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

Joint Test Report
PW-R-1-1

for Alternatives to Zinc Chromate Primer for Galvanic Corrosion Protection for Inserts and Fasteners in Aircraft Engines

January 28, 1999

Contract No. DAAA21-93-C-0046
Task No. N.072
CDRL No. A006

Prepared by
National Defense Center for Environmental Excellence (NDCEE)

Operated by Concurrent Technologies Corporation
Engineering and Technical Services for Joint Group on Pollution Prevention (JG-PP) Pilot Projects

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Prepared by:

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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 and Sustainment Pollution Prevention Activity (JASPPA). The structure, format, and depth of technical content of the report were determined by the JASPPA, Government contractors, and other Government technical representatives in response to the specific needs of this project. All test data and analyses were provided by Pratt and Whitney - United Technologies Corporation (P&W – UTC).

We wish to thank the following organizations for their invaluable contributions towards creating this document.

Aeronautical Systems Centers/Acquisition Environmental Management (ASC/EME and ASC/EMV)
Air Force Propulsion Environmental Working Group (PEWG) (chaired by ASC/LPA)
ASC/YF representing F-22
Defense Contract Auditing Agency (DCAA)
Defense Contract Management Command (DCMC)
F119 Program Office
J52 Program Office
Joint Acquisition and Sustainment Pollution Prevention Activity
National Aeronautics and Space Administration (NASA) Kennedy Space Center
Naval Air Systems Command (NASC)
Pratt and Whitney - United Technologies Corporation
San Antonio Air Logistics Center (SA-ALC/LPFE) (F100)
TF30 Program Office
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EXECUTIVE SUMMARY

Galvanic corrosion occurs when two dissimilar metals or alloys contact each other, and the elements of an electrochemical cell are present. Galvanic corrosion has historically been controlled by applying a protective coating, such as a chromate-containing primer, on the surfaces of the parts requiring corrosion protection. Although chromate-containing primers offer significant corrosion protection, the toxicity and suspected carcinogenicity of chromium raises environmental, safety, and health concerns. For this reason, manufacturers have begun to identify and evaluate acceptable alternatives for chromate-containing primers. These alternative technologies commonly generate less pollution than chromate primers, and have fewer associated health and safety risks.

At Pratt and Whitney –United Technologies Corporation (P&W –UTC), West Palm Beach, Florida, a JG-PP project site, chromium contained in zinc chromate primer was identified as a hazardous material (HazMat) of concern, and targeted for elimination or reduction. The zinc chromate primer provides galvanic corrosion protection for internal and external surfaces of aircraft engine components (inserts and fasteners) used in aircraft engines manufactured by P&W –UTC. The substrates protected are primarily aluminum alloys used in F100 engine components and magnesium alloy used in F119 engine components.

The Joint Test Protocol, PW-P-1-1, for Validation of Alternatives to Zinc Chromate Primer for Galvanic Corrosion Protection for Inserts and Fasteners in Aircraft Engines, dated June 20, 1996 (revised May 11, 1998), documents the critical technical and performance requirements that an alternative must satisfy to be qualified. The Potential Alternatives Report, PW-A-1-1, for Alternatives to Zinc Chromate Primer for Galvanic Corrosion Protection for Inserts and Fasteners in Aircraft Engines, dated March 3, 1998, lists the four potential alternative primers that the project technical representatives recommended for testing. The primers included: Alumazite ZDA (Tiodize Co., Inc.), TT-P-645B Zinc Molybdate Primer (Randolph Products Company), TT-P-664D High Solids (Zinc Phosphate) Primer (Randolph Products Company), and ZRC Cold Galvanizing Compound (ZRC Products Company).

P&W –UTC subjected each potential alternative primer to six laboratory-screening tests: substrate coverage, adhesion, limited hot corrosion, salt spray corrosion, water resistance, and fuel/oil resistance. The ZRC Cold Galvanizing Compound failed hot corrosion testing on aluminum (Al) and magnesium (Mg) alloys. The other three potential alternative primers passed laboratory screening and were subjected to Phase I Material Compatibility Testing in accordance with the Joint Test Protocol (JTP). All three potential alternative primers passed Phase I testing (zinc chromate baseline primer failed Phase I Hot Corrosion Testing on nickel alloy Hastelloy X) and were subjected to Phase II Durability and Corrosion Resistance Testing. The Alumazite ZDA primer failed the Salt Quench with Intermediate Heating Test on both Al and Mg alloys and was eliminated from further consideration.

Based on the results of this testing, P&W –UTC concluded that TT-P-664D High Solids (Zinc Phosphate) Primer and TT-P-645B Zinc-Molybdate Primer are both acceptable alternatives to zinc chromate primer, with TT-P-664D being preferred, for providing...
galvanic corrosion protection for inserts and fasteners used in aircraft engines manufactured at P&W –UTC.
1. INTRODUCTION

The Joint Logistics Commanders (JLC) and Headquarters NASA co-chartered the Joint Group on Pollution Prevention (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)/processes at manufacturing, remanufacturing, and sustainment locations.
- Avoid duplication of effort in actions required to reduce or eliminate HazMats through joint service cooperation and technology sharing.

This project was conducted under the auspices of JG-PP. The goal was to eliminate the use of zinc chromate primer for corrosion protection of inserts and fasteners used in aircraft engines manufactured by Pratt and Whitney –United Technologies Corporation (P&W –UTC) at its West Palm Beach, Florida facility.

P&W –UTC uses conventional manual dipping or brushing to apply zinc chromate primer. This primer contains chromium, which was identified as the target HazMat to be eliminated or reduced for the P&W –UTC project. The substrates protected are primarily aluminum alloys used in F100 engine components and magnesium alloy used in F119 engine components.

A Joint Test Protocol (JTP), Joint Test Protocol, PW-P-1-1, for Validation of Alternatives to Zinc Chromate Primer for Galvanic Corrosion Protection for Inserts and Fasteners in Aircraft Engines, dated June 20, 1996 (revised May 11, 1998), was developed for the P&W –UTC project that documents the critical technical and performance requirements that an alternative must satisfy to be qualified. Selected potential alternatives for testing are described in the P&W –UTC Potential Alternatives Report (PAR), Potential Alternatives Report, PW-A-1-1, for Alternatives to Zinc Chromate Primer for Galvanic Corrosion Protection for Inserts and Fasteners in Aircraft Engines, dated March 3, 1998.

This Joint Test Report (JTR) documents the data and results of the testing as well as any test modifications made during the execution of testing on the potential alternative primers. It also identifies any technically acceptable alternatives to the baseline zinc chromate primer. This JTR will be made available as a reference for future pollution prevention efforts by other Department of Defense (DoD) and commercial users to minimize duplication of effort.

Table 1 below lists the target HazMat, process, application, current specifications, affected programs, and candidate parts/substrates included in the scope of this project.
Table 1. P&W –UTC Target HazMat Summary

<table>
<thead>
<tr>
<th>Target HazMat(s)</th>
<th>Current Process(es)</th>
<th>Application(s)</th>
<th>Current Specification(s)</th>
<th>Affected Programs</th>
<th>Affected Parts/Substrates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chromium, as contained in zinc chromate primer</td>
<td>Manual dip or brush coating processes</td>
<td>Galvanic corrosion protection for internal and external surfaces of engine components</td>
<td>AMS 3110&lt;br&gt;MIL-P-7962&lt;br&gt;MIL-P-8585&lt;br&gt;TT-P-1757</td>
<td>Navy: J52, TF30&lt;br&gt;Air Force: F119, F100 (100, 200, 220, 220E, 229)&lt;br&gt;NASA*: SSME&lt;br&gt;Army: N/A</td>
<td>J52: &lt;li&gt;Fuel heater assembly, aluminum alloy&lt;/li&gt;&lt;li&gt;Fuel control, aluminum alloy&lt;/li&gt;&lt;br&gt;F100: &lt;li&gt;Gearbox housing, alloy C355.0-T6P (anodized)&lt;/li&gt;&lt;li&gt;Lubricating oil tank assembly, alloy 6061-0 (heat treated and anodized)&lt;/li&gt;&lt;li&gt;Block grommet clamp, alloy C355.0-T6P (anodized)&lt;/li&gt;</td>
</tr>
</tbody>
</table>

*a NASA has a vested interest in qualifying alternatives to the zinc chromate primer used in galvanic corrosion protection for inserts and fastener applications. However, in NASA’s Space Shuttle Main Engine (SSME) project, this particular primer is not an issue. Therefore, while NASA has taken an active role in the technical decisions made in developing the JTP, it will not rely on the selected replacement primer for its SSME project.*
2. ENGINEERING AND TEST REQUIREMENTS

A joint group led by JG-PP and consisting of technical representatives from P&W -UTC, affected DoD Program Managers, representatives from the Sustainment Community, and other government technical representatives identified application, performance, and operational impact (supportability) requirements. The group then reached consensus on the test procedures, methodologies, and acceptance criteria that alternatives must meet to be deemed technically acceptable. The group also agreed to the sequence in which the tests would be performed.

Tests were conducted in a manner that eliminated duplication and maximized the use of each test specimen. The destructiveness of the tests determined the amount and type of tests run on any one specimen.

The engineering and test requirements for validating alternatives to zinc chromate primer for providing galvanic corrosion protection for aircraft engine inserts and fasteners are summarized in Section 2.1. Also, all modifications to the testing procedures or testing sequence described in the JTP are documented, including rationale for such modifications, in Section 2.2. A test flow diagram illustrating the sequence in which testing was performed is provided in Section 2.3.

2.1. Engineering and Test Requirements Summary

Table 2 lists the engineering and test requirements identified by the JG-PP project participants for validating alternatives to zinc chromate primer. These tests were divided into two testing phases to be performed sequentially: Phase I Material Compatibility Testing and Phase II Durability and Corrosion Resistance Testing. The JTP fully describes the tests comprising each of these two test phases.
<table>
<thead>
<tr>
<th>Engineering Requirement</th>
<th>Test</th>
<th>JTP Section</th>
<th>Acceptance Criteria</th>
<th>Testing Facility</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phase I</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Material Compatibility</td>
<td>Stress Corrosion Cracking</td>
<td>3.1 (a)</td>
<td>Inspect visually or at low magnification: acceptable if no evidence of cracks or breaks in the interior (away from edge) of any test specimen</td>
<td>P&amp;W –UTC West Palm Beach, FL</td>
</tr>
<tr>
<td></td>
<td>• Titanium Alloy</td>
<td>3.1 (b)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Aluminum Alloy</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Hot Corrosion</td>
<td>3.2</td>
<td>Examine metallographically for intergranular attack, intergranular carbide oxidation, and general corrosion at 500x magnification: acceptable if no evidence of attack exceeding 0.0002 inches</td>
<td>P&amp;W –UTC East Hartford, CT</td>
</tr>
<tr>
<td>Phase II</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Durability</td>
<td>Water Resistance/Adhesion</td>
<td>3.3</td>
<td>Inspect visually: acceptable if no peel away of coating from alloy</td>
<td>P&amp;W –UTC West Palm Beach, FL</td>
</tr>
<tr>
<td>Durability</td>
<td>Fuel/Engine Oil Resistance</td>
<td>3.4</td>
<td>Inspect visually: acceptable if no deterioration as compared to similar specimen not immersed and if there is no peel away of coating from alloy</td>
<td>P&amp;W –UTC West Palm Beach, FL</td>
</tr>
<tr>
<td>Corrosion Resistance</td>
<td>Electrochemical Evaluation of Galvanic Protection Capability</td>
<td>3.5</td>
<td>None; documentation of protection and degradation mechanisms based on impedance analysis</td>
<td>P&amp;W –UTC West Palm Beach, FL</td>
</tr>
</tbody>
</table>

(Table 2 continued on next page)
Table 2. Engineering and Test Requirements (Continued)

<table>
<thead>
<tr>
<th>Engineering Requirement</th>
<th>Test</th>
<th>JTP Section</th>
<th>Acceptance Criteria</th>
<th>Testing Facility</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corrosion Resistance</td>
<td>Salt Spray</td>
<td>3.6</td>
<td>Inspect visually: acceptable if no signs of white corrosion after 250 hours of salt exposure time</td>
<td>P&amp;W –UTC West Palm Beach, FL</td>
</tr>
<tr>
<td></td>
<td>• Adjacent Protection</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>− Sheet</td>
<td>3.6.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>− Fitted Block</td>
<td>3.6.1 (a)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Repairability</td>
<td>3.6.1 (b)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>− Sheet</td>
<td>3.6.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>− Fitted Block</td>
<td>3.6.2 (a)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>3.6.2 (b)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Salt Quench with Intermediate Heating</td>
<td>3.7</td>
<td>Inspect visually: acceptable if specimens coated with alternative shows less signs of white corrosion than zinc chromate primer</td>
<td>P&amp;W –UTC West Palm Beach, FL</td>
</tr>
</tbody>
</table>

Joint Test Report
In addition to the engineering and test requirements listed in Table 2, the project technical representatives agreed that laboratory screening of potential alternatives was necessary to identify the most promising alternatives for meeting the requirements of the JTP and eliminate deficient alternatives without going through extensive JTP testing. The screening tests consisted of six tests: coverage, adhesion, substrate compatibility (hot corrosion), corrosion resistance (salt spray), water resistance, and fuel/oil resistance. The results of the laboratory screening tests and JTP tests are presented in Sections 4.1 and 4.2, respectively.

