Environmentally Preferred Coatings for Steel

NASA Corrosion Technology Laboratory (CTL)
&
NASA Technology Evaluation for Environmental Risk Mitigation (TEERM)

2016 INTERNATIONAL WORKSHOP ON ENVIRONMENT AND ALTERNATIVE ENERGY
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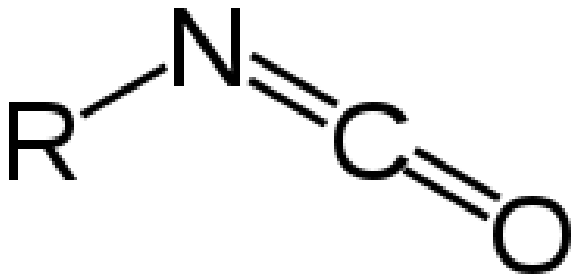
Background

- NASA is responsible for a number of facilities and structures with metallic structural and nonstructural components in a highly corrosive environment.
- 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 deleterious effects of corrosion result in steep costs, asset downtime affecting mission readiness, and safety risks to personnel.
- It is vital to reduce corrosion costs and risks in a sustainable manner.

Risk

- **Potential Obsolescence and Additional Management Costs for HAPs, VOCs, and isocyanates:** Due to the regulations and restrictions on the use of HAPs , VOCs and isocyanates in coatings and preventative compounds containing these materials it is possible that materials containing VOCs, HAPS and isocyanates could become unavailable and that there will be significant and potentially increasing costs associated with the handling and disposal of hazardous materials and the management of VOC, HAP and isocyanate emissions.
- **Potential Human Exposures and Non-Compliance for HAPS, VOCs and isocyanates:** Due to the toxicity of VOCs, HAPs, and isocyanates used in NASA operations, and the restrictions on VOC content is possible that there will be occupational or public exposures or that NASA Centers could be out of compliance with Federal, State and local regulations and Agency requirements.

http://home.howstuffworks.com



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Volatile Organic Compound (VOC) Levels

NASA-STD-5008B includes an “Approved Products List” (APL) of coatings that have very high volatile organic compound (VOC) levels which are no longer compliant with current environmental regulations.

- Currently the APL is divided into two categories:
  - Materials With Greater Than 400 Grams/Liter VOC
  - Materials With Less Than 400 Grams/Liter VOC
- Several states with NASA Centers have more restrictive limits or additional categories of coatings and the trend is to reduce the amount of VOCs allowed in coatings. CA is the most stringent.

