SDT/3.15	None	*Temperature ramp at 10°F/minute in air, stop at 900°F*	
		Mass change: Trial 1 +1.7% between 122°F and 732°F then –1.8% between 732°F and 904°F; Trial 2 +2.3% between 95°F and 733°F then –1.9% between 733°F and 904°F; Average +2.0% then –1.9%	N.A.
		Energy transfer between sample and atmosphere: Trial 1 inflection at 367°C (693°F); Trial 2 inflection at 368°C (694°F); inflections within drift of instrument and therefore not quantifiable	
		Temperature ramp at 10°F/minute in argon, stop at 900°F	
		Mass change: Trial 1 +1.8% between 122°F and 904°F; Trial 2 +3.6% between 122°F and 904°F; Average +2.7%	N.A.
		Energy transfer between sample and atmosphere: None detectable	
		Temperature ramp at 50°F/minute in air, stop at 600°F and hold for 24 hours	
		Mass change: Trial 1 no change detected; Trial 2 no change detected	N.A.
		Energy transfer between sample and atmosphere: None detectable	
		Temperature ramp at 50°F/minute in argon, stop at 600°F and hold for 24 hours	
		Mass change: Trial 1 –3.7% between 1 hour 36 minutes (1:36) and 10:00; Trial 2 –1.1% between 1:36 and 7:36; Average –2.4%	N.A.
		Energy transfer between sample and atmosphere: None detectable	

(Table 22 continued on next page)

Table 22. Phase II Test Results: Everlube 812 (DFL Code D) (continued)

Test Name/ JTP Section	Substrate	Results per Trial	Pass/ Fail
Thermal Stability by SDT/3.15 (continued)	None	*Temperature ramp at 50°F/minute in air, stop at 900°F and hold for 24 hours*	
		Mass change: Trial 1 –3.9% between 1:36 and 7:36 then +5.0% between 7:36 and 15:36; Trial 2 –2.8% between 1:36 and 3:36 then +5.7% between 3:36 and 24:00; Average –3.3% then +5.4%	N.A.
		Energy transfer between sample and atmosphere: Trial 1 inflection at 9:00; Trial 2 inflection at 4:40; inflections within drift of instrument and therefore not quantifiable	
		Temperature ramp at 50°F/minute in argon, stop at 900°F and hold for 24 hours	
		Mass change: Trial 1 –2.9% between 1:36 and 13:24; Trial 2 –1.1% between 2:24 and 7:24; Average –2.0%	N.A.
		Energy transfer between sample and atmosphere: None detectable	

N.A. – Not Applicable
NT – Not Tested
[a] This DFL is considered to have passed the Fluid Resistance test even though one combination of substrate and fluid resulted in film removal.

Table 23. Phase II Test Results: Surf-Kote LOB-1800G (DFL Code E)

Test Name/ JTP Section	Substrate	Results per Trial		Pass/ Fail
Elevated Temperature Material Compatibility/ 3.5	NI2a, NI3, ST9b, ST10, TI1a	*400°F ±5°F* 1 ST10, 1 TI1a	*For all:* No degradation observed at 500X magnification	Pass
		750°F ±5°F 1 ST10, 1 TI1a		
		1050°F ±5°F 1 ST9b		
		1600°F ±5°F 1 NI2a, 1 NI3		
Fluid Resistance/3.7	AL1d, ST9b, ST10, TI1a	*Engine Oil*		
		3 AL1d panels, each with no film defects		Pass
		3 ST9b panels, one with no film defects and two with exposed substrate		Fail
		3 ST10 panels, each with no film defects		Pass
		3 TI1a panels, each with no film defects		Pass
		Anti-Icing Fluid		
		3 AL1d panels, each with minor film removal but no substrate exposure		Pass
		3 ST9b panels, each with exposed substrate		Fail
		3 ST10 panels, each with minor film removal but no substrate exposure		Pass
		3 TI1a panels, each with minor film removal but no substrate exposure		Pass
		JP-5 Fuel		
		3 AL1d panels, each with minor film removal but no substrate exposure		Pass
		3 ST9b panels, each with minor film removal but no substrate exposure		Pass
		3 ST10 panels, each with minor film removal but no substrate exposure		Pass
		3 TI1a panels, each with minor film removal but no substrate exposure		Pass

(Table 23 continued on next page)

Table 23. Phase II Test Results: Surf-Kote LOB-1800G (DFL Code E) (continued)

Test Name/ JTP Section	Substrate	Results per Trial	Pass/ Fail
Fluid Resistance/3.7 (continued)	AL1d, ST9b, ST10, TI1a	*JP-8 Fuel*	
		3 AL1d panels, each with minor film removal but no substrate exposure	Pass
		3 ST9b panels, each with minor film removal but no substrate exposure	Pass
		3 ST10 panels, each with minor discoloration and minor film removal but no substrate exposure	Pass
		3 TI1a panels, each with minor discoloration (color streaks) and minor film removal but no substrate exposure	Pass
		Distilled H_2O	
		3 AL1d panels, each with minor film removal but no substrate exposure	Pass
		3 ST9b panels, each with minor film removal but no substrate exposure	Pass
		3 ST10 panels, each with minor film removal but no substrate exposure	Pass
		3 TI1a panels, each with minor film removal but no substrate exposure	Pass
		Skydrol	
		3 AL1d panels, each with minor film removal but no substrate exposure	Pass
		3 ST9b panels, each with minor film removal but no substrate exposure	Pass
		3 ST10 panels, each with minor film removal but no substrate exposure	Pass
		3 TI1a panels, each with minor film removal but no substrate exposure	Pass
		Damping Fluid	
		3 AL1d panels, each with minor film removal but no substrate exposure	Pass
		3 ST9b panels, each with minor film removal but no substrate exposure	Pass
		3 ST10 panels, each with minor film removal but no substrate exposure	Pass
		3 TI1a panels, each with minor film removal but no substrate exposure	Pass