2.2. Test Modifications

In executing some of the tests, P&W –UTC deviated from those procedures described in the Joint Test Protocol for Validation of Alternatives to Zinc Chromate Primer for Galvanic Corrosion Protection for Inserts and Fasteners in Aircraft Engines, dated June 20, 1996 (revised May 11, 1998). The primary differences between the procedures used by P&W –UTC for executing these tests and the procedures described in the JTP consisted of the following:

- Numbers of test specimens
- Test temperatures
- Types test fluids
- Cleaning methods for test specimens.

These procedural deviations were agreed upon by JASPPA and are described in detail in Sections 2.2.1 through 2.2.4 below. Each of these Sections includes a representative description of the original JTP test; a description of the test modification; and the rationale for deviating from the original test procedure. For reference purposes, each test is identified by its corresponding JTP section number.

2.2.1. Modifications to Hot Corrosion Test - JTP Section 3.2

Original Test Procedure

The original JTP procedure instructed that specimens should be exposed for a minimum of eight hours and a maximum of ten hours at the following temperatures:

<table>
<thead>
<tr>
<th>Alloy</th>
<th>Temperature, °F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum alloy 2024-T3</td>
<td>750 ± 5</td>
</tr>
</tbody>
</table>
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<table>
<thead>
<tr>
<th>Material</th>
<th>Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum alloy C355.0-T6P</td>
<td>750 ± 5</td>
</tr>
<tr>
<td>Aluminum alloy 6061-0</td>
<td>750 ± 5</td>
</tr>
<tr>
<td>Magnesium alloy AZ31B-0</td>
<td>750 ± 5</td>
</tr>
<tr>
<td>Steel alloy 4340</td>
<td>750 ± 5</td>
</tr>
<tr>
<td>Steel alloy Greek Ascoloy</td>
<td>1050 ± 5</td>
</tr>
<tr>
<td>Nickel alloy Hastelloy X</td>
<td>1600 ± 5</td>
</tr>
<tr>
<td>Nickel alloy Waspaloy</td>
<td>1600 ± 5</td>
</tr>
<tr>
<td>Cobalt alloy Haynes 188</td>
<td>1600 ± 5</td>
</tr>
</tbody>
</table>

Test Procedure Modifications

P&W –UTC modified this test procedure by reducing the test temperature for aluminum (Al) and magnesium (Mg) alloy test specimens from 750°F to 450°F. The rationale for reducing the test temperature were (a) Al and Mg alloys are not used in aircraft engine applications where temperatures are expected to exceed 450°F and (b) the maximum recommended use temperature for these alloys is significantly lower than 750°F. Therefore, testing these specimens at 450°F was entirely representative of actual engine operating conditions, and therefore appropriate.

2.2.2. Modifications to Fuel/Engine Oil Resistance Test - JTP Section 3.4

The Test Procedure and Test Methodology in Section 3.4 of the JTP stated:

Test Procedure

Test specimens (except for control specimens) shall be totally immersed in JP-5 fuel or synthetic-base aircraft turbine engine lubricating oil for four hours. The coating shall show no deterioration when compared with a control specimen not immersed in fuel or oil, 24 hours after removal from the fuel or oil.

After visual inspection, specimens shall be cleaned with an alkaline cleaner, rinsed in clean, distilled water, and wiped dry with a soft cloth. Immediately thereafter, using a stylus, two parallel scratches, down to metal, shall be made one inch apart on the portion of specimen previously immersed. One minute after removal from water, a one-inch-wide strip of masking tape shall be applied, adhesive side down, across the scratches. The tape shall immediately be pressed down, using two passes of a rubber-covered roller weighing 4.5 pounds. Immediately thereafter, the tape shall be removed in one abrupt motion and the panel
examined for damage, such as removal of primer from the metal.

**Test Methodology**

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Total immersion, 4 hours, room temperature JP-5 fuel Synthetic-base aircraft turbine engine lubrication oil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test Specimens</td>
<td></td>
</tr>
<tr>
<td>Substrates</td>
<td>Aluminum alloy C355.0-T6P; solution and precipitation heat treated; casting Aluminum alloy 6061-0; annealed; sheet and plate Magnesium alloy WE43A-T6; solution and precipitation heat treated; sand casting</td>
</tr>
<tr>
<td>Size of each specimen</td>
<td>3&quot; x 6&quot;, 0.050&quot; thick</td>
</tr>
<tr>
<td>Trials</td>
<td></td>
</tr>
<tr>
<td>Specimens per trial</td>
<td>1 specimen per alloy, uncoated, as controls 3 specimens per each alloy coated per designated alternative 3 specimens per each alloy coated per zinc chromate as reference</td>
</tr>
<tr>
<td>Number of trials</td>
<td>2 trials, one each for synthetic-base aircraft turbine engine lubrication oil and JP-5 fuel to include all alloys, per each alternative</td>
</tr>
<tr>
<td>Pass/Fail Criteria</td>
<td>Inspect visually: acceptable if no deterioration as compared to control specimen not immersed in fuel or oil and if there is no peel away of coating from alloy</td>
</tr>
</tbody>
</table>
Test Procedure Modifications

Several modifications were made to this test involving numbers of test specimens, types of test fluids, and the method used for cleaning test specimens.

P&W –UTC used a total of 24 test specimens to conduct this test (two specimens per primer [four primers] per alloy [three alloys]). Twelve specimens were immersed in jet fuel and another 12 specimens were immersed in engine oil. Three adhesion tests were performed on each test specimen, for a total of 72 adhesion tests. The JTP requirement for this test is three specimens per primer per alloy per trial (two trials), for a total of 72 specimens, 36 specimens each per test fluid. The JTP also requires that one adhesion test be conducted on each test specimen for a total of 72 adhesion tests. By conducting three adhesion tests on each of the 24 test specimens used for this test (48 fewer test specimens than required in the JTP), P&W –UTC maximized the use of each test specimen while still meeting the JTP requirement for 72 adhesion tests.

Due to limited specimen preparation capability, all 72 test specimens originally required for this test could not be prepared in a single batch. The variability associated with preparing several batches of test specimens to obtain 72 test specimens was a concern to P&W –UTC. However, by reducing the total number of test specimens used for this test from 72 to 24 specimens and preparing all 24 test specimens in a single batch, P&W –UTC eliminated this variability.

P&W –UTC changed the type of jet fuel used for conducting immersion testing from JP-5 jet fuel to JP-8 jet fuel. This modification to the JTP procedure was made because JP-8 jet fuel is more commonly used in P&W –UTC aircraft engines, and is more representative of actual engine operating conditions.

Prior to conducting adhesion testing on oil-immersion test specimens, P&W –UTC used the organic solvent hexane to remove residual oil from the surfaces of these specimens. The use of hexane for cleaning test specimens was a modification to the JTP requirement for cleaning test specimens using an alkaline cleaner (the JTP did not call out a specific alkaline cleaner), rinsing in distilled water, and wiping dry. P&W –UTC used hexane for cleaning these specimens because it had previously determined that hexane is a better cleaning agent than alkaline-type cleaners for removing oil from the surfaces of test specimens used for adhesion testing. If the surface of a test specimen used for adhesion testing is not clean and oil-free, poor adhesion can result between the masking tape that is used to conduct the adhesion test and the surface of the test
specimen. If poor adhesion occurs, then the outcome of the adhesion test can be adversely affected.

2.2.3. Modifications to Salt Spray Tests - JTP Section 3.6

Salt spray testing was comprised of two tests: Adjacent Protection and Repairability. During testing, P&W –UTC modified the JTP procedures for these two tests. These modifications primarily involved changes in the physical size of test specimens and the numbers of tests conducted on each test specimen.

The original procedures and modified procedures for these two tests are described below.

2.2.3.1. Adjacent Protection Test– JTP Section 3.6.1

The Test Procedure and Test Methodology in Section 3.6.1 of the JTP stated:

**Test Procedure**

3.6.1(a) Sheet Test: Coated test specimens shall be scribed with an “x” pattern by a carbide tool with scribes approximately 0.015–0.020 inches wide and 0.005 inches deep. Cover back and edges of specimens with vinyl tape. Suspend the specimens in the salt spray chamber between 15° and 30° from the vertical and preferably parallel to the principal direction of horizontal flow of salt fog through the chamber. The specimens shall not contact each other or any metallic material or any material capable of acting as a wick. Each specimen shall be placed so as to permit free settling of fog on all specimens. Salt solution from one specimen shall not drip on any other specimen.

The salt solution shall be 5% by weight NaCl in water and shall have a pH range of 6.5 to 7.2 at a temperature of 95°F. The exposure zone of the salt spray chamber shall be maintained at 95°F. Specimens shall be exposed for a minimum of 250 hours. Additionally, specimens shall be tested up to the time at which the zinc chromate primer reference specimen fails (if greater than 250 hours) or to a maximum of 1,000 hours. Specimens shall be carefully removed from the chamber and gently washed or dipped in
clean running water not warmer than 100°F to remove salt deposits from their surface, and then immediately dried. Drying shall be accomplished with a stream of clean, compressed air. Examine specimens immediately by visually inspecting specimens for white corrosion.

3.6.1(b) Fitted Block Test: Coated test specimen shall be drilled through and a stainless steel or nickel bolt and nut shall be attached through the hole. Scratches shall be scribed in the aluminum block underneath the heads of the bolt and nut with a carbide tool approximately 0.015–0.020 inches wide and 0.005 inches deep. This is to simulate a galvanic cell typical of field damage. Remaining procedure follows that for the above sheet test.

Test Methodology

<table>
<thead>
<tr>
<th>Parameters</th>
<th>3.6.1 (a) Sheet Test</th>
<th>3.6.1 (b) Fitted Block Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parameters</td>
<td>5% by weight NaCl solution, 95°F, test to a minimum of 250 hours; additionally test up to the time at which the zinc chromate primer reference specimen fails (if &gt; 250 hours) or to a maximum of 1,000 hours</td>
<td>5% by weight NaCl solution, 95°F, test to a minimum of 250 hours; additionally test up to the time at which the zinc chromate primer reference specimen fails (if &gt; 250 hours) or to a maximum of 1,000 hours</td>
</tr>
</tbody>
</table>

(Test Methodology continued on next page)
Test Methodology (Continued)

<table>
<thead>
<tr>
<th>Test Specimens</th>
<th>3.6.1 (a) Sheet Test</th>
<th>3.6.1 (b) Fitted Block Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Substrates</td>
<td>Anodized aluminum alloy C355.0-T6P; solution and precipitation heat treated; casting Anodized aluminum alloy 6061-0; annealed; sheet and plate Magnesium alloy WE43A-T6; solution and precipitation heat treated; sand casting</td>
<td>Anodized aluminum alloy C355.0-T6P; solution and precipitation heat treated; casting Anodized aluminum alloy 6061-0; annealed; sheet and plate Magnesium alloy WE43A-T6; solution and precipitation heat treated; sand casting</td>
</tr>
<tr>
<td>Size of each specimen</td>
<td>3” x 6”, 0.050” thick</td>
<td>2” x 2” x 1” block</td>
</tr>
<tr>
<td>Trials</td>
<td>Specimens per trial</td>
<td>Specimens per trial</td>
</tr>
<tr>
<td></td>
<td>3 specimens per alloy coated per designated alternative 3 specimens per alloy coated per zinc chromate as a reference</td>
<td>3 specimens per alloy coated per designated alternative 3 specimens per alloy coated per zinc chromate as a reference</td>
</tr>
<tr>
<td></td>
<td>Number of trials</td>
<td>1 trial, to include all alloys, per alternative</td>
</tr>
<tr>
<td></td>
<td>Pass/Fail Criteria</td>
<td>Inspect visually: acceptable if no signs of white corrosion after 250 hours</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Inspect visually: acceptable if no signs of white corrosion after 250 hours</td>
</tr>
</tbody>
</table>
2.2.3.2. Repairability Test – JTP Section 3.6.2

The Test Procedure and Test Methodology in Section 3.6.2 of the JTP stated:

Test Procedure

*Sheet Test:* Uncoated anodized test specimens shall be scribed with an “x” pattern by a carbide tool with scribes approximately 0.015–0.020 inches wide and 0.005 inches deep. Repair scribes with application of alternative material or zinc chromate reference into cracks. Remaining procedure follows sheet test in Section 3.6.1.

*Fitted Block Test:* Uncoated anodized test specimen shall be drilled through and a stainless steel or nickel bolt and nut shall be attached through the hole. Scratches shall be scribed in the aluminum block underneath the heads of the bolt and nut with a carbide tool approximately 0.015–0.020 inches wide and 0.005 inches deep. Repair scribes with application of alternative material or zinc chromate reference into cracks. This is to simulate a galvanic cell typical of field damage. Remaining procedure follows sheet test in Section 3.6.1.