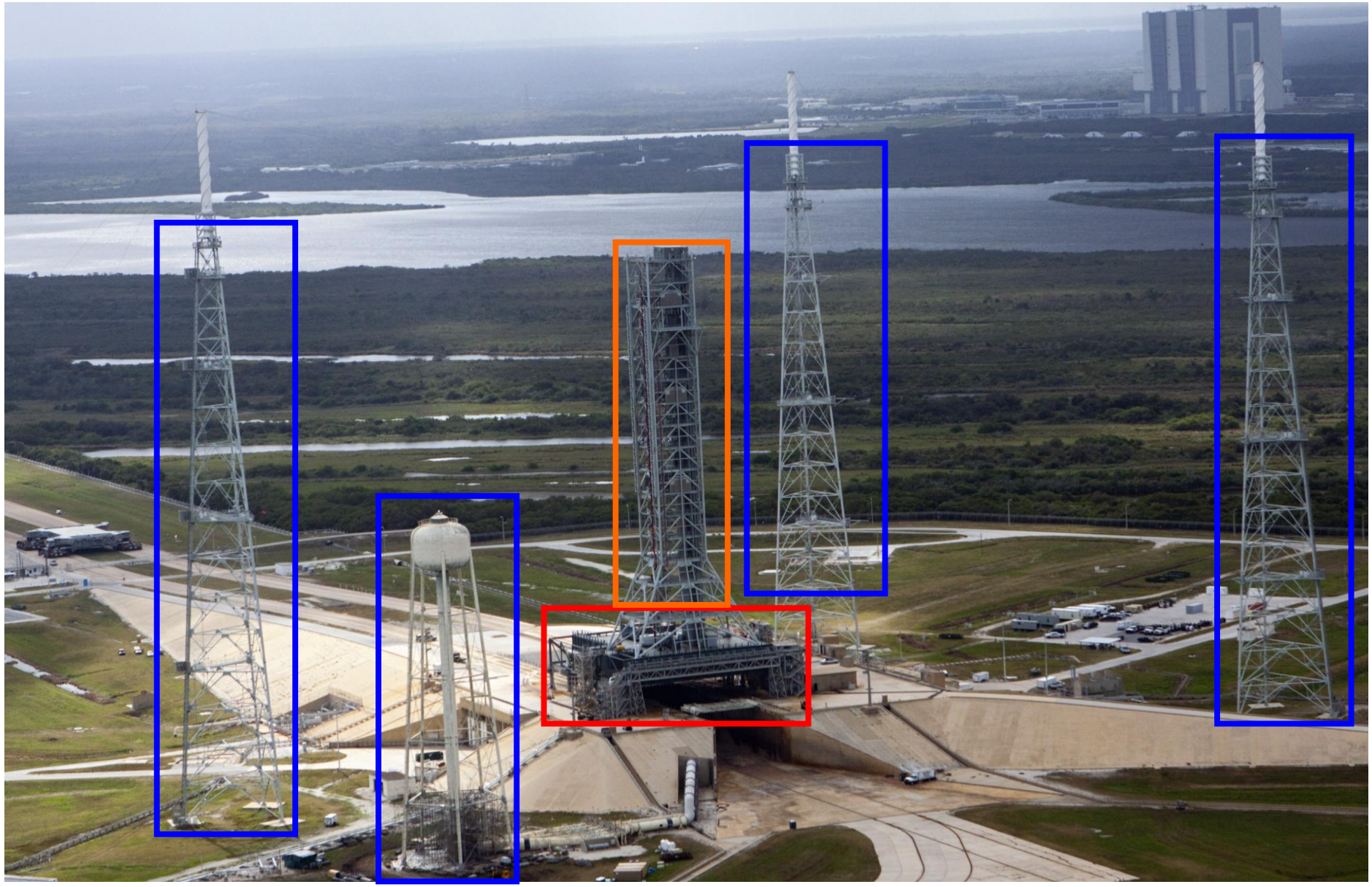
Coating Type	State	CA: Bay Area	CA: SQAMD	FL	TX	AL	MS	VA	OH
	NASA Center	**Ames**	**Armstrong**	**KSC**	**JSC**	**MSFC**	**SSC**	**Wallops / Langley**	**Glenn**
Rust Preventative		250	100	400	400	400	400	400	400
Industrial Maintenance Coatings		250	100	450	450	450	450	340	340
Zinc Rich Primers		340	100						

Zones of Exposure

Zone 3: Surfaces, other than those located in Zones 1 or 2, that receive acid deposition from solid rocket booster exhaust products.
Surfaces that are exposed to other types of chemical contamination (e.g., cooling towers, diesel exhaust stacks, acidic industrial environments, and water treatment facilities).

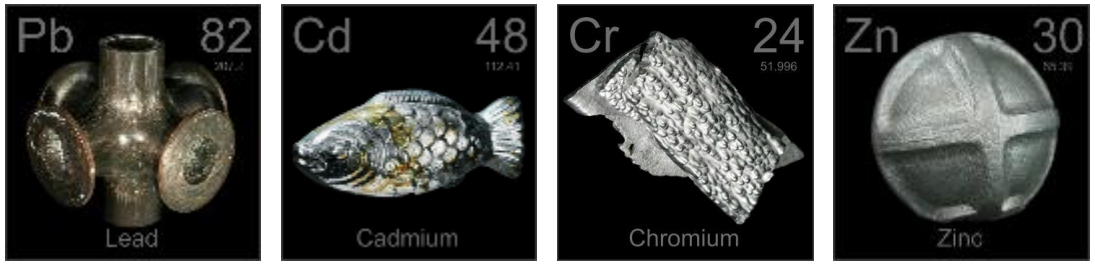
Zone 2: Surfaces that receive elevated temperatures and acid deposition from solid rocket booster exhaust with no exhaust impingement.

Zone 1: Surfaces that are directly impinged on by solid rocket booster (SRB) engine exhaust.
Surfaces that are indirectly impinged on by SRB exhaust.



Coating Selection – Targeting Zones 2 & 3 = no direct exposure to rocket motor exhaust

- Commercial Availability
- Technical Feasibility
- Volatile Organic Compound (VOC) Content <200 g/L
- Hazardous Air Pollutants (HAPs) Content
- Other Hazardous Constituents (RCRA, EPCRA, and CERCLA)
- Isocyanates
  - OSHA requires employers to provide a work environment that minimizes or eliminates exposure to isocyanate-containing products. Isocyanates are classified as potential human carcinogens and are known to cause cancer in animals. The main effects of overexposure are occupational asthma and other lung problems, as well as irritation of the eyes, nose, throat, and skin.
- Heavy Metal Content
  - Lead Free
  - Cadmium Free
  - Chromium Free
  - Zinc