(Table 23 continued on next page)

Table 23. Phase II Test Results: Surf-Kote LOB-1800G (DFL Code E) (continued)

Test Name/ JTP Section	Substrate	Results per Trial	Pass/ Fail
Fluid Resistance/3.7 (continued)	AL1d, ST9b, ST10, TI1a	*Substitute Ocean Water*	
		3 AL1d panels, each with some powdery white residue and minor film removal but no substrate exposure	Pass
		3 ST9b panels, each with minor film removal but no substrate exposure	Pass
		3 ST10 panels, each with minor film removal but no substrate exposure	Pass
		3 TI1a panels, each with minor film removal but no substrate exposure	Pass
		Hydraulic Fluid	
		3 AL1d panels, each with minor film removal but no substrate exposure	Pass
		3 ST9b panels, each with minor film removal but no substrate exposure	Pass
		3 ST10 panels, each with minor film removal but no substrate exposure	Pass
		3 TI1a panels, each with minor film removal but no substrate exposure	Pass
		Overall	**Fail**
Stress Corrosion/ 3.12	TI1a	3 TI1a panels, no cracking observed at 500X magnification	Pass
Thermal Shock Stability/3.14	NI2a, ST10, TI1b	*600°F ± 10°F*	
		3 ST10 panels, each with no film defects	Pass
		3 TI1b panels, two with no film defects, one with film removal exposing substrate	Pass [a]
		900°F ± 10°F	
		3 ST10 panels, two with minor film removal but no substrate exposure, one with film removal exposing substrate	Pass [a]
		1200°F ± 25°F	
		2 NI2a panels, each with severe discoloration and minor film removal but no substrate exposure	Pass [a]
		1400°F ± 25°F	
		2 NI2a panels, each with no film removal but multiple tiny blisters covering surface	Fail
		Overall	**Fail**

(Table 23 continued on next page)

Table 23. Phase II Test Results: Surf-Kote LOB-1800G (DFL Code E) (continued)

Test Name/ JTP Section	Substrate	Results per Trial	Pass/ Fail
Thermal Stability by SDT/3.15	None	*Temperature ramp at 10°F/minute in air, stop at 900°F*	
		Mass change: Trial 1 –2.0% between 122°F and 885°F; Trial 2 –1.3% between 311°F and 895°F; Average –1.7%	N.A.
		Energy transfer between sample and atmosphere: None detectable	
		Temperature ramp at 10°F/minute in argon, stop at 900°F	
		Mass change: Trial 1 +1.0% between 401°F and 886°F; Trial 2 +0.91% between 392°F and 894°F; Average +0.97%	N.A.
		Energy transfer between sample and atmosphere: None detectable	
		Temperature ramp at 50°F/minute in air, stop at 600°F and hold for 24 hours	
		Mass change: Trial 1 –3.7% between 1 hour 36 minutes (1:36) and 10:24; Trial 2 –2.0% between 1:36 and 8:00; Average –2.9%	N.A.
		Energy transfer between sample and atmosphere: None detectable	
		Temperature ramp at 50°F/minute in argon, stop at 600°F and hold for 24 hours	
		Mass change: Trial 1 none detectable; Trial 2 none detectable	N.A.
		Energy transfer between sample and atmosphere: None detectable	
		Temperature ramp at 50°F/minute in air, stop at 900°F and hold for 24 hours	
		Mass change: Trial 1 –39.6% between 1:36 and 24:00; Trial 2 –39.2% between 1:36 and 24:00; Average 39.4%	N.A.
		Energy transfer between sample and atmosphere: None detectable	

(Table 23 continued on next page)

Table 23. Phase II Test Results: Surf-Kote LOB-1800G (DFL Code E) (continued)

Test Name/ JTP Section	Substrate	Results per Trial	Pass/ Fail
Thermal Stability by SDT/3.15 (continued)	None	*Temperature ramp at 50°F/minute in argon, stop at 900°F and hold for 24 hours*	
		Mass change: Trial 1 –2.6% between 1:36 and 9:12; Trial 2 –0.46% between 4:00 and 6:48 then –1.0% between 14:48 and 24:00; Average 2.1% over 24 hours	N.A.
		Energy transfer between sample and atmosphere: None detectable	

N.A. – Not Applicable
NT – Not Tested
[a] These results are considered equivalent to the "worst" results observed with the lead-containing experimental control DFL.

Table 24. Phase II Test Results: Tiolube 614-T9B (DFL Code G)

Test Name/ JTP Section	Substrate	Results per Trial		Pass/ Fail
Elevated Temperature Material Compatibility/ 3.5	CO1, CO2, NI1, NI2a, NI2b, ST3, ST4, ST9a, ST10, TI1a	*400°F ± 5°F* 1 ST10, 1 TI1a	*For all:* No degradation observed at 500X magnification	Pass
		750°F ± 5°F 1 ST3, 1 ST10, 1 TI1a		
		1050°F ± 5°F 1 ST4, 1 ST9a		
		1600°F ± 5°F 1 CO1, 1 CO2, 1 NI1, 1 NI2a, 1 NI2b		

(Table 24 continued on next page)

Table 24. Phase II Test Results: Tiolube 614-T9B (DFL Code G) (continued)