Test Methodology

<table>
<thead>
<tr>
<th>Parameters</th>
<th>3.6.2 (a) Sheet Test</th>
<th>3.6.2 (b) Fitted Block Test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5% by weight NaCl solution, 95°F, test to a minimum of 250 hours; additionally test up to the time at which the zinc chromate primer reference specimen fails (if &gt; 250 hours) or to a maximum of 1,000 hours</td>
<td>5% by weight NaCl solution, 95°F, test to a minimum of 250 hours; additionally test up to the time at which the zinc chromate primer reference specimen fails (if &gt; 250 hours) or to a maximum of 1,000 hours</td>
</tr>
</tbody>
</table>

(Test Methodology continued on next page)
### Test Methodology (Continued)

<table>
<thead>
<tr>
<th>Test Specimens</th>
<th>3.6.2 (a) Sheet Test</th>
<th>3.6.2 (b) Fitted Block Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Substrates</td>
<td>Anodized aluminum alloy C355.0-T6P; solution and precipitation heat treated; casting</td>
<td>Anodized aluminum alloy C355.0-T6P; solution and precipitation heat treated; casting</td>
</tr>
<tr>
<td></td>
<td>Anodized aluminum alloy 6061-0; annealed; sheet and plate</td>
<td>Anodized aluminum alloy 6061-0; annealed; sheet and plate</td>
</tr>
<tr>
<td></td>
<td>Magnesium alloy WE43A-T6; solution and precipitation heat treated; sand casting</td>
<td>Magnesium alloy WE43A-T6; solution and precipitation heat treated; sand casting</td>
</tr>
<tr>
<td>Size of each specimen</td>
<td>3” x 6”, 0.050” thick</td>
<td>2” x 2” x 1” block</td>
</tr>
<tr>
<td>Trials</td>
<td>3 specimens per alloy repaired per designated alternative</td>
<td>3 specimens per alloy repaired per designated alternative</td>
</tr>
<tr>
<td></td>
<td>3 specimens per alloy repaired per zinc chromate as a reference</td>
<td>3 specimens per alloy repaired per zinc chromate as a reference</td>
</tr>
<tr>
<td>Specimens per trial</td>
<td>1 trial, to include all alloys, per alternative</td>
<td>1 trial, to include all alloys, per alternative</td>
</tr>
<tr>
<td>Number of trials</td>
<td>Inspect visually: acceptable if no signs of white corrosion after 250 hours</td>
<td>Inspect visually: acceptable if no signs of white corrosion after 250 hours</td>
</tr>
</tbody>
</table>

Test Procedure Modifications
P&W –UTC used two sheet specimens per primer per alloy instead of three sheet specimens per primer per alloy, as required in the JTP, for conducting the Adjacent Protection and Repairability Sheet tests. P&W –UTC chose to make two scribes on one sheet specimen of each duplicate pair and one scribe on the second sheet specimen of the pair. This resulted in a total of three scribes per each pair of sheet specimens. By making three scribes per pair of sheet specimens instead of one scribe on each of three triplicate sheet specimens, P&W –UTC was able to eliminate the third sheet specimen from each of these tests, thus reducing the number of specimens to be tested.

P&W –UTC conducted the Adjacent Protection and Repairability Fitted Block tests using a total of 12 (6” x 2” x 1.6”) fitted block test specimens, which was a modification to the JTP. The JTP required 36 (2” x 2” x 1”) fitted block specimens for conducting the Adjacent Protection Fitted Block Test and another 36 (2” x 2” x 1”) fitted block specimens for conducting the Repairability Fitted Block Test. The rationale for modifying the JTP was that the number of fitted block specimens required for conducting these tests could be reduced by using larger fitted block test specimens that allowed the Adjacent Protection and Repairability Fitted Block tests to be conducted simultaneously on the same test specimens.

P&W –UTC applied a protective Tagnite/Rockhard coating to each magnesium alloy test specimen before applying the alternative primer, per P&W –UTC specification PWA 36490. The JTP did not specify a protective coating for magnesium alloy test specimens. However, magnesium alloy is very prone to salt spray corrosion and P&W –UTC reasoned that, without a protective coating, the magnesium test specimens would corrode significantly in less than four hours of salt spray exposure.

2.2.4. Modifications to Salt Quench with Intermediate Heating Test - JTP Section 3.7

Section 3.7 of the JTP stated:

**Test Procedure**

Heat test specimens to 300°F. Spray specimens with artificial seawater and place in closed container for one week. Remove specimens from container and heat to 450°F and maintain for 20 hours. Re-heat test specimens to 300°F. Spray specimens with artificial seawater and place in closed container for one week. Remove test specimens and examine for signs of white corrosion.
Test Methodology

### Parameters

| Preheating to 300°F, artificial seawater, closed container for 1 week, immediate heating at 450°F for 20 hours, and reheating to 300°F, artificial seawater, closed container for 1 week |

### Test Specimens

#### Substrates

- Aluminum alloy C355.0-T6P; solution and precipitation heat treated; casting
- Aluminum alloy 6061-0; annealed; sheet and plate
- Magnesium alloy WE43A-T6; solution and precipitation heat treated; sand casting

#### Size of each specimen

| 3” x 6”, 0.050” thick |

### Trials

#### Specimens per trial

- 3 specimens per alloy coated per designated alternative
- 3 specimens per alloy coated per zinc chromate as a reference

#### Number of trials

| 1 trial, to include all alloys, per alternative |

#### Pass/Fail Criteria

| Inspect visually: acceptable if specimens coated with alternative shows less signs of white corrosion than zinc chromate primer |

### Unique Equipment and Instrumentation

- Air-circulating oven capable of maintaining 450°F for 20 hours

### Data Analysis

- Inspect test specimens visually. Compare test specimens coated with alternative material to reference specimens coated with zinc chromate primer. Acceptable if specimens coated with the alternative show less signs of white corrosion than zinc chromate primer.

### Test Procedure Modifications
Two modifications were made to this test. The first modification involved lowering the test temperature from 450°F to 400°F. Lowering the test temperature was necessary because all primer coatings on the original 36 test specimens were destroyed (thermally oxidized) when the specimens were heated to 450°F. Zinc chromate and Alumazite ZDA primers were oxidized to a greater extent than the other primers. Subsequent testing by P&W –UTC showed that primer coatings began to thermally oxidize at 425°F, but showed little sign of thermal oxidation at 400°F. The results of the initial test were disregarded and a second test was conducted at the lower temperature.

The other test modification involved reducing the numbers of test and reference specimens used in the second test from three each test and reference specimens per alloy per primer as required by the JTP, to one each test and reference specimen per alloy per primer. Reducing the numbers of specimens used in the second test was necessary because none of the original 36 test specimens that were destroyed during the initial test were suitable for reuse and there were insufficient numbers of spare test specimens available to replace them. The decision to reduce the numbers of test specimens also took into consideration that two JTP tests, other than the Salt Quench with Intermediate Heating Test, were planned for evaluating corrosion resistance of alternative primers. The other two corrosion resistance tests were Electrochemical Evaluation of Galvanic Protection Capability Test (JTP Section 3.5) and Salt Spray Test (JTP Section 3.6). Therefore, reducing the numbers of specimens used in the Salt Quench with Intermediate Heating Test would not negatively affect the overall evaluation of corrosion resistance of alternative primers. Furthermore, reducing the numbers of specimens used in this test increased the likelihood that the testing schedule would not be delayed. If the numbers of test specimens had not been reduced, preparation of additional specimens would have been required and this would have delayed completing the testing by several weeks.

Prior to proceeding with the modified Salt Quench with Intermediate Heating Test, P&W –UTC requested and received written approval from government technical representatives allowing it to proceed.

2.3. Test Flow Diagram

The following test flow diagram (Figure 1) illustrates the order in which the tests identified in Section 2 were performed. The purpose of the laboratory screening effort was to eliminate any unsuitable alternatives, thereby ensuring that only the most promising alternatives were selected for validation testing. Alternatives that passed the laboratory screening tests were then subjected to Phase I Material
Compatibility Testing, and subsequently to Phase II Durability and Corrosion Resistance Testing in accordance with the JTP.

Figure 1. Flow Diagram for Testing Alternatives to Zinc Chromate Primers
3. ALTERNATIVES TESTED

Initially, 18 candidate alternatives were identified for replacing zinc chromate primer through a technology survey consisting of literature searches and direct vendor queries. The technical information and other data gathered on these candidate alternatives are documented in the project’s PAR, Potential Alternatives Report, PW-A-1-1, for Alternatives to Zinc Chromate Primer for Galvanic Corrosion Protection for Inserts and Fasteners in Aircraft Engines, dated March 3, 1998.

The project technical representatives selected seven of the candidate alternatives as technically viable alternatives based on available information. These seven viable alternatives were 02-W-38 (Deft Inc.), Alumazite ZDA (Tiodize Co., Inc.), EEAE136 A/B (Spraylat Corporation), PR-1875-C (Courtaulds Aerospace, Inc.), TT-P-664D High Solids (Zinc Phosphate) Primer (Randolph Products Company), TT-P-645B Zinc Molybdate Primer (Randolph Products Company), and ZRC Cold Galvanizing Compound (ZRC Products Company). The environmental, safety, and occupational health (ESOH) characteristics of these viable alternatives were evaluated and documented in the PAR. In addition, the key process characteristics of these viable alternatives were compared to those of the existing process. The project technical representatives selected four of the seven viable alternatives as potential alternatives for laboratory screening tests.

The four potential alternatives selected for laboratory screening are shown in Table 3.

Table 3. Potential Alternatives Selected for Laboratory Screening Tests

<table>
<thead>
<tr>
<th>Product</th>
<th>Manufacturer/Developer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alumazite ZDA</td>
<td>Tiodize Co., Inc.</td>
</tr>
<tr>
<td>TT-P-645B Zinc Molybdate Primer</td>
<td>Randolph Products Company</td>
</tr>
<tr>
<td>TT-P-664D High Solids (Zinc Phosphate) Primer</td>
<td>Randolph Products Company</td>
</tr>
<tr>
<td>ZRC Cold Galvanizing Compound</td>
<td>ZRC Products Company</td>
</tr>
</tbody>
</table>

Three of the four potential alternatives passed laboratory screening testing and were subjected to Phase I and Phase II testing in accordance with the JTP.

Table 4 lists the three potential alternatives subjected to the JTP tests.
Table 4. Potential Alternatives Selected for JTP Tests

<table>
<thead>
<tr>
<th>Product</th>
<th>Manufacturer/Developer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alumazite ZDA</td>
<td>Tiodize Co., Inc.</td>
</tr>
<tr>
<td>TT-P-645B Zinc Molybdate Primer</td>
<td>Randolph Products Company</td>
</tr>
<tr>
<td>TT-P-664D High Solids (Zinc Phosphate) Primer</td>
<td>Randolph Products Company</td>
</tr>
</tbody>
</table>
4. TEST RESULTS

The results of laboratory screening tests and the JTP tests are discussed in Sections 4.1 and 4.2, respectively. Three of the four potential alternatives subjected to laboratory screening testing passed, and were further subjected to Phase I Material Compatibility Testing and subsequently to Phase II Durability and Corrosion Resistance Testing in accordance with the JTP.

4.1. Laboratory Screening Tests Results

Laboratory screening consisted of six tests: coverage, adhesion, substrate compatibility (hot corrosion), corrosion resistance, water resistance, and fuel/oil resistance. Based on the results of the screening tests, three potential alternatives passed and were selected for Phase I Material Compatibility Testing in accordance with the JTP: Alumazite ZDA, TT-P-645B Zinc Molybdate Primer, and TT-P-664D High Solids (Zinc Phosphate) Primer. ZRC Cold Galvanizing Compound failed the hot corrosion test, and was eliminated from further testing.

