

**National Aeronautics and Space Administration (NASA)
Technology Evaluation for Environmental Risk Mitigation
Principal Center (TEERM)**

Joint Test Plan

For

Gas Dynamic Spray Technology Demonstration

FINAL

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PREFACE

This report was prepared by ITB, Inc., through the National Aeronautics and Space Administration (NASA) Technology Evaluation for Environmental Risk Mitigation Principal Center (TEERM) under Contract Number NNH06CC40C, Task Order No. 12. The structure, format, and depth of technical content of the report were determined by Air Force Space Command, NASA TEERM, Government contractors, and other Government technical representatives in response to the specific needs of this project.

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1. INTRODUCTION

Headquarters National Aeronautics and Space Administration (NASA) chartered the Technology Evaluation for Environmental Risk Mitigation Principal Center (TEERM) to coordinate agency activities affecting pollution prevention issues identified during system and component acquisition and sustainment processes. The primary objectives of TEERM are to:

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

Air Force Space Command (AFSPC) and NASA have similar missions, facilities, and structures located in similar harsh environments. Both are responsible for a number of facilities/structures with metallic structural and non-structural components in highly and moderately corrosive environments. Regardless of the corrosivity of the environment, all metals require periodic maintenance activity to guard against the insidious effects of corrosion and thus ensure that structures meet or exceed design or performance life.

The standard practice for protecting metallic substrates in atmospheric environments is the use of an applied coating system. Current coating systems used across AFSPC and NASA contain volatile organic compounds (VOCs) and hazardous air pollutants (HAPs). These coatings are subject to environmental regulations at the Federal and State levels that limit their usage. In addition, these coatings often cannot withstand the high temperatures and exhaust that may be experienced by AFSPC and NASA structures.

In response to these concerns, AFSPC and NASA have approved the use of thermal spray coatings (TSCs). Thermal spray coatings are extremely durable and environmentally friendly coating alternatives, but utilize large cumbersome equipment for application that make the coatings difficult and time consuming to repair. Other concerns include difficulties coating complex geometries and the cost of equipment, training, and materials.

Gas Dynamic Spray (GDS) technology (also known as Cold Spray) will be evaluated as a smaller, more maneuverable repair method as well as for areas where thermal spray techniques are not as effective. The technology can result in reduced maintenance and thus reduced hazardous materials/wastes associated with current processes. Thermal spray and GDS coatings also have no VOCs and are environmentally preferable coatings.

To achieve a condition suitable for the application of a coating system, including GDS coatings, the substrate must undergo some type of surface preparation and/or depainting operation to ensure adhesion of the new coating system. The GDS unit selected for demonstration has a powder feeding system that can be used for surface preparation or coating application. The surface preparation feature will also be examined.

The primary objective of this effort is to demonstrate GDS technology as a repair method for TSCs. The project will also determine the optimal GDS coating thickness for acceptable

performance. Successful completion of this project will result in approval of GDS technology as a repair method for TSCs at AFSPC and NASA installations and will improve corrosion protection at critical systems, facilitate easier maintenance activity, extend maintenance cycles, eliminate flight hardware contamination, and reduce the amount of hazardous waste generated.

This project is a continuation of various AFSPC and NASA studies including:

- Coatings Pollution Prevention Opportunity Assessment.
- AFSPC Protective Coating Evaluation.
- The Testing and Demonstration of Metal Wire Arc Spray Materials on Rocket Launch Facilities.
- 18-Month Climate Exposure, Hypergolic Fuel and High Temperature Service Testing, and Field Demonstration Test Plan Cape Canaveral Air Force Station, FL.
- Depainting Pollution Prevention Opportunity Assessment.
- Low Emission Surface Preparation/Depainting Technologies for Structural Steel.
- Alternatives to Isocyanate Urethanes for Structural Steel.
- Low VOC Coatings and Depainting Technologies Field Testing Phase 2.

This project will help AFSPC and NASA meet the tenets of agency and federal directives, such as Presidential Executive Order 13148, *Greening the Government through Leadership in Environmental Management*. The reduction or elimination of hazardous materials will also reduce the amount of hazardous waste and the associated disposal fees and fugitive emissions. This project will also better prepare the Air Force and NASA to comply with federal, state and local regulations. Finally, by working together on this project, both AFSPC and NASA will benefit through the merging of data and knowledge from current pollution prevention projects.

This Joint Test Protocol (JTP) defines the test coupon matrix and performance requirements for validating the GDS technology as a repair method for TSCs.

2. COUPON MATRIX

In order to meet the objectives of the project, a variety of coupons with a combination of the TSCs, GDS coatings, and topcoats will be used to simulate potential applications. The coupon matrix was developed based on information provided by the technical stakeholders and encompasses a wide range of possible applications.