Test Name/ JTP Section	Substrate	Results per Trial	Pass/ Fail
Fluid Resistance/3.7	ST10, TI1a	*Engine Oil*	
		3 ST10 panels, each with minor film removal but no substrate exposure	Pass
		3 TI1a panels, each with minor film removal but no substrate exposure	Pass
		Anti-Icing Fluid	
		3 ST10 panels, one with no film defects, two with minor film removal but no substrate exposure	Pass
		3 TI1a panels, each with minor film removal but no substrate exposure	Pass
		JP-5 Fuel	
		3 ST10 panels, each with no film defects	Pass
		3 TI1a panels, each with minor film removal but no substrate exposure	Pass
		JP-8 Fuel	
		3 ST10 panels, each with minor film removal but no substrate exposure	Pass
		3 TI1a panels, each with minor film removal but no substrate exposure	Pass
		Distilled H_2O	
		3 ST10 panels, each with minor discoloration and minor film removal but no substrate exposure	Pass
		3 TI1a panels, each with minor discoloration and minor film removal but no substrate exposure	Pass
		Skydrol	
		3 ST10 panels, each with minor film removal but no substrate exposure	Pass
		3 TI1a panels, each with minor film removal but no substrate exposure	Pass
		Damping Fluid	
		3 ST10 panels, one with no film defects, two with minor film removal but no substrate exposure	Pass
		3 TI1a panels, each with minor film removal but no substrate exposure	Pass

(Table 24 continued on next page)

Table 24. Phase II Test Results: Tiolube 614-T9B (DFL Code G) (continued)

Test Name/ JTP Section	Substrate	Results per Trial		Pass/ Fail
Fluid Resistance/3.7 (continued)	ST10, TI1a	*Substitute Ocean Water*		
		3 ST10 panels, each with minor discoloration and minor film removal but no substrate exposure		Pass
		3 TI1a panels, each with minor discoloration and minor film removal but no substrate exposure		Pass
		Hydraulic Fluid		
		3 ST10 panels, each with minor film removal but no substrate exposure		Pass
		3 TI1a panels, each with minor film removal but no substrate exposure		Pass
		Overall		**Pass**
Stress Corrosion/ 3.12	TI1a, TI2	3 TI1a panels, 3 TI2 panels	*For all*: No cracking observed at 500X magnification	Pass
Thermal Shock Stability/3.14	ST10, TI1b	*600°F ± 10°F*		
		3 ST10 panels, each with no film defects		Pass
		3 TI1b panels, each with minor film removal but no substrate exposure		Pass
		900°F ± 10°F		
		3 ST10 panels, each with no film defects		Pass
		Overall		**Pass**
Thermal Stability by SDT/3.15	None	*Temperature ramp at 10°F/minute in air, stop at 1450°F*		
		Mass change: Trial 1 –4.6% between 212°F and 788°F; Trial 2 –3.9% between 212°F and 931°F then –2.4% between 1200°F and 1433°F; Average –5.5% over entire temperature range		N.A.
		Energy transfer between sample and atmosphere: None detectable		

(Table 24 continued on next page)

Table 24. Phase II Test Results: Tiolube 614-T9B (DFL Code G) (continued)

Test Name/ JTP Section	Substrate	Results per Trial	Pass/ Fail
Thermal Stability by SDT/3.15 (continued)	None	*Temperature ramp at 10°F/minute in argon, stop at 1450°F*	
		Mass change: Trial 1 –6.6% between 212°F and 1452°F; Trial 2 –3.0% between 212°F and 876°F then –9.1% between 876°F and 1451°F; Average –9.4% over entire temperature range	N.A.
		Energy transfer between sample and atmosphere: None detectable	
		Temperature ramp at 50°F/minute in air, stop at 600°F and hold for 24 hours	
		Mass change: Trial 1 –0.68% between 1 hour 36 minutes (1:36) and 8:48; Trial 2 none detectable; Average –0.34%	N.A.
		Energy transfer between sample and atmosphere: None detectable	
		Temperature ramp at 50°F/minute in argon, stop at 600°F and hold for 24 hours	
		Mass change: Trial 1 –0.72% between 2:00 and 6:48; Trial 2 none detectable; Average –0.36%	N.A.
		Energy transfer between sample and atmosphere: None detectable	
		Temperature ramp at 50°F/minute in air, stop at 900°F and hold for 24 hours	
		Mass change: Trial 1 –1.2% between 1:36 and 5:36 then –0.59% between 11:12 and 16:48; Trial 2 none detectable; Average 0.89% over entire time	N.A.
		Energy transfer between sample and atmosphere: None detectable	

(Table 24 continued on next page)

Table 24. Phase II Test Results: Tiolube 614-T9B (DFL Code G) (continued)

Test Name/ JTP Section	Substrate	Results per Trial	Pass/ Fail
Thermal Stability by SDT/3.15 (continued)	None	*Temperature ramp at 50°F/minute in argon, stop at 900°F and hold for 24 hours*	
		Mass change: Trial 1 –3.1% between 1:36 and 24:00; Trial 2 –1.8% between 1:36 and 24:00; Average 2.4%	N.A.
		Energy transfer between sample and atmosphere: None detectable	
		Temperature ramp at 50°F/minute in air, stop at 1200°F and hold for 24 hours	
		Mass change: Trial 1 none detectable; Trial 2 none detectable	N.A.
		Energy transfer between sample and atmosphere: None detectable	
		Temperature ramp at 50°F/minute in argon, stop at 1200°F and hold for 24 hours	
		Mass change: Trial 1 –5.0% between 4:24 and 24:24; Trial 2 –4.0% between 3:12 and 24:24; Average –4.5%	N.A.
		Energy transfer between sample and atmosphere: None detectable	
		Temperature ramp at 50°F/minute in air, stop at 1450°F and hold for 24 hours	
		Mass change: Trial 1 –6.8% between 1:36 and 24:24; Trial 2 –2.5% between 1:36 and 11:36 then –2.2% between 13:36 and 24:24; Average -5.7% over entire time	N.A.
		Energy transfer between sample and atmosphere: None detectable	
		Temperature ramp at 50°F/minute in argon, stop at 1450°F and hold for 24 hours	
		Mass change: Trial 1 –18% between 1:36 and 24:24; Trial 2 –19% between 1:36 and 24:24; Average –18%	N.A.
		Energy transfer between sample and atmosphere: None detectable	