Table 5 lists the objective of each laboratory screening test, a summary of the test procedure, and the test results.
Table 5. Results of Laboratory Screening Tests on Potential Alternatives

<table>
<thead>
<tr>
<th>Screening Test</th>
<th>Objective</th>
<th>Test Procedure Summary</th>
<th>Test Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Substrate Coverage (with spray and brush applications)</td>
<td>To evaluate coverage capability of alternatives on flat Al 6061-0 test specimen and fastener.</td>
<td>Spray alternatives, including zinc chromate (baseline), on vapor blasted Al 6061-0 test specimen. Brush alternatives and baseline material on fasteners.</td>
<td>All four alternatives passed substrate coverage testing. No difficulties in spraying or brushing were observed. Coverage on flat and threaded area was acceptable. No delamination, pinholes, cracking, or exposed substrate anomalies were observed.</td>
</tr>
<tr>
<td>Adhesion</td>
<td>To determine adhesion of alternatives to substrate by dry tape test.</td>
<td>Conduct tape test on Al 6061-0 test specimens sprayed with each alternative using one-inch wide, 3M™ tape.</td>
<td>All four alternatives passed dry tape test indicating adequate adhesion of alternative coatings to substrate.</td>
</tr>
<tr>
<td>Limited Hot Corrosion</td>
<td>To determine compatibility of alternatives to Al and Mg alloys.</td>
<td>Conduct hot corrosion per JTP on Al alloys 6061 and 2024 and Mg alloy AZ31B. Apply alternatives to alloy test specimens and expose to 450°F for 8-10 hours and conduct metallurgical exam at 500x magnification.</td>
<td>Except for ZRC Cold Galvanizing Compound, all alternatives passed hot corrosion testing. ZRC Cold Galvanizing Compound attacked all alloys well beyond 0.0002 inch and caused alloy degradation of 0.0016 inch.</td>
</tr>
<tr>
<td>Salt Spray Corrosion</td>
<td>To determine galvanic corrosion resistance capability of alternatives.</td>
<td>Conduct salt spray corrosion test using Mg alloy WE43A-T6 fitted block and anodized (per AMS 2470) Al (C355-0) fitted block for up to 250 hours exposure time.</td>
<td>All four alternatives passed salt spray testing, providing adequate corrosion resistance up to 260 hours on anodized Al alloy. Only TT-P-645B, provided corrosion resistance comparable to zinc chromate close to 250 hours on Mg alloy.</td>
</tr>
<tr>
<td>Water Resistance</td>
<td>To determine water resistance capability of alternatives.</td>
<td>Immerse Al 6061-0 test specimens, sprayed with alternatives, in room temperature DI water for four days and record condition of coatings.</td>
<td>All four alternatives passed water resistance testing. No delamination, lifting, or cracking of coatings was observed.</td>
</tr>
<tr>
<td>Fuel/Oil Resistance</td>
<td>To determine fuel and oil resistance capability of alternatives.</td>
<td>Immerse Al 6061-0 test specimens, sprayed with alternatives, in JP-8 fuel and MIL-L-7808K oil for four hours and record condition of coatings.</td>
<td>All four alternatives passed fuel/oil resistance testing. No delamination, lifting, or cracking of coatings was observed.</td>
</tr>
</tbody>
</table>
4.2. **JTP Tests Results**

The tests specified in the JTP were divided into two testing phases, Phase I Material Compatibility and Phase II Durability and Corrosion Resistance, performed sequentially. The three potential alternatives that passed laboratory screening tests (Alumazite ZDA, TT-P-645B Zinc Molybdate Primer, and TT-P-664D High Solids (Zinc Phosphate) Primer) were first subjected to Phase I testing. As discussed in this section, all three potential alternatives successfully passed Phase I testing and were further subjected to Phase II testing. The results of the Phase I and Phase II testing are reported below.

4.2.1. **Phase I Material Compatibility**

During Phase I testing, each of the three potential alternatives were subjected to two material compatibility tests, Stress Corrosion Cracking and Hot Corrosion. Both of these tests are fully described in the JTP. Any modifications from the JTP requirements were identified and documented in Section 2.2 of this JTR.

4.2.1.1. **Stress Corrosion Cracking Tests– JTP Section 3.1**

Stress corrosion cracking tests were conducted on titanium (Ti) alloy 8-1-1 and Al 7075-T6 alloy test specimens. Zinc chromate primer was used as a baseline against which potential alternative primers Alumazite ZDA, TT-P-645B Zinc Molybdate Primer, and TT-P-664D High Solids (Zinc Phosphate) Primer were compared. Each primer was applied to Ti and Al alloy test specimens (two test specimens per alloy per primer). The primer coatings were air dried then cured at 180°F. The coated specimens were inserted into a two-point bend specimen holder to achieve a 60 thousand pound per square inch (60 ksi) stress on Ti alloy test specimens and a 51 ksi stress on Al alloy test specimens. The Ti alloy test specimens were tested for 100 hours at a temperature of 900°F and Al alloy test specimens were tested for 250 hours at a temperature of 425°F. Uncoated Ti specimens and Ti specimens coated with three percent sodium chloride solution were used as control specimens for Ti alloy test specimens. Uncoated Al specimens were used as control specimens for Al alloy test specimens. After heat exposure, test specimens were processed to remove the residual coating for ease of inspection for cracks in the substrate. Specimens were inspected visually at 10x magnification. No cracks were detected in any of the test specimens, indicating that these alternative primers are compatible with the alloys tested and therefore meet the acceptance criteria defined in the JTP.
4.2.1.2. Hot Corrosion Test – JTP Section 3.2

Hot corrosion testing was conducted on nine different metal alloys as specified in the JTP. Each primer, including zinc chromate primer as a reference, was applied to one test specimen per alloy. Coatings were air cured then dried under heat lamps. The coated specimens were then exposed to specified test temperatures for eight hours. One uncoated specimen per alloy served as a control specimen.

After heat exposure, all coated specimens were processed for metallographic examination at 500x magnification. Coated specimens were compared with uncoated control specimens for intergranular attack (IGA) and surface degradation beyond 0.0002 inch. No IGA was detected and no degradation beyond 0.0002 inch was observed, indicating that the potential alternative primers are compatible with the alloys tested and therefore meet the acceptance criteria defined in the JTP.

The zinc chromate primer reference specimen failed hot corrosion testing on Hastelloy X with substrate degradation of 0.0007 inch, exceeding the 0.0002-inch limit.

4.2.1.3. Phase I Test Results Summary

Phase I Material Compatibility Testing, consisting of Stress Corrosion Cracking and Hot Corrosion Testing, was used to evaluate material compatibility of potential alternative primers with various metal alloy substrates as specified in the JTP. All three potential alternative primers tested in Phase I passed both Stress Corrosion Cracking and Hot Corrosion Testing and were accepted for Phase II Durability and Corrosion Resistance Testing. Table 7 lists the results of Phase I testing.
Table 6. Phase I Material Compatibility Testing Results

<table>
<thead>
<tr>
<th>Phase I Material Compatibility Tests</th>
<th>Baseline Primer Zinc Chromate</th>
<th>Potential Alternatives Alumazite ZDA</th>
<th>Potential Alternatives TT-P-645B</th>
<th>Potential Alternatives TT-P-664D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stress Corrosion Cracking (Titanium 8-1-1 Alloy)</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>P</td>
</tr>
<tr>
<td>Stress Corrosion Cracking (Aluminum 7075-T6 Alloy)</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>P</td>
</tr>
<tr>
<td>Hot Corrosion (Nine alloys tested a)</td>
<td>F b</td>
<td>P</td>
<td>P</td>
<td>P</td>
</tr>
</tbody>
</table>

a See Section 2.2.1
b Zinc chromate reference specimen failed hot corrosion testing on Hastelloy X with substrate degradation of 0.0007 inches, exceeding the JTP acceptance criteria of not greater than 0.0002 inch and passed on the other eight alloys tested.

F = Fail
P = Pass

4.2.2. Phase II Durability and Corrosion Resistance

Phase II Durability and Corrosion Resistance Testing was conducted on each of the three potential alternative primers that passed Phase I Material Compatibility Testing. Each of the eight tests comprising Phase II testing (see Table 2, Engineering and Test Requirements) is fully described in the JTP. Any modifications from the JTP requirements were identified and documented in Section 2.2 of this JTR.

4.2.2.1. Water Resistance/Adhesion Test – JTP Section 3.3

Water resistance/adhesion testing was conducted on 3”x 6”x 0.05” test specimens sprayed with alternative primers and baseline zinc chromate primer. Each primer was applied to three test specimens of each alloy at a coating thickness of 1 mil to 1.5 mils. Al alloys (6061-0 and C355-T6P) and Mg alloy (WE43A-T6) specimens were vapor blasted and acetone wiped prior to primer application. No other surface treatment was performed on the test specimens such as anodizing of aluminum or protective Tagnite/Rockhard coating over magnesium, as is normally done by P&W – UTC on these alloys, because the JTP did not specify additional surface treatments. Test specimens were immersed in 120°F deionized water for four days. After immersion, the specimens were allowed to dry out and adhesion testing (three tests per specimen) was conducted.

All three potential alternative primers and zinc chromate baseline primer exhibited peel away (removal of coating from substrate) on Mg alloy test
specimens. In addition, except for Alumazite ZDA, the alternative primers and the zinc chromate baseline primer exhibited peel away on Al alloy test specimens. All three alternative primers exhibited substantially less peel away on all alloys tested than did the zinc chromate baseline primer.

Since peel away occurred to some extent on all test specimens, with the exception of Al alloy test specimens coated with Alumazite ZDA, neither the alternative primers nor the zinc chromate primer met the acceptance criteria for this test as defined in the JTP. However, the relative performance of the alternative primers was better than the baseline zinc chromate primer on all alloys tested. In addition, none of the test specimens used in this test received standard P&W –UTC protective coating treatments (anodizing on Al alloys and Tagnite/Rockhard on Mg alloy), because the use of protective coatings was not specified in the JTP for this test. P&W –UTC believes that if standard protective coatings had been applied to these test specimens before applying the primers, peel away of the primer coatings may have been reduced or eliminated.

4.2.2.2. Fuel/Engine Oil Resistance Test – JTP Section 3.4

A total of 24 test specimens, two specimens each per primer (including zinc chromate primer) per alloy, were immersed in JP-8 fuel and MIL-L-7808K oil (12 specimens each per fluid) for four hours. After immersing the specimens in JP-8 fuel, the specimens were placed under an exhaust hood and remained there over the weekend to evaporate the fuel. Oil-immersion specimens were removed from the oil bath and allowed to drain overnight. Residual oil remaining on the surfaces of the specimens was removed by wiping the surfaces of each specimen with hexane.

No substrate exposure was observed after the tape test on the any of the Al alloy test specimens indicating that all primers met the acceptance criteria defined in the JTP. However, substrate exposure was evident on the Mg alloy test specimens for all the primers tested, including the baseline zinc chromate primer. As a result, neither the alternative primers nor the zinc chromate primer met the acceptance criteria for this test as defined in the JTP.

The overall performance of alternative primers was comparable to zinc chromate primer on Mg alloy test specimens. In addition, none of the test specimens used in this test received standard P&W –UTC protective coating treatments (anodizing on Al alloys and Tagnite/Rockhard on Mg alloy), because the use of protective coatings was not specified in the JTP for this test. P&W –UTC believes that if standard protective coatings had
been applied to these test specimens before applying the primers, peel away of the primer coatings may have been reduced or eliminated.

### 4.2.2.3. Electrochemical Galvanic Evaluation of Protection Capability Test - JTP Section 3.5

Al and Mg alloy test specimens, each having surface areas of one square centimeter, were electrically coupled with stainless steel alloy A286 and immersed in artificial seawater. During immersion, the galvanic current of test specimens was monitored for up to eight hours. The Alumazite ZDA primer was not included in this test because it failed the Salt Quench with Intermediate Heating Test on both Al and Mg alloys and was eliminated from further testing.

P&W –UTC used an EG&G Princeton Applied Research Model 273 Potentiostat/Galvanostat (P/G) for all testing and a Schlumberger Model 1255 Frequency Response Analyzer for impedance measurements in conjunction with the P/G.

The impedance corrosion evaluations were done in a cell with a platinum counter electrode. Most of the time a Silver-Silver Chloride reference electrode was used, in some cases a Saturated Calomel electrode was used.

In order to simulate field conditions, P&W –UTC intentionally damaged the coatings (pinhole or scratch down to the substrate) on some of the test specimens to determine corrosion resistance provided by damaged coatings.

The test results showed that Al alloy test specimens coated with either TT-P-645B Zinc-Molybdate Primer or TT-P-664D High Solids (Zinc Phosphate) Primer were more resistant to galvanic corrosion relative to Al alloy test specimens coated with zinc chromate primer.

The results of this testing also showed that Mg alloy test specimens coated with TT-P-645B Zinc-Molybdate Primer were more resistant to galvanic corrosion relative to Mg alloy test specimens coated with zinc chromate primer. However, Mg alloy test specimens coated with TT-P-664D High Solids (Zinc Phosphate) Primer did not perform as well as zinc chromate-coated or zinc molybdate-coated specimens.

P&W –UTC had expected better results from the zinc phosphate primer on this test because it had performed well during salt spray corrosion testing. P&W –UTC suspected that inadequate surface preparation of test specimens prior to coating with zinc phosphate primer was the cause of this
problem. To determine if this was the case, P&W –UTC prepared new zinc phosphate-coated Mg alloy test specimens and performed the test again.

The results of the re-test showed that, for Mg alloy test specimens whose primer coatings were undamaged, corrosion resistance provided by zinc-phosphate primer was equal to or better than corrosion resistance provided by zinc chromate primer. However, for Mg alloy test specimens whose coatings were intentionally damaged by P&W –UTC to simulate field conditions, the zinc phosphate-coated specimens did not perform as well as those specimens coated with zinc chromate primer or zinc molybdate primer.

The laboratory data obtained from both the original tests and the re-tests are included in Appendix A of this report.