Coating Selection – Targeting Zones 2 & 3

Manufacturer	Type	Primer	Intermediate	Topcoat
A&E Group	Isocyanate Free	N/A	N/A	Alocit 28.15 Standard Grade Epoxy Coating Primer/Finish
A&E Group	Isocyanate Free	Alocit 28.14 Epoxy Coating-Zinc Primer	N/A	Alocit 28.15 Standard Grade Epoxy Coating Primer/Finish
Carboline	Isocyanate Free	Carbozinc 11 WB	Carbotherm 3300	Carbocyrlic 3359
Carboline	Zinc Free	Carbomastic 615	Carboguard 893	Carbothane 134 MC
Polyset	Isocyanate Free	Ply-Zinc WB 18	N/A	Ply-Guard ME
Polyset	Isocyanate & Zinc Free	N/A	N/A	Ply-Guard ME
Pratt & Lambert	Isocyanate & Zinc Free	Universal HP Acrylic Primer Z6631	N/A	Acrylic Waterborne DTM Z6841
Shield Products	Isocyanate & Zinc Free	SKU40003	N/A	SKU20059VC
Tesla	Isocyanate Free Reduced Zinc	TESLAN ZN Primer (Low VOC)	N/A	TESLAN Low VOC Urethane Topcoat (XUR-12041)
EonCoat	Isocyanate & Zinc Free	N/A	N/A	EonCoat
Carboline	Zinc Free	Carbomastic 615 with uCapsules	Carboguard 893	Carbothane 134MC
Ameron	**Baseline**	Dimetcote 9H	Amerlock 400	Amercoat 450H

N/A - Not Applicable

Manufacturer	Type	Primer	Intermediate	Topcoat
Dampney®	Isocyanate & Zinc Free	Protexior® 795	Protexior® 794	Epodur 791
Excalibur Paints	Isocyanate Free with Zinc	OZWBP-in-710 Water-borne IOZ Dust	EXWBP 700G Epoxy Primer	Aqua-Thane
Excalibur Paints	Isocyanate Free with Zinc	ACWP Series Zinc Modified Conversion Coat Primer	N/A	Aqua-Thane
PPG	Isocyanate Free with Zinc	Dimetcote® 21-5 Water-based Epoxy Primer	N/A	PSX 700 Polysiloxane Finish
Rust-Oleum®	Isocyanate & Zinc Free	S71 Water-based Epoxy Primer	N/A	S37 Metalmax® DTM Acrylic Urethane
Sherwin Williams	Contains Isocyanate Zinc Free	EURONAVY ES301K	N/A	Waterbased Acrolon 100
Sherwin Williams	Contains Isocyanate Zinc Free	Macropoxy 920-100	Pro Industrial 0 VOC Waterbased Epoxy	Waterbased Acrolon 100
Sherwin Williams	Contains Isocyanate with Zinc	Zinc Clad II+	646-100	Hi-Solids Polyurethane - 250
Wasser	Contains Isocyanate with Zinc	MC-Miozinc 100	MC-Miomastic 100	MC-Luster 100
Wasser	Contains Isocyanate Zinc Free	MC-Universal Primer 100	MC-Ferrox B 100	MC-Luster 100