N.A. – Not Applicable
NT – Not Tested

Table 25. Phase II Test Results: X-204 Solid Film Lubricant (DFL Code H)

Test Name/ JTP Section	Substrate	Results per Trial		Pass/ Fail
Elevated Temperature Material Compatibility/ 3.5	AL1c, AL1d, MG, ST3	*400°F ± 5°F* 1 AL1c, 1 AL1d, MG	*For all:* No degradation observed at 500X magnification	Pass
		750°F ± 5°F 1 ST3		
Fluid Resistance/3.7	AL1d, ST9b, TI1a	*Engine Oil*		
		3 AL1d panels, each with no film defects		Pass
		3 ST9b panels, each with minor film removal but no substrate exposure		Pass
		3 TI1a panels, each with minor film removal but no substrate exposure		Pass
		Anti-Icing Fluid		
		3 AL1d panels, each with minor film removal but no substrate exposure		Pass
		3 ST9b panels, each with minor film removal but no substrate exposure		Pass
		3 TI1a panels, each with exposed substrate		Fail
		JP-5 Fuel		
		3 AL1d panels, each with minor film removal but no substrate exposure		Pass
		3 ST9b panels, each with minor film removal but no substrate exposure		Pass
		3 TI1a panels, two with minor film removal but no substrate exposure, one with exposed substrate		Fail
		JP-8 Fuel		
		3 AL1d panels, each with minor film removal but no substrate exposure		Pass
		3 ST9b panels, each with minor film removal but no substrate exposure		Pass
		3 TI1a panels, each with exposed substrate		Fail

(Table 25 continued on next page)

Table 25. Phase II Test Results: X-204 Solid Film Lubricant (DFL Code H) (continued)

Test Name/ JTP Section	Substrate	Results per Trial	Pass/ Fail
Fluid Resistance/3.7 (continued)	AL1d, ST9b, TI1a	*Distilled H_2O*	
		3 AL1d panels, each with some discoloration apparently caused by aluminum corrosion and minor film removal but no substrate exposure	N.C.
		3 ST9b panels, each with minor film removal but no substrate exposure	Pass
		3 TI1a panels, each with exposed substrate	Fail
		Skydrol	
		3 AL1d panels, each with minor film removal but no substrate exposure	Pass
		3 ST9b panels, each with minor film removal but no substrate exposure	Pass
		3 TI1a panels, each with exposed substrate	Fail
		Damping Fluid	
		3 AL1d panels, each with minor film removal but no substrate exposure	Pass
		3 ST9b panels, each with minor film removal but no substrate exposure	Pass
		3 TI1a panels, each with exposed substrate	Fail
		Substitute Ocean Water	
		3 AL1d panels, each with minor film removal but no substrate exposure	Pass
		3 ST9b panels, each with minor film removal but no substrate exposure	Pass
		3 TI1a panels, each with exposed substrate	Fail
		Hydraulic Fluid	
		3 AL1d panels, each with minor film removal but no substrate exposure	Pass
		3 ST9b panels, each with minor film removal but no substrate exposure	Pass
		3 TI1a panels, each with exposed substrate	Fail
		Overall	**Fail**

(Table 25 continued on next page)

Table 25. Phase II Test Results: X-204 Solid Film Lubricant (DFL Code H) (continued)

Test Name/ JTP Section	Substrate	Results per Trial		Pass/ Fail
Stress Corrosion/ 3.12	TI1a, TI1b, TI2	3 TI1a panels, 2 TI1b panels, 3 TI2 panels	*For all*: No cracking observed at 500X magnification	Pass
Thermal Shock Stability/3.14	TI1b	*600°F ± 10°F* 1 TI1b panel with adhesion failure		Fail
Thermal Stability by SDT/3.15	None	*Temperature ramp at 10°F/minute in air, stop at 900°F*		
		Mass change: Trial 1 –4.6% between 598°F and 894°F; Trial 2 –5.2% between 553°F and 903°F; Average –4.9%		N.A.
		Energy transfer between sample and atmosphere: Trial 1 inflection at 393°C (739.4°F); Trial 2 inflection at 391°C (735.8°F); inflections within drift of instrument and therefore not quantifiable		
		Temperature ramp at 10°F/minute in argon, stop at 900°F		
		Mass change: Trial 1 +4.6% between 95°F and 661°F; Trial 2 +3.6% between 95°F and 661°F; Average +4.1%		N.A.
		Energy transfer between sample and atmosphere: None detectable		
		Temperature ramp at 50°F/minute in air, stop at 600°F and hold for 24 hours		
		Mass change: Trial 1 –3.3% between 1 hour 36 minutes (1:36) and 24:00; Trial 2 –3.9% between 1:36 and 24:00; Average –3.6%		N.A.
		Energy transfer between sample and atmosphere: None detectable		

(Table 25 continued on next page)

Table 25. Phase II Test Results: X-204 Solid Film Lubricant (DFL Code H) (continued)