4.2.2.4. Salt Spray Tests – JTP Section 3.6

Salt spray testing consisted of two tests, Adjacent Protection and Repairability. The Adjacent Protection Test evaluated primer capability to provide corrosion protection when there is a scratch on a primed area down to the substrate. The Repairability Test evaluated primer capability to provide substrate corrosion protection when a scratch on the substrate is repaired with the primer. Adjacent Protection and Repairability Tests were conducted on both sheet and fitted block test specimens. The fitted block simulates a galvanic cell between two dissimilar metals and evaluates primer capability to provide corrosion protection for fasteners and inserts in a galvanic environment.

Al 6061-0, Al C355-T6P, and Mg WE43A-T6 alloy test specimens were vapor blasted and acetone wiped prior to primer application. Al alloy test specimens were anodized per AMS 2470 and Mg alloy test specimens received protective Tagnite/Rockhard coatings, applied per P&W –UTC specification PWA 36490.

4.2.2.4.1. Adjacent Protection (Sheet) – JTP Section 3.6.1(a)

A total of 24 sheet specimens (3" x 6" x 0.05") were used for Salt Spray Adjacent Protection Tests. Two test specimens per primer (four primers) per alloy (three alloys) were used for each Adjacent Protection and Repairability Test. The entire surface of each test specimen was first sprayed with primer then scratches were made on the coated specimens penetrating through the coating into the substrate. Two scratches were
made on one test specimen and one scratch was made on the second test specimen (total of three scratches on two test specimens). No sign of corrosion was detected on any of the Al 6061-0 and Al C355-T6P alloy test specimens after 250 hours of exposure to salt spray. Salt spray testing continued on these test specimens beyond the 250 hours required per the JTP and no sign of corrosion was observed on any of these specimens after 500 hours of salt spray exposure. All three alternative primers and zinc chromate primer met the JTP acceptance criteria of no visible white corrosion after 250 hours of salt spray exposure for both Al alloys.

Severe white corrosion was observed on Mg alloy test specimens coated with TT-P-645B Zinc Molybdate Primer within 16 hours of exposure to salt spray. No white corrosion was observed on Mg alloy specimens coated with TT-P-664D High Solids (Zinc Phosphate) Primer after 250 hours of salt spray exposure. Mg alloy specimens coated with zinc chromate primer exhibited several spots of white corrosion within 250 hours of salt spray exposure. The relative corrosion resistance provided by Alumazite ZDA was better than corrosion resistance provided by TT-P-645B Zinc Molybdate Primer, but not as good as corrosion resistance provided by either TT-P-664D High Solids (Zinc Phosphate) Primer or zinc chromate primer on Mg alloy specimens.

Alternative primer TT-P-664D High Solids (Zinc Phosphate) Primer was the only primer that provided the required 250 hours of salt spray corrosion resistance on Mg alloy test specimens.

### 4.2.2.4.2. Adjacent Protection Tests (Fitted Block) – JTP Section 3.6.1(b)

Salt spray testing, similar to that conducted on the sheet test specimens, was also conducted using fitted blocks. A total of 12 fitted blocks, four each of Al 6061-0, Al C355-T6P, and Mg WE43A-T6 alloys, were used to evaluate adjacent protection of each primer. The same 12 fitted blocks were also used for repairability evaluation. Each block was 6" x 2" x 1.6" with three holes (at equal distance apart) for installation of inserts and fasteners. Al blocks were anodized per AMS 2470 and Mg blocks had protective Tagnite/Rockhard coating applied per P&W –UTC specification PWA 36490.

An insert, P&W –UTC part # ST 2921-10IC (A286 material with 0.25" inside diameter (ID) and 0.4375" outside diameter (OD)), with primer applied to its outer diameter was installed in each hole in the test block. Primer was applied around one hole in each block for adjacent protection testing (two of the holes in each test block were used for repairability
testing). After the primer cured at room temperature (approximately 68°F to 78°F) overnight, one light scratch penetrating into the primer and one heavy scratch penetrating through the primer and into the block were made (the heavy scratch was made for study purposes and is not representative of actual engine operating conditions). A fastener/washer assembly was then installed in the appropriate insert using 60-70 inch-pound (in-lb) torque.

No sign of white corrosion was observed on any of the Al alloy test blocks after 250 hours of the salt spray exposure, indicating that all three alternative primers met the JTP acceptance criteria for application on Al 6061-0 and Al C355-T6P alloys.

On Mg alloy test blocks, no white corrosion was observed on the light scratch but a significant amount of white corrosion was observed on the heavy scratch for all primers tested including zinc chromate primer within 250 hours of salt spray exposure. The corrosion resistance provided by TT-P-664D High Solids (Zinc Phosphate) Primer was comparable to the corrosion resistance provided by zinc chromate primer on Mg alloy. There was no corrosion noted in the insert and fastener.

4.2.2.4.3. Repairability Tests (Sheet) – JTP Section 3.6.2(a)

A total of 24 sheet specimens (3" x 6" x 0.05") were used for Salt Spray Repairability Tests, two test specimens per primer per alloy. Two scratches were made on one test specimen and one scratch was made on the second test specimen (total of three scratches on two test specimens). Scratches were repaired by applying primer using a cotton swab.

No sign of corrosion was detected on any of the Al 6061-0 and Al C355-T6P alloy test specimens after 250 hours of exposure to salt spray. Salt spray testing continued on these test specimens beyond the 250 hours required in the JTP and no sign of corrosion was observed on any of these specimens after 500 hours of salt spray exposure. All three alternative primers and zinc chromate primer met the JTP acceptance criteria of no white corrosion after 250 hours of salt spray exposure for both Al alloys.

None of the alternative primers provided 250 hours of salt spray corrosion resistance on Mg alloy test specimens. Mg alloy specimens coated with zinc chromate primer exhibited no white corrosion after 250 hours of salt spray exposure. Severe white corrosion was observed on Mg alloy specimens coated with TT-P-645B Zinc Molybdate Primer within 44 hours of exposure to salt spray. A few spots of white corrosion were detected on Mg alloy specimens coated with TT-P-664D High Solids (Zinc Phosphate)
Primer within 250 hours of salt spray exposure. The relative corrosion resistance on Mg alloy specimens provided by Alumazite ZDA was better than the corrosion resistance provided by TT-P-645B Zinc Molybdate Primer, but not as good as the corrosion resistance provided by TT-P-664D High Solids (Zinc Phosphate) Primer.

4.2.2.4.4. Repairability Tests (Fitted Block) – JTP Section 3.6.2(b)

Salt spray testing, similar to that conducted on sheet test specimens, was also conducted using fitted blocks. A total of 12 fitted blocks, four each of Al 6061-0, Al C355-T6P, and Mg WE43A-T6 alloys, were used to evaluate the repairability of each primer. The same 12 fitted blocks were also used for adjacent protection evaluation. Each block was 6" x 2" x 1.6" with three holes (at equal distance apart) for installing inserts and fasteners. Al blocks were anodized per AMS 2470 and Mg blocks had protective Tagnite/Rockhard coating applied per P&W –UTC specification PWA 36490.

An insert, P&W –UTC part # ST 2921-10IC (A286 material with 0.25" ID and 0.4375" OD), with primer applied to its outer diameter was installed in each of the three holes in each test block. Using a carbide tool, a total of three scratches, penetrating through the anodized and/or Tagnite/Rockhard layer into the substrate, were made in each test block. The scratches were located on the blocks so they would be underneath heads of fastener/washer assemblies subsequently installed in two inserts in each block. The scratches were repaired with each primer and cured at room temperature overnight. Primer was also applied to the block under the entire washer face of each installed fastener/washer assembly. Stainless steel fasteners, P&W –UTC part # ST 1315-16 (nickel alloy with 1/4" pitch diameter), with steel washers (A286 material with 0.28" ID, 0.65" OD and 1" thickness) were then installed into two inserts (the remaining insert was used for adjacent protection testing) at 60-70 in-lb torque.

No sign of white corrosion was observed on any repaired Al test blocks after 250 hours of the salt spray exposure, indicating all alternative primers met the JTP acceptance criteria for application on Al 6061-0 and Al C355-T6P alloys. White corrosion was observed near the steel washer within 30 hours of the salt spray exposure on Mg blocks with scratches repaired using TT-P-645B Zinc Molybdate Primer and Alumazite ZDA. After 250 hours, all scratches repaired using TT-P-645B Zinc Molybdate Primer and Alumazite ZDA exhibited significant corrosion.

Corrosion resistance on scratches repaired using TT-P-664D High Solids (Zinc Phosphate) Primer on Mg alloy was comparable to corrosion
resistance provided by zinc chromate primer. At an exposure time of 165
hours, no white corrosion was observed on Mg alloy test blocks with
scratches repaired using either TT-P-664D High Solids (Zinc Phosphate)
Primer or zinc chromate primer. After 187 hours of salt spray exposure,
spots of white corrosion were observed on blocks with scratches repaired
using TT-P-664D High Solids (Zinc Phosphate) Primer. After 216 hours
of exposure, similar spots of white corrosion were observed on blocks with
scratches repaired using zinc chromate primer. The spots of white
corrosion observed on these test blocks were located away from the steel
washers, indicating non-galvanic-type corrosion. No corrosion was noted
in the insert and fastener. No galvanic corrosion (white spots at or near
steel washer) was observed after 250 hours of salt spray exposure for
TT-P-664D High Solids (Zinc Phosphate) Primer or zinc chromate primer.

4.2.2.5. Salt Quench with Intermediate Heating Test – JTP Section 3.7

The Salt Quench with Intermediate Heating Test was conducted using 36
(3" x 6" x 0.05") test specimens (three specimens per alloy per primer)
sprayed with alternative primers and zinc chromate primer. The thickness
range of the primer coatings was 1 mil to 1.5 mils. Al 6061-0, Al
C355-T6P, and Mg WE43A-T6 alloy test specimens were vapor blasted
and acetone wiped prior to primer application. Test specimens were
heated to 300°F in an oven, removed from the oven and then sprayed with
artificial seawater (prepared per ASTM-D-1141). Evaporation of artificial
seawater was observed initially as it was sprayed over the hot test
specimens. Additional artificial seawater was sprayed on the test
specimens to keep them wet. All test specimens were stored in a closed
container for one week. Test specimens were then removed from the
container and heated to 450°F for 20 hours per the JTP. Thermal
oxidation of primers was observed after test specimens were heated to
450°F, so the test was aborted.

The zinc chromate primer appeared to thermally oxidize to a greater extent
(zinc chromate primer color changed from yellow to dark brown) than the
alternative primers. An experiment was conducted to determine the effect
of temperature on the primers. One test specimen of each primer was
gradually heated in an oven to 375°F, 400°F, 425°F, and 450°F. Specimens
were inspected at each temperature for any sign of thermal
oxidation. Thermal oxidation of primers was observed at temperatures of
425°F and above, no significant thermal oxidation of primers was observed
at temperatures of 400°F and below.

The Salt Quench with Intermediate Heating Test was repeated using a total
of 12 test specimens, one specimen per primer per alloy. Each test
specimen was heated to 300°F and sprayed with artificial seawater. Wetted specimens were stored in a closed container for one week. After one week, specimens were removed from the container and heated to 380-400°F for 20 hours. Specimens were cooled to room temperature then reheated to 300°F and sprayed with artificial seawater for the last time. Wetted specimens were stored in a closed container for a week. After one week, test specimens were removed from the container and visually inspected for signs of white corrosion.

The results of this testing showed that alternative primers TT-P-645B Zinc Molybdate Primer and TT-P-664D High Solids (Zinc Phosphate) Primer and the baseline zinc chromate primer met the acceptance criteria for this test as defined in the JTP. Alternative primer Alumazite ZDA did not meet the acceptance criteria for this test. Visual inspection of the Alumazite ZDA test specimens detected cracks in the substrate on the Mg alloy test specimen and minor pitting of the substrate on both Al alloys tested.