Three substrates of interest were identified:

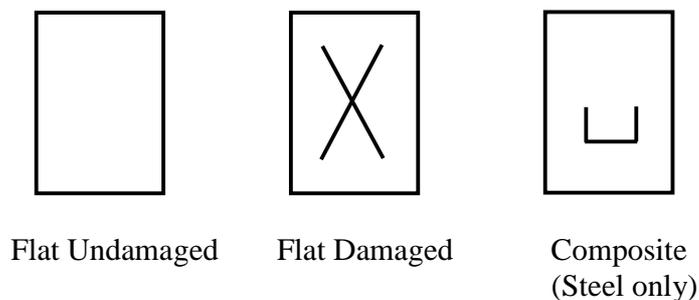
- A36 Carbon Steel
- 6061-T6 Aluminum alloy
- 5052-H32 Aluminum alloy

Five Base/Repair Coating materials of interest were identified:

- Zinc (Zn) TSC
- Aluminum-Magnesium (Al-Mg) TSC
- Zn GDS coating
- Zinc-Aluminum (Zn-Al) GDS coating
- Aluminum (Al) GDS coating

The following coupons (Figure 1) were decided upon:

- Flat panel, undamaged—to provide baseline data
- Flat panel, damaged—to simulate damaged/repaired coatings
- Composite panel—to simulate corners and edges



damaged and then repaired with the alternative coatings to determine how effective the alternatives are at providing corrosion protection. Composite coupons will be used to simulate corners and edges that are difficult to coat using TSC. The GDS coatings will be applied to these areas to determine whether they provide additional corrosion protection.

Topcoated coupons and non-topcoated coupons are also desired to determine whether a topcoat supplements corrosion protection in addition to providing aesthetic appeal. The topcoat will be selected based on performance potential and lack of environmental concerns such as volatile organic compound and hazardous material content.

Table 1 Coupon Matrix				
<i>Substrate</i>	<i>Base Coat</i>	<i>Coupon</i>	<i>Repair Coat</i>	<i>Topcoat</i>
A36 Carbon Steel	Zn TSC <i>or</i> Al-Mg TSC <i>or</i> Zn GDS <i>or</i> Zn-Al GDS <i>or</i> Al GDS	Undamaged	Not Applicable	Yes
				No
		Damaged	Zn GDS	Yes
				No
			Zn-Al GDS	Yes
				No
			Al GDS	Yes
				No
		None	Yes	
			No	
		Composite	Zn GDS	Yes
				No
			Zn-Al GDS	Yes
				No
Al GDS	Yes			
	No			
None	Yes			
	No			
6061-T6 Aluminum	Zn TSC <i>or</i> Al-Mg TSC <i>or</i> Zn GDS <i>or</i> Zn-Al GDS <i>or</i> Al GDS	Undamaged	Not Applicable	Yes
				No
		Damaged	Zn GDS	Yes
				No
			Zn-Al GDS	Yes
				No
			Al GDS	Yes
				No
		None	Yes	
			No	
5052-H32 Aluminum	Zn TSC <i>or</i> Al-Mg TSC <i>or</i> Zn GDS <i>or</i> Zn-Al GDS <i>or</i> Al GDS	Undamaged	Not Applicable	Yes
				No
		Damaged	Zn GDS	Yes
				No
			Zn-Al GDS	Yes
				No
			Al GDS	Yes
				No
		None	Yes	
			No	

Due to funding, this project will be divided into two phases. Phase 1 will include those coatings identified as being of most interest to technical stakeholders, and Phase 2 will be the remainder of the coupon matrix. Table 2 identifies those coupons selected for Phase 1 of this effort.

Table 2 Phase 1 Coupon Matrix				
<i>Substrate</i>	<i>Base Coat</i>	<i>Coupon</i>	<i>Repair Coat</i>	<i>Topcoat</i>
A36 Carbon Steel	Zn TSC	Undamaged	NA	Yes
				No
		Damaged	Zn GDS	Yes
				No
			None	Yes
				No
		Composite	Zn GDS	Yes
				No
	None		Yes	
			No	
	Zn GDS	Undamaged	NA	Yes
				No

3. ENGINEERING AND TESTING REQUIREMENTS

A joint group consisting of technical representatives from AFSPC and NASA reached technical consensus on engineering, performance, and testing requirements for the GDS technology. The joint group defined critical tests with procedures, methodologies, and acceptance criteria to qualify alternatives against these technical requirements.

Table 3 lists the testing requirements intended to evaluate the performance of the repair coatings. The table includes acceptance criteria and reference specifications, if any, used to conduct the tests. The proposed test and evaluation are based on the aggregate knowledge and experience of the assigned technical project personnel and prior testing where "None" appears under *Test Method References*. All generated data will be recorded by the project engineer and include photographic documentation.