Test Name/ JTP Section	Substrate	Results per Trial	Pass/ Fail
Thermal Stability by SDT/3.15 (continued)	None	*Temperature ramp at 50°F/minute in argon, stop at 600°F and hold for 24 hours*	
		Mass change: Trial 1 –4.1% between 1:36 and 24:00; Trial 2 –3.7% between 1:36 and 24:00; Average –3.9%	N.A.
		Energy transfer between sample and atmosphere: None detectable	
		Temperature ramp at 50°F/minute in air, stop at 900°F and hold for 24 hours	
		Mass change: Trial 1 –10.2% between 1:36 and 24:00; Trial 2 –23% between 1:36 and 24:00; Average –17%	N.A.
		Energy transfer between sample and atmosphere: Trial 1 inflections at 3:19 and at 9:32, "valley" (exothermic reaction) between 17:26 and 18:39; Trial 2 "valleys" between 5:56 and 7:32 and between 7:32 and 8:53; inflections and "valleys" within drift of instrument and therefore not quantifiable	
		Temperature ramp at 50°F/minute in argon, stop at 900°F and hold for 24 hours	
		Mass change: Trial 1 +0.41% between 1:36 and 3:12 then –3.1% between 3:12 and 24:00; Trial 2 –2.2% between 1:36 and 16:48 then +0.51% between 16:48 and 20:48 then –0.60% between 20:48 and 24:00; Average –2.5% over entire time	N.A.
		Energy transfer between sample and atmosphere: Trial 1 inflection at 3:36; Trial 2 inflection at 3:05; inflections within drift of instrument and therefore not quantifiable	

N.A. – Not Applicable
NT – Not Tested
N.C. – Not Clear, no pass/fail decision made

Table 26. Phase II Test Results: Experimental Control DFL (DFL Code J)

Test Name/ JTP Section	Substrate	Results per Trial	Pass/ Fail
Elevated Temperature Material Compatibility/ 3.5	N.A.	Not tested by decision of participants	NT
Fluid Resistance/3.7	ST10, TI1a	*Engine Oil*	
		3 ST10 panels, two with no film defects, one with exposed substrate	Fail
		3 TI1a panels, two with no film defects, one with exposed substrate	Fail
		Anti-Icing Fluid	
		3 ST10 panels, each with minor film removal but no substrate exposure	Pass
		3 TI1a panels, each with minor film removal but no substrate exposure	Pass
		JP-5 Fuel	
		3 ST10 panels, each with minor film removal but no substrate exposure	Pass
		3 TI1a panels, each with exposed substrate	Fail
		JP-8 Fuel	
		3 ST10 panels, each with minor film removal but no substrate exposure	Pass
		3 TI1a panels, each with minor film removal but no substrate exposure	Pass
		Distilled H_2O	
		3 ST10 panels, each with minor film removal but no substrate exposure	Pass
		3 TI1a panels, each with minor film removal but no substrate exposure	Pass
		Skydrol	
		3 ST10 panels, one with minor film removal but no substrate exposure, two with exposed substrate	Fail
		3 TI1a panels, one with minor film removal but no substrate exposure, two with exposed substrate	Fail

(Table 26 continued on next page)

Table 26. Phase II Test Results: Experimental Control DFL (DFL Code J) (continued)

Test Name/ JTP Section	Substrate	Results per Trial	Pass/ Fail
Fluid Resistance/3.7 (continued)	ST10, TI1a	*Damping Fluid*	
		3 ST10 panels, each with exposed substrate	Fail
		3 TI1a panels, each with exposed substrate	Fail
		Substitute Ocean Water	
		3 ST10 panels, each with minor film removal but no substrate exposure	Pass
		3 TI1a panels, each with minor film removal but no substrate exposure	Pass
		Hydraulic Fluid	
		3 ST10 panels, each with exposed substrate	Fail
		3 TI1a panels, each with minor film removal but no substrate exposure	Pass
		Overall	**Fail**
Stress Corrosion/ 3.12	TI1a	3 TI1a panels, no cracking observed at 500X magnification	Pass
Thermal Shock Stability/3.14	ST10, TI1b	*600 °F ± 10 °F*	
		3 ST10 panels, two with no film defects, one with film removal exposing substrate	Pass [a]
		3 TI1b panels, each with no film defects	Pass [a]
		900 °F ± 10 °F	
		3 ST10 panels, two with no film defects, one with film removal exposing substrate	Pass [a]
		Overall	**Pass [a]**

(Table 26 continued on next page)

Table 26. Phase II Test Results: Experimental Control DFL (DFL Code J) (continued)

Test Name/ JTP Section	Substrate	Results per Trial	Pass/ Fail
Thermal Stability by SDT/3.15	None	*Temperature ramp at 10°F/minute in air, stop at 900°F*	
		Mass change: Trial 1 +2.5% between 95°F and 625°F then –8.3% between 679°F and 895°F; Trial 2 +2.1% between 95°F and 454°F then –6.5% between 454°F and 895°F; Average +2.3% then –7.4%	N.A.
		Energy transfer between sample and atmosphere: Trial 1 inflection at 427°C (800.6°F); Trial 2 inflection at 405°C (761.0°F); inflections within drift of instrument and therefore not quantifiable	
		Temperature ramp at 10°F/minute in argon, stop at 900°F	
		Mass change: Trial 1 +5.2% between 95°F and 661°F; Trial 2 none detectable; Average +2.6%	N.A.
		Energy transfer between sample and atmosphere: None detectable	
		Temperature ramp at 50°F/minute in air, stop at 600°F and hold for 24 hours	
		Mass change: Trial 1 –2.6% between 1 hour 36 minutes (1:36) and 24:00; Trial 2 –6.2% between 1:36 and 21:36; Average –4.4%	N.A.
		Energy transfer between sample and atmosphere: None detectable	
		Temperature ramp at 50°F/minute in argon, stop at 600°F and hold for 24 hours	
		Mass change: Trial 1 –2.5% between 1:36 and 20:48; Trial 2 –2.4% between 1:36 and 24:00; Average –2.5%	N.A.
		Energy transfer between sample and atmosphere: None detectable	