4.2.2.6. Phase II Test Results Summary

Phase II testing evaluated durability and corrosion resistance of potential alternative primers on various metal alloy substrates as specified in the JTP. The results of Phase II testing of potential alternative primers are summarized in Table 8.
<table>
<thead>
<tr>
<th>Phase II Durability and Corrosion Resistance Tests</th>
<th>Baseline Primer</th>
<th>Potential Alternatives</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Zinc Chromate</td>
<td>Alumazite ZDA</td>
</tr>
<tr>
<td>Alloy</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mg</td>
<td>Al</td>
<td>Mg</td>
</tr>
<tr>
<td>Salt Spray Adjacent Protection (Sheet)</td>
<td>F</td>
<td>P</td>
</tr>
<tr>
<td>Salt Spray Adjacent Protection (Fitted Block)</td>
<td>P</td>
<td>P</td>
</tr>
<tr>
<td>Salt Spray Repairability (Sheet)</td>
<td>P</td>
<td>P</td>
</tr>
<tr>
<td>Salt Spray Repairability (Fitted Block)</td>
<td>F&lt;sup&gt;a&lt;/sup&gt;</td>
<td>P</td>
</tr>
<tr>
<td>Electrochemical Evaluation of Galvanic Protection Capability&lt;sup&gt;c&lt;/sup&gt;</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Salt Quench with Intermediate Heating</td>
<td>P</td>
<td>P</td>
</tr>
<tr>
<td>Water Resistance/Adhesion</td>
<td>F&lt;sup&gt;e&lt;/sup&gt;</td>
<td>F&lt;sup&gt;e&lt;/sup&gt;</td>
</tr>
<tr>
<td>Fuel Resistance</td>
<td>F&lt;sup&gt;e&lt;/sup&gt;</td>
<td>P</td>
</tr>
<tr>
<td>Engine Oil Resistance</td>
<td>F&lt;sup&gt;e&lt;/sup&gt;</td>
<td>P</td>
</tr>
</tbody>
</table>

<sup>a</sup> White corrosion observed after 216 hours of salt spray exposure
<sup>b</sup> White corrosion observed after 187 hours of salt spray exposure
<sup>c</sup> There are no pass/fail criteria listed in the JTP for this test
<sup>d</sup> Alumazite ZDA failed the Salt Quench with Intermediate Heating Test on both Al and Mg alloys and was eliminated from further testing
<sup>e</sup> Failure contributed to lack of anodizing on Al surface and protective Tagnite/Rockhard coating on Mg surface

Al = Aluminum alloys 6061-0 & C355-T6P
Mg = Magnesium alloy WE43A-T6
NA = Not Applicable
NT = Not Tested
P = Pass
4.2.3. Summary of Phase I and Phase II Testing

Phase I Material Compatibility Testing, consisting of Stress Corrosion Cracking and Hot Corrosion Testing, was used to evaluate material compatibility of potential alternative primers with selected metal alloy substrates. All three alternative primers tested in Phase I passed Stress Corrosion Cracking Tests on Ti alloy 8-1-1 and aluminum alloy 7075-T6 and Hot Corrosion Tests on nine alloys: Al alloys 2024-T3, C355-T6P, and 6061-0; magnesium alloy AZ31B-0; steel alloys 4340 and Greek Ascoloy; nickel (Ni) alloys Hastelloy X and Waspaloy; and cobalt (Co) alloy Haynes 188. The three alternative primers were then subjected to Phase II testing.

Phase II testing evaluated durability and corrosion resistance characteristics of potential alternative primers on selected metal alloy substrates.

Durability testing consisted of two tests, Water Resistance/Adhesion and Fuel/Engine Oil Resistance. Neither the alternative primers nor the zinc chromate baseline primer passed either of these two tests on Mg alloy WE43A-T6. All three alternative primers and the zinc chromate baseline primer passed the Fuel/Engine Oil Resistance Test on Al alloys 6061-0 and C355-T6P. Alumazite ZDA was the only primer, including zinc chromate primer, which passed the Water Resistance/Adhesion Test on Al alloys 6061-0 and C355-T6P. Overall, the durability demonstrated by the three alternative primers on these two tests was equal to or better than zinc chromate primer on all alloys tested.

Corrosion resistance testing consisted of six tests: Salt Quench with Intermediate Heating; Salt Spray Adjacent Protection Sheet; Salt Spray Adjacent Protection Fitted Block; Salt Spray Repairability Sheet; Salt Spray Repairability Fitted Block; Electrochemical Evaluation of Galvanic Protection Capability.

All primers, except Alumazite ZDA, passed all six corrosion resistance tests on Al alloys 6061-0 and C355-T6P. Alumazite ZDA failed the Salt Quench with Intermediate Heating test on both Al and Mg alloys and was eliminated from further testing.

The results of corrosion resistance testing on Mg alloy WE43A-T6 were mixed.

All primers, except Alumazite ZDA, passed the Salt Quench with Intermediate Heating Test on Mg alloy.
Alternative primer TT-P-664D High Solids (Zinc Phosphate) Primer was the only primer that passed the Salt Spray Adjacent Protection Sheet Test on Mg alloy after 250 hours of salt spray exposure.

All primers passed the Salt Spray Adjacent Protection Fitted Block Test on Mg alloy after 250 hours of salt spray exposure.

Only zinc chromate primer passed the Salt Spray Repairability Sheet Test on Mg alloy after 250 hours of salt spray exposure.

The performance of the baseline zinc chromate primer and alternative primer TT-P-664D High Solids (Zinc Phosphate) Primer was comparable on the Salt Spray Repairability Fitted Block Test on Mg alloy.

The results of the Electrochemical Galvanic Evaluation of Protection Capability Test showed that both remaining alternative primers, TT-P-664D and TT-P-645B, (Alumazite ZDA failed the Salt Quench with Intermediate Heating Test and was not tested for electrochemical galvanic corrosion protection) performed as well as or better than the baseline zinc chromate primer on Mg alloy when the coatings were undamaged. However, when the coatings were intentionally damaged, only the TT-P-645B Zinc-Molybdate primer performed as well as zinc chromate primer on Mg alloy.

Overall corrosion test results on Mg alloy were mixed; particularly for repair capability of any primer. Since no corrosion was noted in insert and fastener locations, alternate primers, TT-P-645B and TT-P-664D, are acceptable on Mg alloy. For repairability of Mg alloy, P&W – UTC will use PWA 36490 Rockhard resin over magnesium alloy.

Phase I and Phase II test results for the three potential alternative primers and the zinc chromate baseline primer are tabulated in Table 9.
Table 8. Phase I and Phase II Tests Results

<table>
<thead>
<tr>
<th>Potential Alternative Primer</th>
<th>Phase I Testing</th>
<th>Phase II Testing</th>
<th>Durability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stress Corrosion Cracking</td>
<td>Hot Corrosion</td>
<td>Salt Spray</td>
<td></td>
</tr>
<tr>
<td>Nine Alloys&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Adjacent Protection</td>
<td>Repairability</td>
<td></td>
</tr>
<tr>
<td>Ti 8-1-1 Alloy</td>
<td>Sheet</td>
<td>Sheet</td>
<td></td>
</tr>
<tr>
<td>Al 7075-T6 Alloy</td>
<td>Fitted Block</td>
<td>Fitted Block</td>
<td></td>
</tr>
<tr>
<td>Mg</td>
<td>Al</td>
<td>Mg</td>
<td>Al</td>
</tr>
<tr>
<td>Alumazite ZDA</td>
<td>P</td>
<td>P</td>
<td>P</td>
</tr>
<tr>
<td>TT-P-645B</td>
<td>P</td>
<td>P</td>
<td>P</td>
</tr>
<tr>
<td>TT-P-664D</td>
<td>P</td>
<td>P</td>
<td>P</td>
</tr>
<tr>
<td>ZnCr Primer&lt;sup&gt;d&lt;/sup&gt;</td>
<td>P</td>
<td>P</td>
<td>F&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

**JTP Acceptance Criteria**

- No cracks or breaks
- No cracks or breaks
- No white corrosion
- No white corrosion
- No white corrosion
- No white corrosion
- None, impedance analysis only
- White corrosion < that for reference specimens
- No peel away of coating from surface
- No peel away of coating from surface

- Failure contributed to lack of anodizing on Al surface and protective Tagnite/Rockhard coating on Mg surface
- White corrosion observed after 187 hours of salt spray exposure
- Zinc chromate primer is the baseline primer
- Zinc chromate primer failed hot corrosion testing on Hastelloy X with substrate degradation of 0.0007 inches, exceeding the JTP acceptance criteria of not greater than 0.0002 inch and passed on the other eight alloys tested
- White corrosion observed after 216 hours of salt spray exposure

<sup>a</sup> Aluminum alloys 2024-T3, C355-T6P, and 6061-0; magnesium alloy AZ31B-0; steel alloys 4340 and Greek Ascoloy; nickel alloys Hastelloy X and Waspaloy; and cobalt alloy Haynes 188

<sup>b</sup> Failure contributed to lack of anodizing on Al surface and protective Tagnite/Rockhard coating on Mg surface

<sup>c</sup> White corrosion observed after 187 hours of salt spray exposure

<sup>d</sup> Zinc chromate primer is the baseline primer

<sup>e</sup> Zinc chromate primer failed hot corrosion testing on Hastelloy X with substrate degradation of 0.0007 inches, exceeding the JTP acceptance criteria of not greater than 0.0002 inch and passed on the other eight alloys tested

<sup>f</sup> White corrosion observed after 216 hours of salt spray exposure

<sup>A1</sup> = Aluminum alloys 6061-0 & C355-T6P unless otherwise noted

<sup>Mg</sup> = Magnesium alloy WE43A-T6

<sup>NT</sup> = Not Tested

<sup>NA</sup> = Not Applicable
5.  CONCLUSIONS AND RECOMMENDATIONS

At the P&W –UTC West Palm Beach, Florida, JG-PP project site, chromium, as contained in zinc chromate primer, was identified as a hazardous material of concern, and targeted for elimination or reduction. The zinc chromate primer provides galvanic corrosion protection for aircraft engine components (inserts and fasteners). The substrates protected are primarily aluminum alloys used in F100 engine components and magnesium alloy used in F119 engine components.

The approach for validating potential alternative primers involved identifying alternatives, determining by consensus the performance requirements the alternatives must meet, and testing the alternatives.

The project technical representatives selected four potential alternative primers from an initial list of 18 candidates to undergo laboratory screening tests. Those potential alternatives that passed the screening tests were subjected to Phase I Material Compatibility Testing and Phase II Durability and Corrosion Resistance Testing in accordance with the Joint Test Protocol for Validation of Alternatives to Zinc Chromate primer for Galvanic Corrosion Protection for Inserts and Fasteners in Aircraft Engines, dated June 20, 1996 (revised May 11, 1998).

Based on the results of this testing, P&W –UTC concluded that TT-P-664D High Solids (Zinc Phosphate) Primer and TT-P-645B Zinc-Molybdate Primer are both acceptable alternatives to zinc chromate primer, with TT-P-664D being preferred, for providing galvanic corrosion protection for inserts and fasteners used in aircraft engines manufactured at P&W –UTC.
6. **REFERENCE DOCUMENTS**

All reference documents used to develop descriptions of tests used to execute validation testing are listed in Section 4, Table 3 of the *Joint Test Protocol for Validation of Alternatives to Zinc Chromate primer for Galvanic Corrosion Protection for Inserts and Fasteners in Aircraft Engines*, dated June 20, 1996 (revised May 11, 1998).
APPENDIX A

Laboratory Data for Electrochemical Evaluation of Galvanic Protection Capability
The data contained in this appendix was collected by P&W –UTC during the Electrochemical Evaluation of Galvanic Protection Capability test. The original test data are found on pages A-2 through A-47 and data collected during the re-test are found on pages A-48 through A-53.

The graphs on pages A-2 through A-25 and A-48 plot resistance (ohms) on the y-axis verse frequency in hertz (Hz) on the x-axis. A simple interpretation of this data is that the larger the difference in resistance between the starting point and ending point on each graph the more resistant the material is to corrosion (polarization resistance).

On pages A-26 through A-47 and A-49 through A-53 are graphs plotting current (amp) per unit area (square centimeter) (A/cm\(^2\)) on the y-axis verse time in kiloseconds (Ks) on the x-axis. Those graphs for which the plotted data show a negative slope indicate that the material is stable or tends toward passivity rather than accelerated galvanic corrosion. In addition to slope, the magnitude of the current measurement shown on each graph must be considered in the overall interpretation of the data. The lower the magnitude of the current measurement the more resistant the material is to galvanic corrosion.
Model 398 Electrochemical Impedance Software, v. 1.01
Filename: c:\m398\data\JG-SS81.DAT
Patent: M273 (92,98) Ver 107
Analyzer: M255 Ver 8
SS Single sine EIS 2(f)
Date Run: 01-21-98
Time Run: 10:59:36

Cond. Time CT pass s
Cond. Pot. CP pass V
Initial Delay ID 300 s
Equil. Time ET pass s
DC Potential DC 0.0000 V
No. of Points NP 31

Measure Delay MD pass
Data Quality DQ 1
Working Elec. WE Solid
Elect. Area AR 1.000 cm²
Ref. Elec. RE AgCl 197.0E-3 V
Open Circuit OC -261.0E-3 V

Comment: AMS 4025 (BARE) IN ASTH D1141...OPEN TO AIR...NEW...NO STIR

JG-SS81.DAT
Model 398 Electrochemical Impedance Software, v. 1.01
Filename: c:\m398\data\JG-SS02.DAT
Filestat: M273 192.76 Ver 107
Analyzer: M1253 Var 5
SS Single sine EIS 2(f)
Date Run: 01-22-98
Time Run: 11:49:16
Cond. Time CT pass s Initial Freq. IF 100.0 kHz
Cond. Pot. CP pass V Final Freq. FF 100.0 mHz
Initial Delay ID 30 s Point Spacing PS Log
Equill. Time ET pass s Points/Decade PD 5
DC Potential DC 0.000 V oc No. of Points NP 31
Measure Delay MD pass AC Amplitude AC 5.000 mV rms
Data Quality DQ 1 Curr. Range CR Auto
Working Elec. WE Solid Ref. Elec. RE AgCl 197.0E-3V
Elec. Area AR 1.000 cm² Open Circuit OC -247.0E-3 V