Table 3 Engineering and Testing Requirements

<i>Test</i>	<i>JTP Section</i>	<i>Acceptance Criteria</i>	<i>Test Method References</i>
Surface Preparation	3.1		VARIOUS
<i>SSPC Surface Cleaning Level</i>	3.1.1	Concurrence that technology meets agreed upon cleaning level using visual determination and SSPC Surface cards at 10X magnification	SSPC-SP-10/ NACE-NO. 2
<i>Surface Profile/ Roughness</i>	3.1.2	Concurrence that technology meets agreed upon surface profile using visual determination	NACE-STD-RP0287
Coating Application	3.2	Smooth coat with acceptable appearance and Dry Film Thickness (DFT)	SSPC-PA-2
18-Month Marine Environment Exposure	3.3		NASA-STD-5008A
<i>Degree of Rusting</i>	3.3.1	Attain a numerical rating of not less than 9 for primer only and 8 for topcoated systems.	ASTM D 610
<i>Degree of Blistering</i>	3.3.2	Attain a numerical rating of not less than 9F. This applies to topcoated coupons only.	ASTM D 714
<i>Scribe Ratings</i>	3.3.3	Attain a numerical rating of not less than 9 for primer only and 8 for topcoated systems.	ASTM D 1654
<i>Gloss Measurements</i>	3.3.4	High gloss minimum of 85 Gloss Units at 60 ⁰ angle and retaining 80% gloss over 18 months. This applies to topcoated coupons only.	ASTM D 2244; ASTM D 523
<i>Color Measurements</i>	3.3.5	Less than 3 ΔE color change units over 18 months. This applies to topcoated coupons only.	ASTM D 2244; ASTM D 523
<i>Heat Adhesion</i>	3.3.6	Dry-temperature resistance to 400°C (750°F) for 24 hours for untopcoated systems.	ASTM D 4541

3.1 Surface Preparation Evaluation

To achieve a substrate condition suitable for the application of a coating system, including repair coatings, substrates must undergo some type of surface preparation and/or depainting operation to ensure adhesion of the new coating system. The level of cleanliness or anchor profile desired is typically a function of the type of coating to be applied and the specification being adhered to.

3.1.1 SSPC Surface Cleaning Level

This test shall be performed in accordance with SSPC-SP-10/NACE-No. 2 (*Near-White Blast Cleaning*, issued 2000). SSPC-SP-10 is the industry standard for surface preparation of carbon steel for application of most coating systems.

An engineering evaluation substantiated by written description and photographs will be submitted for concurrence that technology meets the agreed upon cleaning level using visual determination and SSPC Surface cards at 10X magnification.

3.1.2 Surface Profile/Roughness

This test serves to evaluate substrate damage as a result of using the coating removal technology. Surface roughness shall be measured in accordance with NACE-STD-RP0287 (*Field Measurement of Surface Profile of Abrasive Blast-Cleaned Steel Surfaces Using a Replica Tape*, revised 2002). Any surface abnormalities shall be noted and photographed. Due to the potential for substrate damage posed by any coatings removal process, preliminary appraisal must be made to estimate the magnitude of this potential.

The surface roughness shall be measured using a minimum of three readings along different directions and different places on the panel. An engineering evaluation substantiated by written description and photographs will be submitted for concurrence that technology meets agreed upon surface profile using visual determination.

3.2 Coating Application

This is used to determine how easy the equipment is to use and how easily the coating system may be applied in actual field conditions. The evaluation is based on the aggregate knowledge and experience of the technician applying the coating. This test will also measure Dry Film Thickness (DFT) nondestructively in accordance with SSPC-PA-2 (*Measurement of Dry Coating Thickness with Magnetic Gages*, revised 2004).

This test is conducted to determine whether GDS coatings are difficult to properly apply under normal maintenance operation conditions. An engineering evaluation substantiated by written description and photographs will be submitted for applicator evaluation of the surface coating condition, Ease of Use, DFT, and other issues. DFT measurements will be recorded for TSCs, GDS, and topcoats.

3.3 18-Month Marine Environment Exposure

The purpose of this test is to evaluate the corrosion resistance and surface appearance of the repair coating and performance after exposure to a marine environment for 18 months. This test is conducted to provide critical detailed evaluation of coating appearance and integrity by the actual exposure of the coatings to UV radiation, as well as different cycles of salt spray exposure.

Test panels shall be coated according to the coupon matrix and installed at the Kennedy Space Center (KSC) outdoor exposure rack 100 feet from the ocean high tide line. All KSC test rack procedures for fasteners, exposure angle, and inspection interval shall be followed.

Coating evaluators will complete a written evaluation and documentation checklist to organize and quantify the observations of coating system performance under actual operating conditions 24 ± 3 hours following application and at six-month, 12-month, and 18-month intervals.