(Table 26 continued on next page)

Table 26. Phase II Test Results: Experimental Control DFL (DFL Code J) (continued)

Test Name/ JTP Section	Substrate	Results per Trial	Pass/ Fail
Thermal Stability by SDT/3.15 (continued)	None	*Temperature ramp at 50°F/minute in air, stop at 900°F and hold for 24 hours*	
		Mass change: Trial 1 –16% between 1:36 and 24:00; Trial 2 –5.7% between 1:36 and 5:36 then +2.9% between 5:36 and 21:12; Average –9.2% over entire time	N.A.
		Energy transfer between sample and atmosphere: Trial 1 "valleys (exothermic reactions) at 5:03, 8:55, 9:35, 10:07, and 15:03; Trial 2 "peak" (endothermic reaction) at 3:55; valleys and peaks within drift of instrument and therefore not quantifiable	
		Temperature ramp at 50°F/minute in argon, stop at 900°F and hold for 24 hours	
		Mass change: Trial 1 –2.9% between 1:36 and 24:00; Trial 2 –3.1% between 1:36 and 24:00; Average –3.0%	N.A.
		Energy transfer between sample and atmosphere: Trial 1 inflection at 2:44, "peak" at 6:52; Trial 2 inflection at 2:34, "peak" at 7:23; inflections and peaks within drift of instrument and therefore not quantifiable	

[a] These experimental control specimens coated with lead-containing DFL are the standard against which the nonlead DFL-coated specimens are judged, therefore they "pass" by definition.
N.A. – Not Applicable
NT – Not Tested

Table 27. Phase II Test Results: Experimental Control DFL (DFL Code K)

Test Name/ JTP Section	Substrate	Results per Trial		Pass/ Fail
Elevated Temperature Material Compatibility/ 3.5	N.A.	Not tested by decision of participants		NT
Fluid Resistance/3.7	N.A.	Not tested by decision of participants		NT
Stress Corrosion/ 3.12	TI1a, TI2	3 TI1a panels, 3 TI2 panels	*For all*: No cracking observed at 500X magnification	Pass
Thermal Shock Stability/3.14	N.A.	Not tested by decision of participants		NT
Thermal Stability by SDT/3.15	N.A.	Not tested by decision of participants		NT

N.A. – Not Applicable
NT – Not Tested

Table 28. Phase II Test Results: Uncoated Experimental Control Specimens

Test Name/ JTP Section	Substrate	Results per Trial		Pass/ Fail
Elevated Temperature Material Compatibility/ 3.5	AL1c, AL1d, MG, NI2a, NI3, ST3, ST9b, ST10, TI1a	*400°F ±5°F* 1 AL1c, 1 AL1d, 1 MG, 1 ST10, 1 TI1a	*For all:* No degradation observed at 500X magnification	Pass [a]
		750°F ±5°F 1 ST3, 1 ST10, 1 TI1a		
		1050°F ±5°F 1 ST9b		
		1600°F ±5°F 1 NI2a, 1 NI3		
Fluid Resistance/3.7	N.A.	Not tested by decision of participants		NT

(Table 28 continued on next page)

Table 28. Phase II Test Results: Uncoated Experimental Control Specimens (continued)

Test Name/ JTP Section	Substrate	Results per Trial		Pass/ Fail
Stress Corrosion/ 3.12	TI1a, TI1b, TI2	*No coating (bare panels)*		
		3 TI1a panels, 2 TI1b panels, 3 TI2 panels	*For all*: No cracking observed at 500X magnification	Pass [a]
		Panels dipped in 3% NaCl solution All panels observed at 500X magnification		
		3 TI1a panels, each cracked along tension edge		Pass [a]
		2 TI1b panels, no cracking observed		Fail [b]
		3 TI2 panels, each cracked along tension edge		Pass [a]
Thermal Shock Stability/3.14	N.A.	Not tested by decision of participants		NT
Thermal Stability by SDT/3.15	N.A.	Not tested by decision of participants		NT

[a] These uncoated control specimens are the standard against which the DFL-coated specimens are judged, therefore they "pass" by definition.

[b] It is believed that the residual compressive stress caused by the shot-peening of TI1b specimens prevented stress corrosion cracking.

N.A. – Not Applicable

NT – Not Tested

4.3. Phase III Test Results

After reviewing the results of the Phase II testing, the project participants chose to eliminate DFLs B (Alseal 360), E (Surf-Kote LOB-1800G Class A), and H (X-204 Solid Film Lubricant). Candidate DFLs C' (Everlube 10030), D (Everlube 812), and G (Tiolube 614-T9B) were tested in Phase III, along with DFL J, a lead-containing experimental control DFL. The participants had determined prior to the beginning of testing that experimental control DFL K would not be tested in Phase III.

The Phase III tests were performed at *CTC* in fall of 1999. The results of the Phase III tests are summarized in Table 29 and the individual results for each candidate DFL are reported in Tables 30 through 32. Table 33 contains the results of the evaluation of the experimental control specimens (DFL J).

The three tests included in Phase III are each specific to a limited number of DFL application categories. The application categories to which each test apply are noted in the tables.