Comment: AMS 4025 (AMS 2470) IN ASTM D1141...OPEN TO AIR...NEW...NO STIR...FLAT CELL

--- JG-SS02.DAT ---

\[ 10^n \]

--- Joint Test Report ---
Joint Test Report
Model 398 Electrochemical Impedance Software. v. 1.01
Filename: c:\398\data\JG-SS03.DAT
File Status: NORMAL
Parameters: M273 (92.96) Ver 107
Analyzer: M275 Ver 8
SS Single sine EIS Z(f)
Data Run: 01-23-98
Time Run: 11:34:11

Cond. Time CT pass
Cond. Pot. CP pass
Initial Delay ID 30
Equil. Time ET pass
DC Potential DC 0.0000 pass

Initial Freq. IF 100.0 kHz
Final Freq. FF 100.0 mHz
Point Specimen PS Log
Points/Decade PD 5
No. of Points NP 31

Measure Delay MD pass
Data Quality DQ 1
AC Amplitude AC 5.000 mV rms
Curr. Range CR Auto

Working Elec. WE Solid
Ref. Elec. RE AgCl 177.0E-3V
Elect. Area AR 1.000 cm²
Open Circuit OC -750.0E-3 V

Comment: ANS 4025 (BARE) IN ASTM D1141...ARGON PURGED...NEW...NO STIR

JG-SS03.DAT

![Graph showing impedance vs frequency]
Model 398 Electrochemical Impedance Software, v. 1.01
Filename: c:\m398\data\JG-MS52.DAT
Path: H:\273 (92.96) Var 197
MS Multi-sine EIS Z(f)
Date Run: 91-26-98
Time Run: 09:34:27
Cond. Time CT pass s Initial Freq. IF 8,850 m Hz
Cond. Pot. CP pass V Final Freq. FF 1,000 Hz
Initial Delay ID 30 s
Equl. Time ET pass s
DC Potential DC 0.0000 V oc No. of Points NP 20
Measure Delay MD pass AC Amplitude AC 5,000 mV rms
Data Quality DQ 2 Curr. Range CR Auto
Working Elec. WE Solid Ref. Elec. RE AgCl 197.0E-3
Elec. Area AR 1.000 cm^2 Open Circuit OC -457.0E-3 V

Comment: AMS 4325 (BARE) IN ASTM D1141...ARGON PURGED...SUPPLEMENT TO JG-SS03C.DAT

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JG-MS52.DAT

![Graph showing frequency response with logarithmic scales for a test result.](image-url)
Model 398 Electrochemical Impedance Software, v. 1.01
Filename: c:\m398\data\JG-SS04.DAT
Patent: M273 (92.96) Ver 107
Analyzer: M1255 Ver 8
SS Single sine EIS Z(f)
Date Run: 01-26-96
Time Run: 11:00:04

Cond. Time CT pass 8 Initial Freq. IF 100.0 K Hz
Cond. Pot. CP pass V Final Freq. FF 100.0 m Hz
Initial Delay ID 30 a Point Spacing PS Log
Equil. Time ET pass a Points/Decade PD 5
DC Potential DC 0.0000 V oc

No. of Points NP 31
AC Amplitude AC 5.000 mV rms
Data Quality DQ 1 Curr. Range CK Auto
Working Elec. WE Solid Ref. Elec. RE AgCl 197.0E-3 V
Elec. Area AR 1.000 cm² Open Circuit OC -775.0E-3 V

Comment: AMS 4215 (DARE) IN ASHT D1141...ARGON PURGED...NEW...LT STIR

---

JG-SS04.DAT

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Joint Test Report
### Joint Test Report

Model 398 Electrochemical Impedance Software, v. 1.01
Filename: c:\m398\data\JG-MS03.DAT
Status: HZ73 [22, 78] Var 107
MS Multi-site EIS Z(f)

#### Data Run: 01-27-98
- **Cond. Time:** CT pass s
- **Cond. Pot:** CP pass V
- **Initial Delay:** ID 0.0000 s
- **Equil. Time:** ET pass s
- **DC Potential:** DC 0.0000 V
- **Measure Delay:** MD pass s
- **Data Quality:** DQ 2
- **Working Elec.:** WE Solid
- **Elect. Area:** AR 1.000 cm²

<table>
<thead>
<tr>
<th>Initial Freq. IF</th>
<th>Final Freq. FF</th>
<th>No. of Points NP</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.050 m Hz</td>
<td>1.000 Hz</td>
<td>20</td>
</tr>
<tr>
<td>AC Amplitude AC</td>
<td>5.000 mV rms</td>
<td></td>
</tr>
<tr>
<td>Ref. Elec. RE</td>
<td>AgCl 177.0E-3V</td>
<td></td>
</tr>
<tr>
<td>Open Circuit OC</td>
<td>-254.2E-3 V</td>
<td></td>
</tr>
</tbody>
</table>

**Comment:** AMS 4215 (BARE) IN ASTM D1441...ARGON PURGED...SUPPLEMENT TO JG-SS048.DAT

---

![Graph](image-url)
Model 398 Electrochemical Impedance Software, v. 1.01
Filename: c:\m398\data\JG-SS05.DAT
Preset: M273 (92.761 Var 107)
Analyzer: M1255 Ver B
SS Single sine EIS Z(f)
Date Run: 01-27-98
File Status: NORMAL
Time Run: 15:01:01

Cond. Time CT pass s Initial Freq. IF 100.0 kHz
Cond. Pot. CP pass V Final Freq. FF 100.0 mHz
Initial Delay ID 30 s Point Spacing PS Log
Equil. Time ET pass s Points/Decade PD 5
DC Potential DC 0.0000 V oc No. of Points NP 31

Measure Delay MD pass AC Amplitude AC 5.000 mV rms
Data Quality DO 2 Curr. Range CR Auto
Working Elec. WE Solid Ref. Elec. RE SCE 241.5E-3V
Elec. Area AR 1.000 cm² Open Circuit OC -1.915 V

Comment: AMS 4427 (BARE) IN ASTM D1141...AIR PURGED...NEW...LT STIR

--- JG-SS05.DAT ---
Model 398 Electrochemical Impedance Software, v. 1.01
Filename: c:\n398\data\JO-SS06.DAT
Path: M273 (92.96) Var 107
Analyzer: M1295 Var 8
SS Single sine EIS Z(f)
Date Run: 01-27-98
File Status: NORMAL
Time Run: 16:22:16
Cond. Time CT pass 8 Initial Freq. IF 100.0 K Hz
Cond. Pot. CP pass U Final Freq. FF 100.0 m Hz
Initial Delay ID 30 V Point Spacing PS Log
Equl. Time ET pass s Points/Decade PD 5
DC Potential DC 0.0000 V oc No. of Points NP 31
Measure Delay MD pass AC Amplitude AC 5.000 mV rms
Data Quality DQ 1 Curr. Range CR Auto
Working Elec. WE Solid Ref. Elec. RE AgCl 197.0E-3 V
Elec. Area AR 1.000 cm^2 Open Circuit OC -245.0E-3 V
Comment: AMS 4427 (TAG/RH) IN ASIM D1141...OPEN TO AIR...NEW...LT STIR

---

JO-SS06.DAT

![Graph of impedance vs. frequency]
Model J78 Electrochemical Impedance Software v. 1.01
Filename: c:\m398\data\J6-MS04.DAT
File Status: NORMAL
Date Run: 01-27-98
Time Run: 16:32:46

Cond. Time CT pass s
Cond. Pot. CP pass V
Initial Delay ID 30 s
Equil. Time ET pass s
DC Potential DC 0.0000 V
No. of Points NP 20

Measure Delay MD pass s
AC Amplitude AC 5.000 mV rms
Data Quality DQ Z
Curr. Range CR Auto

Working Elec. WE Solid
Ref. Elec. RE AgCl 197.0E-3 V
Elec. Area AR 1.000 cm²
Open Circuit OC -118.0E-3 V

Comment: AMS 4427 (TAB/RH) IN ASTM D1141...OPEN TO AIR...NEW...LT STIR...SUPP TO JG-SS06

---

Joint Test Report
Model 398 Electrochemical Impedance Software, v. 1.01
Filename: c:\398\data\JG-SS97.DAT
File Status: NORMAL
Date Run: 01-30-98
Time Run: 10:45:19

Cond. Time CT pass s
Initial Freq. IF 100.0 kHz
Cond. Pot. CP pass V
Final Freq. FF 100.0 mHz
Initial Delay ID 30 s
Point Spacing PS Log
Equil. Time ET pass s
Points/Decade PD 5
DC Potential DC 0.0000 V oc
No. of Points NP 31
Measure Delay MD pass
Data Quality DQ 1
AC Amplitude AC 5.000 mV rms
Curr. Range CR Auto
Working Elec. WE Solid Ref. Elec. RE AgCl 197.0E-3V
Elec. Area AR 1.000 cm² Open Circuit OC -1.121 V

Comment: AMS 4427 (TAG RH) IN ASTM D1141 AIR PURGE DOT DAMAGE NEW NO STIR

Joint Test Report
Model 378 Electrochemical Impedance Software, v. 1.01
Filename: c:\M98\data\JG-MS05.DAT
Patat: M273 [92.90] Ver 107
MS Multi-line EIS 2(f)
Date Run: 01-30-98
File Status: NORMAL
Time Run: 12:20:29

| Cond. Time  | CT pass | Initial Freq. IF | 0.050 | Hz |
| Cond. Pot.  | CP pass | Final Freq. FF    | 1.000  | Hz |
| Initial Delay ID | 30 s | E | 6.000 | V oc |
| Equil. Time ET | pass | No. of Points NP  | 28 |
| DC Potential DC | 6.000 | V | 5.000 | mV rms |
| Measure Delay MD | pass | AC Amplitude AC | 5.000 | mV rms |
| Data Quality DQ | 2 | Curr. Range CR | Auto |
| Working Elec. WE | Solid | Ref. Elec. RE | AgCl 197.0E-3V |
| Elec. Area AR | 1.000 | Open Circuit OC | -1.145 | V |

Comment: AMS 4427 (TAS/RH) IN ASTM D1141. AIR PURGE...1.5 HRS...DOT DAMAGE..NO STIR

---

JG-MS05.DAT

---

**Graph**

- **Z**: Conductance
- **F**: Frequency (Hz)
- **Logarithmic Scale**

Joint Test Report

A-19
Model 398 Electrochemical Impedance Software, v. 1.01
Filename: \m398\data\J0-SS08.DAT
Patch: M273 f92.961 Ver 1.07
Analyzer: M1255 Ver B
SS Single sine EIS 2(f)
Date Run: 01-30-98
Time Run: 13:16:10

Cond. Time CT pass s
Cond. Pot. CP pass V
Initial Delay ID 30 s
Equil. Time ET pass s
DC Potential DC 0.0000 V

Initial Freq. IF 100.0 K Hz
Final Freq. FF 100.0 m Hz
Point Spacing PS Low
Points/Decade PD 5

No. of Points NP 31
AC Amplitude AC 5.000 mV rms

Measure Delay MD pass
Data Quality DQ 1
Curr. Range CR Auto

Working Elec. WE Solid
Ref. Elec. RE SCE 241.56-3V
Open Circuit OC -460.0E-3 V

Elect. Area AR 1.000 cm²

Comment: A-295 IN ASTM D1141...ARGON PURGE...NEW...LT STIR

---

J0-SS08.DAT

---

Frequency (Hz) 10^n

Z (ohm) 10^n
Model 398 Electrochemical Impedance Software, v. 1.01
Filename: c:\m398\data\JG-MS06.DAT
Page: M0273 [92.96] Ver 107
MS Multi-sine EIS Z(f)
File Status: NORMAL
Date Run: 01-30-98
Time Run: 13:23:09

Cond. Time  CT pass s
Cond. Pot.  CP pass V
Initial Delay  ID 30 s
Equil. Time  ET pass s
DC Potential  DC 0.0000 V

Measure Delay  MD pass
Data Quality  DQ Z

Working Elec.  WE Solid
Electrode Area  AR 1.000 cm²

Comment: A-286 IN ASTHM DI141...AROON PURGE...NEW...LT STIR...SUPPL TO JG-SS00

--- JG-MS06.DAT

---

Joint Test Report
Joint Test Report

Model 398 Electrochemical Impedance Software, v. 1.01
Filename: c:\398\data\JG-SS09.DAT
Patch: M273 [92,96] Var 107
Analyzer: MI255 Var B
SS Single sine EIS 2(f)
Date Run: 02-02-98
File Status: NORMAL
Time Run: 12:47:05

Cond. Time CT pass s Initial Freq. IF 100.0 kHz
Cond. Pat. CP pass V Final Freq. FF 100.0 nHz
Initial Delay ID 30 s Point Spacing PS Log
Equil. Time ET pass s Point/Decade PD 5
DC Potential DC 0.0000 V oc
No. of Points NP 31

Measure Delay MD pass
Data Quality DD 1
AC Amplitude AC 5.000 mV rms
Curr. Range CR Auto
Working Elec. WE Solid
Ref. Elec. RE SCE 241.5E-3 V
Elec. Area AR 1.000 cm²
Open Circuit OC -746.0E-3 V