3.3.1 Degree of Rusting

Rusting on the test coupon shall be rated per ASTM D 610 (*Standard Test Method for Evaluating Degree of Rusting on Painted Steel Surfaces*) using the numerical grade scale in ASTM D 610, Table 1, *Scale and Description of Rust Grades*, where 0 indicates 100% surface rusting and 10 indicating less than 0.01% surface rusting. An engineering evaluation substantiated by written description and photographs will be submitted for concurrence that coating has an acceptable Rust Grade assessment.

3.3.2 Degree of Blistering

Topcoated coupons shall be rated on Blistering per ASTM D 714 (*Standard Test Method for Evaluating Degree of Blistering of Paints*); using the reference standards in section 3. The surface of each coated area shall also be examined for coating defects with the unaided eye and with 10X magnification. An engineering evaluation substantiated by written description and photographs will be submitted for concurrence that coating has an acceptable Blistering assessment.

3.3.3 Scribe Ratings

A set of undamaged topcoated test coupons will be scribed prior to exposure and their rated per ASTM D 1654, *Standard Test Method for Evaluation of Painted or Coated Specimens Subjected to Corrosive Environments*, as prescribed in Table 1. The representative mean, maximum, and minimum creepage from the scribe shall be recorded; and whether or not the maximum is an isolated spot noted.

3.3.4 Gloss Measurements

Gloss measurements shall be conducted on each topcoated coupon per ASTM D 523 (*Standard Test Method for Specular Gloss*) to document the specular gloss of the original finish of the test areas. Gloss measurements shall also be taken at six months, 12 months, and 18 months to

determine gloss retention. Gloss unit values shall be recorded by the coatings inspector for each measurement.

3.3.5 Color Measurements

Color measurements shall be conducted on each topcoated coupon per ASTM D 2244 (*Test Method for Calculation of Color Differences from Instrumentally Measured Color Coordinates*) to document the color of the original finish of the test areas. Measurements shall also be taken at six months, 12 months, and 18 months to determine color change. All color values shall be recorded by the coatings inspector.

3.3.6 Heat Adhesion

As a part of the 18-month Marine Environment test, NASA-STD-5008A requires that inorganic zinc coatings have a temperature resistance of 400° C (750° F) for use on launch structures and ground support equipment subject to the elevated temperatures associated with rocket exhaust. Alternative coatings tested under this effort will also be tested to that requirement.

The requirement is satisfied by exposing the coated panels in a high temperature oven to a temperature of 400° C for 24 hours. Any visual deterioration, such as destruction or burning of the coating, would indicate failure of the product. Loss of adhesion after heating also constitutes a failure due to temperature effects on the film.

This test shall be performed in accordance with ASTM D 4541 (Standard Test Method for Pull-off Strength of Coatings Using Portable Adhesion Testers). There shall be two adhesion failure readings for each sample: pre-heat and post-heat. There will also be one color photograph of each test patch and coated coupon taken before the test and one color photograph of each test patch, tested coupon, and the dolly taken after the test.

4. REFERENCE DOCUMENTS

American Society for Testing and Materials

1999 *Standard Test Method for Specular Gloss*. Document Identification ASTM D 523.

American Society for Testing and Materials

2001 *Standard Test Method for Evaluating Degree of Rusting on Painted Steel Surfaces*. Document Identification ASTM D 610.

American Society for Testing and Materials

2002 *Standard Test Method for Evaluating Degree of Blistering of Paints*. Document Identification ASTM D 714.

American Society for Testing and Materials

1992 *Standard Test Method for Evaluation of Painted or Coated Specimens Subjected to Corrosive Environments*. Document Identification ASTM D 1654.

American Society for Testing and Materials

2002 *Test Method for Calculation of Color Differences from Instrumentally Measured Color Coordinates*. Document Identification ASTM D 2244.

American Society for Testing and Materials

2002 *Standard Test Method for Pull-off Strength of Coatings Using Portable Adhesion Testers*. Document Identification ASTM D 4541.

CenterLine (Windsor) Ltd.

2005 *Portable Supersonic Spray Machine User's Manual*. Document # SST-PBS-PM-P-1.0-0605.

NACE: National Association of Corrosion Engineers

2002 *Field Measurement of Surface Profile of Abrasive Blast-Cleaned Steel Surfaces Using a Replica Tape*. Document Identification NACE-STD-RP0287.

NASA: National Aeronautics and Space Administration

2004 *Protective Coating of Carbon Steel, Stainless Steel, and Aluminum on Launch Structures, Facilities, and Ground Support Equipment*. Document Identification NASA-STD-5008A.

SSPC: The Society for Protective Coatings

2004 *Measurement of Dry Coating Thickness with Magnetic Gages*. Document Identification SSPC-PA-2.

SSPC/NACE

2000 *Near-White Blast Cleaning*. Document Identification SSPC-SP-10/NACE-No. 2.