It should be noted that the project participants have selected Everlube 812 (DFL Code D) for further testing even though it failed the Sulfurous Acid Salt Spray test (JTP Section 3.13). This exception to the planned testing was made because the project participants reassessed the Sulfurous Acid Salt Spray test, and determined that it is not appropriate to eliminate a candidate DFL from consideration solely because of failure in this test. The project participants decided that it was unreasonable to demand corrosion protection of steel substrates from a nonlead DFL also containing no cadmium or chromium. In actual practice, corrosion-susceptible substrates will probably be treated to protect them from corrosion, and the DFL will not be expected to provide corrosion protection.

Table 29. Phase III Testing Results - Summary

DFL Code	**Test (JTP Section)**		
	3.6 (HS)	3.10 (LG)	3.13 (LG)
C'	Pass	NT	NT
D	NT	Pass	Fail [a]
G	Pass	Fail	Fail
J	NT	Pass	Pass
K	NT	NT	NT

NT = Not Tested

[a] Everlube 812 was selected for further testing in spite of failure in this test.

Table 30. Phase III Test Results: Everlube 10030 (DFL Code C')

Test Name/ JTP Section	Substrate	Results per Trial	Pass/ Fail
Fastener Corrosion/3.6 (HS)	NI2a, NI3, ST9b	*Sodium chloride (NaCl)*	
		1 NI2a nut/bolt, significant corrosion	Pass
		1 NI3 nut/bolt, significant corrosion	Pass
		1 ST9b nut/bolt, corrosion products prevented removal of nut from bolt	Pass
		Sodium sulfate (Na_2SO_4)	
		1 NI2a nut/bolt, significant corrosion	Pass
		1 NI3 nut/bolt, significant corrosion	Pass
		1 ST9b nut/bolt, significant corrosion	Pass
		NaCl and Na_2SO_4	
		1 NI2a nut/bolt, corrosion products prevented removal of nut from bolt	Pass
		1 NI3 nut/bolt, significant corrosion	Pass
		1 ST9b nut/bolt, corrosion products prevented removal of nut from bolt	Pass
		Overall: For each, corrosion no more severe than experimental control	**Pass**
Salt Spray (Fog) Corrosion Resistance/ 3.10 (LG)	N.A.	Not tested by decision of participants	NT
Sulfurous Acid Salt Spray/3.13 (LG)	N.A.	Not tested by decision of participants	NT

N.A. – Not Applicable
NT – Not Tested

Table 31. Phase III Test Results: Everlube 812 (DFL Code D)

Test Name/ JTP Section	Substrate	Results per Trial	Pass/ Fail
Fastener Corrosion/3.6 (HS)	N.A.	Not tested by decision of participants	NT
Salt Spray (Fog) Corrosion Resistance/ 3.10 (LG)	ST10	3 ST10 panels, each no corrosion	Pass
Sulfurous Acid Salt Spray/3.13 (LG)	ST10	3 ST10 panels, each with blistering and staining on bottom quarter of panel and 150–200 corrosion pits	Fail [a]

[a] Everlube 812 was selected for further testing in spite of failure in this test.
N.A. – Not Applicable
NT – Not Tested

Table 32. Phase III Test Results: Tiolube 614-T9B (DFL Code G)

Test Name/ JTP Section	Substrate	Results per Trial	Pass/ Fail
Fastener Corrosion/3.6 (HS)	NI2a, NI3, ST9b	*NaCl*	
		1 NI2a nut/bolt, significant corrosion	Pass
		1 NI3 nut/bolt, corrosion products prevented removal of nut from bolt	Pass
		1 ST9b nut/bolt, bolt disintegrated during attempted removal	Pass
		Na_2SO_4	
		1 NI2a nut/bolt, significant corrosion	Pass
		1 NI3 nut/bolt, corrosion products prevented removal of nut from bolt	Pass
		1 ST9b nut/bolt, corrosion products prevented removal of nut from bolt	Pass
		NaCl and Na_2SO_4	
		1 NI2a nut/bolt, significant corrosion	Pass
		1 NI3 nut/bolt, corrosion products prevented removal of nut from bolt	Pass
		1 ST9b nut/bolt, significant corrosion	Pass
		Overall: For each, corrosion no more severe than experimental control	**Pass**

(Table 32 continued on next page)

Table 32. Phase III Test Results: Tiolube 614-T9B (DFL Code G) (continued)

Test Name/ JTP Section	Substrate	Results per Trial	Pass/ Fail
Salt Spray (Fog) Corrosion Resistance/ 3.10 (LG)	ST10	3 ST10 panels, each with heavy surface corrosion (red rust) and 40–55% of surface pitted	Fail
Sulfurous Acid Salt Spray/3.13 (LG)	ST10	3 ST10 panels, each with heavy surface corrosion and over 75% of surface pitted	Fail

N.A. – Not Applicable
NT – Not Tested

Table 33. Phase III Test Results: Experimental Control DFL (DFL Code J)

Test Name/ JTP Section	Substrate	Results per Trial	Pass/ Fail
Fastener Corrosion/3.6 (HS)	N.A.	Not tested by decision of participants	NT
Salt Spray (Fog) Corrosion Resistance/ 3.10 (LG)	ST10	3 ST10 panels, each no corrosion	Pass
Sulfurous Acid Salt Spray/3.13 (LG)	ST10	3 ST10 panels, each no corrosion	Pass