Comment: TI 6-4 IN ASTM D1141...ARGON PURGE...NEW...ST STIR

--- JG-SS09.DAT ---

Graph showing impedance data over a frequency range.
Model 398 Electrochemical Impedance Software, v. 1.01
Filename: c:\398\data\J8-MS07.DAT
Date Run: 02-02-98
File Status: NORMAL
Time Run: 12:55:27

Conductor Time CT pass s
Conductor Pot. CP pass V
Initial Delay ID 30 s
Equil. Time ET pass s
DC Potential DC 0.0000 V
No. of Points NP 20

Measure Delay MD pass s
Data Quality DQ 2
AC Amplitude AC 5.000 mV rms
Curr. Range CR Auto

Working Elec. WE Solid
Ref. Elec. RE SCE 241.5E-3 V
Open Circuit OC -721.0E-3 V

Electrode Area AR 1.000 cm²

Comment: TI 6-4 IN ASTM D1141...ARBON PURGE...NEW...LT STIR...SUPPL TO JG-SS07

--- J8-MS07.DAT ---
Model 352/252 Corrosion Analysis Software, v. 2.01
Filename: C:\352\Data\JG-BC01.DAT
Preset: M273 (92,96) Var 107
GC GALVANIC CORROSION
Date Run: 02-04-98
File Status: NORMAL
Time Run: 17:48:49

Time/Perf: TP 14.40 s
No. of Points NP 2000

Time Step: TI 20.00E3 s
Curr. Range CK Auto

Line Sync: LS no
Rise Time: RT high stability
Filter: FL Off
Ref. Elec.: RE AgCl 0.1970 V
Equiv. Wt.: EU 8.994 g
Open Circuit OC 0.2860 V

Density: DE 2.713 g/ml

Comment: AMS 4215 (BARE) COUPLED WITH TI 6-4 IN ASTM D1141...AIR PURGE...NO STIR

-- JG-BC01.DAT --

Graph showing I/area (µA/cm²) vs. t (ks)
Model 352/252 Corrosion Analysis Software, v. 2.01
Filename: g:\a352\data\JO-GC02.001
Test: H273 [92.96] Ver 1.07
GC: BALVANIC CORROSION
Date Run: 02-06-98
File Status: NORMAL
Time Run: 17:07:27

No. of Points NP 2000
Time/Point TP 14.40 s
Time Step 1 Ti 28.80E3 s
Curr. Range CR Auto
Line Sync. LS no
Rise Time RT high stability
Filter FL Off
Working Elec. WE Solid
Ref. Elec. RE AgCl 0.1970 V
Sample Area AR 1.000 cm^2
Dens. DE 2.713 g/ml
Equiv. Ht. EH 0.994 g
Open Circuit OC 1.427 V

Comment: AMS 4427 (BARE) IN ASTM D1141...OPEN TO AIR...NO STIR

---

Joint Test Report
Joint Test Report
Model 352/252 Corrosion Analysis Software, v.  2.01
Filename: c:\m352\data\JG-GC03.DAT
Patent: H273 [92.96] Ver 107
GC GALVANIC CORROSION
Date Run: 03-02-98
Time Run: 08:30:51

<table>
<thead>
<tr>
<th>Time/Pt.</th>
<th>TP</th>
<th>7.200 s</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of Points</td>
<td>NP</td>
<td>2000</td>
</tr>
<tr>
<td>Time Step</td>
<td>TI</td>
<td>14.40E3 s</td>
</tr>
<tr>
<td>Curr. Range</td>
<td>CR</td>
<td>Auto</td>
</tr>
<tr>
<td>Line Sync.</td>
<td>LS</td>
<td>no</td>
</tr>
<tr>
<td>Rise Time</td>
<td>RT</td>
<td>high stability</td>
</tr>
<tr>
<td>Working Elec.</td>
<td>WE</td>
<td>Solid</td>
</tr>
<tr>
<td>Sample Area</td>
<td>AR</td>
<td>1.000 cm^2</td>
</tr>
<tr>
<td>Density</td>
<td>DE</td>
<td>1.930 g/cm^3</td>
</tr>
<tr>
<td>Filter</td>
<td>FL</td>
<td>Off</td>
</tr>
<tr>
<td>Ref. Elec.</td>
<td>RE</td>
<td>AgCl 0.1970 V</td>
</tr>
<tr>
<td>Equiv. Wt.</td>
<td>EW</td>
<td>12.15 g</td>
</tr>
<tr>
<td>Open Circuit</td>
<td>OC</td>
<td>1.535 V</td>
</tr>
</tbody>
</table>

Comment: AMS 4427 (BARE) IN ASTM D1141...COUPLED TO A296...NEW...NO STIR...OPEN TO AIR

JG-GC03.DAT

![Graph of Z vs. t (ks)](image)

Joint Test Report  A-31
Model 352/252 Corrosion Analysis Software, v. 2.01
Filename: c:\a352\data\JG-0C04.DAT
Patent: M279 (92, 96) Var L07
GC: GALVANIC CORROSION
Date Run: 03-09-98
File Status: NORMAL
Time Run: 08:37:24

Time/Pt. TP 7.200 s
No. of Points NP 2000
Time Step 1 T1 14.40E3 s

Line Sync. LS no
Rise Time RT high stability
Working Elec. WE Solid
Sample Area AR 1.000 cm²
Density DE 1.830 g/ml
Filter FL Off
Ref. Elec. RE AgCl 0.1970 V
Equiv. Wt. EW 12.15 g
Open Circuit OC 0.500 V

Comment: AMS 4427 (ZN-CR) IN ASTM D1141...COUPLED TO A286...NEW...NO STIR...OPEN TO AIR

Joint Test Report
A-33
Joint Test Report
Model 352/252 Corrosion Analysis Software, v. 2.01
Filename: 2:\m352\data\JG-GC06.DAT
Date Run: 03-12-98
File Status: NORMAL
Time Run: 17:15:35

Time/pt. TP 14.40 s Time Step 1 T1 28.80E3 s
No. of Points NP 2000 Curr. Range CR Auto

Line Sync. LS no Filter FL Off
Rise Time RT high stability Ref. Elec. RE AgCl 0.1970 V
Working Elec. WE Solid Eqv. Wt. EW 12.15 g
Sample Area AR 1.000 cm² Open Circuit OC 1.356 V
density DE 1.893 g/ml

Density DE 1.893 g/ml

Comment: AMS 4427 (ZN-P04) COUPLED TO A288 IN D1141...NEW...OPEN TO AIR...NO STIR

---

JG-GC06.DAT
Model 352/252 Corrosion Analysis Software, v. 2.01
Filename: c:\m352\data\JO-0007.DAT
Test: M273 (72.76) Ver 107
GC: GALVANIC CORROSION
Date Run: 04-28-98
File Status: NORMAL
Time Run: 08:46:57

Time/Flt. TP 7.208 s
No. of Points NP 3000

Line Sync. LS no
Rise Time RT high stability
Filter FL Off
Working Elec. WE Solid
Ref. Elec. RE AgCl 0.1970 V
Sample Area AR 1.000 cm^-2
Density DE 1.830 g/ml

Comment: AMS 4427 (ZN-M084)...TO A296..D1141...NEW...OPEN TO AIR...NO STIR

---

JO-0007.DAT

I/area (mA/cm^-2)

t (Ks)

---

Joint Test Report
Model 352/252 Corrosion Analysis Software, v. 2.01
Filename: c:\352\data\JG-GC08.DAT
Petat: M273 (92-96) Var 107
GC GALVANIC CORROSION
Date Run: 05-21-98
File Status: NORMAL
Time Run: 13:02:55

Time/Step, TP 2.400 s  Time Step 1, T1 7.200E3 s
No. of Points, NP 3000
Curr. Range, CR

Line Sync, LS no
Rise Time, RT high stability
Working Elec, WE Solid
Filter, FL Off
Ref. Elec, RE AgCl 0.1970 V
Sample Area, AR 1.000 cm²
Equiv. Volts, EV 12.15 V
Density, DE 1.830 g/ml
Open Circuit, OC 1.221 V

Comment: AMS 4427 (ZN-M004)...TO A286...D1141...AFTER JG-GC07...OPEN...PINHOLE DEFECT

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Joint Test Report
Joint Test Report

Model 352/252 Corrosion Analysis Software, v. 2.01
Filename: c:\m352\data\J6-SC09.DAT
Path: M273 (92.96) Ver 107
GC GALVANIC CORROSION
Date Run: 06-26-98
File Status: NORMAL
Time Run: 16:31:48

Time/Point TP 8.334s Time Step 1 T1 25.00E3 s
No. of Points NP 3000 Curr. Range CR Auto

Line Sync. LS no
Rise Time RT high stability Filter FL off
Valid Working Elec. WE Solid Ref. Elec. RE AgCl 0.1978 V
Sample Area AR 1.000 cm² Eqv. Ht. EW 0.994 g
Density DE 2.713 g/ml Open Circuit OC 0.6578 V

Comment: AMS 4215 (ZN-CR)...TO A286...D1141...NEW...OPEN...SCRATCH..NO STIR

J6-SC09.DAT

I/area (mA/cm²)

-2.000 2.000 6.000 10.000 14.000 18.000 22.000 26.000 30.000

t (ks)
A-43
<table>
<thead>
<tr>
<th>Model 352/252 Corrosion Analysis Software, v. 2.01</th>
</tr>
</thead>
<tbody>
<tr>
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</tr>
<tr>
<td>GC BALVANIC CORROSION</td>
</tr>
<tr>
<td>Date Run: 05-29-98</td>
</tr>
<tr>
<td>Time Run: 15:03:00</td>
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<tr>
<td>Time/Pt.  TP 3.600 s</td>
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<tr>
<td>No. of Points NP 2000</td>
</tr>
<tr>
<td>Time Step 1 TI 7.280E3 s</td>
</tr>
<tr>
<td>Curr. Range CR Auto</td>
</tr>
<tr>
<td>Line Sync. LS no</td>
</tr>
<tr>
<td>Rise Time RT high stability</td>
</tr>
<tr>
<td>Working Elec. WE Solid</td>
</tr>
<tr>
<td>Sample Area AR 1.000 cm²</td>
</tr>
<tr>
<td>Density DE 2.713 g/ml</td>
</tr>
<tr>
<td>Comment: AMS 4215 (ZN-M004)...TO A286...D1141...NEW...OPEN...SCRATCH...NO STIR</td>
</tr>
</tbody>
</table>

![Graph showing corrosion analysis results](image-url)
Model 398 Electrochemical Impedance Software, v. 1.01
Filename: c:\m398\data\JG-MS01.DAT
File Status: NORMAL
Date Run: 01-22-90
Time Run: 12:15:07

Cond. Time CT pass s Initial Freq. IF 8.856 m Hz
Cond. Pot. CP pass V Final Freq. FF 1.000 Hz
Initial Delay ID 30 s
Equil. Time ET pass s
DC Potential DC 0.0000 V oc No. of Points NP 20
Measure Delay MD pass AC Amplitude AC 5.000 mV rms
Data Quality DQ 2 Curr. Range CR Auto
Working Elec. WE Solid Ref. Elec. RE AgCl 197.0E+3
Elec. Area AR 1.000 cm² Open Circuit OC -224.0E-3 V

Comment: AMS 4025 (AMS 2470) IN ASTM D1141...OPEN TO AIR...NEW...NO STIR...FLAT CELL

Joint Test Report
Model 352/252 Corrosion Analysis Software, v. 2.01
Filename: c:\m352\data\JS-SC12.DAT
Stat: M273 [92.96] Var 107
GC GALLUANIC CORROSION
Date Run: 09-22-92

Time/Point TP 12.00 s
No. of Points NP 2000
Line Sync. LS no
Rise Time RT high stability
Working Elec. WE Solid
Sample Area AR 1.000 cm²
Density DE 1.630 g/ml

Filter FL Off
Ref. Elec. RE AgCl 0.1970 V
Equiv. Mt. EM 12.15 g
Open Circuit OC 84.09E-3 V

Comment: AMS 4427 (ZN-P04) COUPLED TO A286 IN D1141...NEW...OPEN TO AIR...NO STIR

JS-SC12.DAT
Joint Test Report

Model 352/252 Corrosion Analysis Software, v. 2.01
Filename: c:\352\data\JG-GC13.DAT
Patat: M273 [92, 96] Ver 107
BC BALVANIC CORROSION
Date Run: 09-29-96

Time/Pt. TP 12.60 s Time Step 1 T1 25.20E3 s
No. of Points NP 2000 Curr. Range CR Auto

Line Sync. LS no Filter FL off
Rise Time RT high stability Ref. Elec. RE AgCl 0.1970 V
Sample Area AR 1.000 cm² Equiv. Uf. EU 12.15 g
Density DE 1.030 g/ml Open Circuit OC 1.183 V

Comment: AMS 4427 (ZN-P04) COUPLED TO A286 IN D1141...NEW...OPEN...NO STIR...DOT DAMAGE

--- JG-GC13.DAT ---

Joint Test Report A-51