N.A. – Not Applicable
NT – Not Tested

Table 34. Phase III Test Results: Uncoated Experimental Control Specimens

Test Name/ JTP Section	Substrate	Results per Trial	Pass/ Fail
Fastener Corrosion/3.6 (HS)	NI2a, NI3, ST9b	*NaCl*	
		1 NI2a nut/bolt, severe corrosion and nut threads were stripped during removal	Pass [a]
		1 NI3 nut/bolt, severe corrosion products prevented removal of nut from bolt	Pass [a]
		1 ST9b nut/bolt, bolt disintegrated during attempted removal	Pass [a]
		Na_2SO_4	
		1 NI2a nut/bolt, severe corrosion products prevented removal of nut from bolt	Pass [a]
		1 NI3 nut/bolt, severe corrosion products prevented removal of nut from bolt	Pass [a]
		1 ST9b nut/bolt, bolt disintegrated during attempted removal	Pass [a]
Fastener Corrosion/3.6 (HS) (continued)	NI2a, NI3, ST9b	*NaCl and Na_2SO_4*	
		1 NI2a nut/bolt, severe corrosion products prevented removal of nut from bolt	Pass [a]
		1 NI3 nut/bolt, severe corrosion products prevented removal of nut from bolt	Pass [a]
		1 ST9b nut/bolt, severe corrosion and nut threads were stripped during removal	Pass [a]
		Overall	**Pass [a]**
Salt Spray (Fog) Corrosion Resistance/ 3.10 (LG)	N.A.	Not tested by decision of participants	NT
Sulfurous Acid Salt Spray/3.13 (LG)	N.A.	Not tested by decision of participants	NT

[a] These uncoated control specimens are the standard against which the DFL-coated specimens are judged, therefore they "pass" by definition.
N.A. – Not Applicable
NT – Not Tested

5. SUMMARY AND RECOMMENDATIONS

The PEWG is a tri-service forum established to help resolve environmental issues common to aircraft engine users and manufacturers. Rolls-Royce-Allison (formerly Allison Engine Company), AlliedSignal Engines, General Electric Aircraft Engines, and Pratt & Whitney-United Technologies Corporation, participate in PEWG. These four manufacturers apply DFLs to components of aircraft engines to prevent galling, fretting, and seizing at temperatures up to 1400°F. DFLs also aid in assembly of engines by providing lubrication and protecting against nicks and scratches. These DFLs are applied to a wide variety of metal substrates. Many of the DFLs currently used by the PEWG participants contain lead or other materials that cause environmental or health concerns.

The JG-PP and PEWG pursued a joint project to identify and validate more environmentally friendly alternatives to current DFLs. Target hazardous materials in current DFLs include lead, VOCs, antimony, cadmium, and carcinogenic chemicals. A joint group led by JG-PP and PEWG defined critical requirements for alternative DFLs and tests to validate alternative DFLs. These tests are documented in the JTP. The requirements in the JTP were identified for a number of general application categories: low temperature antigalling/antifretting applications (LG), high temperature antigalling/antifretting applications (HG), low temperature antiseizing applications (LS), high temperature antiseizing applications (HS), and short-term assembly aid applications (AD).

Selected alternative DFLs were subjected to tests described in the JTP. Prior to testing, the project participants decided not to pursue validation of any candidates for the AD application category. The project participants also planned to divide the testing into four successive phases, and eliminate some DFLs after each phase. This phased test approach was intended to minimize the cost of validating suitable alternatives. This JTR documents the results of the first three phases of that testing.

Nine candidate DFLs were initially tested for compliance with the requirements defined for LG, LS, HG, and HS application categories. Three candidate DFLs were eliminated after Phase I of testing. Three more were eliminated after Phase II of testing. No candidate DFLs were eliminated after Phase III of testing, leaving three candidate DFLs for testing in Phase IV. The elimination of candidate DFLs through the first three testing phases is summarized in Table 35.

Table 35. Candidate Alternative DFLs

Product	Application Categories				Phase I	Phase II	Phase III
	LG	LS	HG	HS			
Alseal 333					Eliminated	Not tested	Not tested
Alseal 360					Continued	Eliminated	Not tested
E/M-1380B					Eliminated	Not tested	Not tested
Everlube 10030					Continued	Continued	Continued
Everlube 812					Continued	Continued	Continued
Surf-Kote LOB-1800G Class A					Continued	Eliminated	Not tested
Tiolube 29					Eliminated	Not tested	Not tested
Tiolube 614-T9B					Continued	Continued	Continued
X-204 Solid Film Lubricant					Continued	Eliminated	Not tested

It should be noted that the project participants have selected Everlube 812 (DFL Code D) for further testing even though it failed the Sulfurous Acid Salt Spray test (JTP Section 3.13). This exception to the planned testing was made because the project participants reassessed the Sulfurous Acid Salt Spray test, and determined that it is not appropriate to eliminate a candidate DFL from consideration solely because of failure in this test. The project participants decided that it was unreasonable to demand corrosion protection of steel substrates from a nonlead DFL also containing no cadmium or chromium. In actual practice, corrosion-susceptible substrates will probably be treated to protect them from corrosion, and the DFL will not be expected to provide corrosion protection.

In Phase IV, Tiolube 614-T9B from Tiodize Co., Inc. will be tested for compliance with the requirements of the LS, HG, and HS application categories. Everlube 812 will be tested for compliance with the requirements of the LG application category. Everlube 10030 from E/M Corporation will be tested for compliance with the requirements of the HG and HS application categories. The results of the Phase IV testing will be reported in a subsequent JTR.

Users of this JTR should remember that the tests and acceptance criteria in the JTR were defined by the participants in this project for their specific needs. The DFLs that were eliminated during this testing are all suitable for a number of different uses and situations not covered by this testing. Specific interactions between substrates used for this testing and the DFLs tested should not be used to predict the interactions between these DFLs and other substrates.