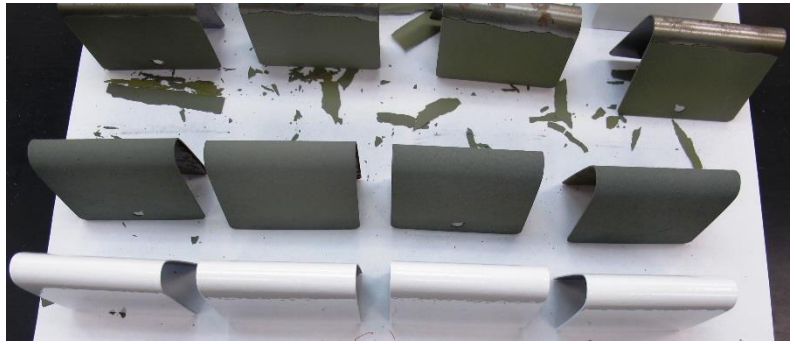
N/A - Not Applicable

Phase 1 Critical Requirement Testing

Phase 1 Testing CRITICAL Requirements for Environmentally-preferable Coatings				
Test	**Test Specimen**	**Acceptance Criteria**	**Requirement**	**Test Methodology References**
Pot Life	Mixed Coating System	Based on Applicator Evaluation: Equal to or better than control coating	NASA-STD-5008B	None
Ease of Application	Coupon	Based on Applicator Evaluation: Smooth coat, with acceptable appearance, no runs, bubbles or sags; Ability to cover the properly prepared/primed substrate with a single coat (one-coat hiding ability); Measure Dry Film Thickness.	NASA-STD-5008B	SSPC-PA-2
Surface Appearance	Coupon	Based on Applicator Evaluation: No streaks, blistering, voids, air bubbles, cratering, lifting, blushing, or other surface defects/irregularities; No micro-cracks observable at 10X magnification	NASA-STD-5008B	ASTM D 523 ASTM D 2244
Atmospheric Exposure	Coupon	Attain a rating of not less than 8 in accordance with ASTM D610; 18 months initial acceptance, 5 years for final acceptance	NASA-STD-5008B	ASTM D 610, ASTM D 714

Phase 2 Performance Testing

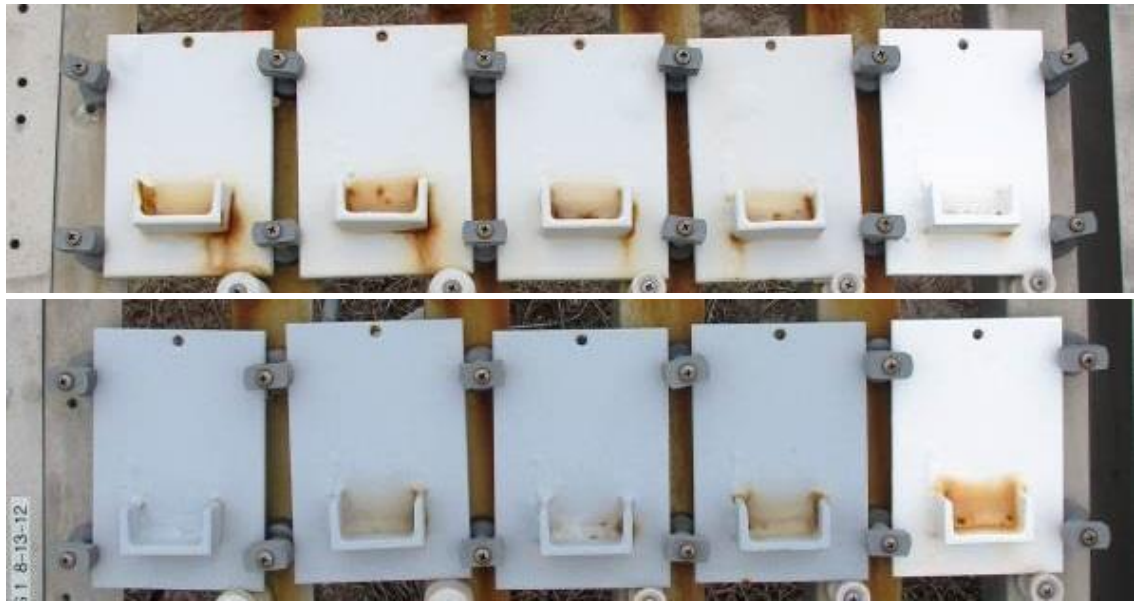
Phase 2 Testing Requirements for Environmentally-preferable Coatings				
Hypergol Compatibility	Coupon	Slight to Moderate Reactivity Observed: When test data based on visual observations with the unaided eye reveal reactivity (but no ignition) and/or any changes in the visual characteristics, bulk characteristics, and/or surface characteristics of the test sample	NASA-STD-6001	KSC MTB-175-88
Cure Time (MEK Solvent Rub)	Coupon	Coating will be tested every two (2) days for a total of 14 days; No effect on surface or coating on the cloth (Resistance Rating 5)		ASTM D 4752
Tensile (Pull-off) Adhesion	Coupon	Pull-off strength achieved at time of failure equal to or better than control coatings		ASTM D 4541
Removability	Coupon	Less than one minute to penetrate substrate; Tested during Reparability and Abrasion Resistance Tests; Measure Dry Film Thickness of remaining coating		ASTM G 155, SSPC-PA-2
Reparability	Coupon	Ease of removal and replacement of damaged areas of the test coatings, color matching of aged versus new material; No streaks, blistering, voids, air bubbles, over-spray “halo”, cratering, lifting, blushing, or other surface irregularities, No peel away of the repaired coating during the dry tape adhesion test		ASTM D 523, ASTM D 2244, ASTM D 3359
Mandrel Bend Flexibility	Coupon	No peeling or delamination from the substrate and no cracking greater than ¼-inch from the edges.		ASTM D 522

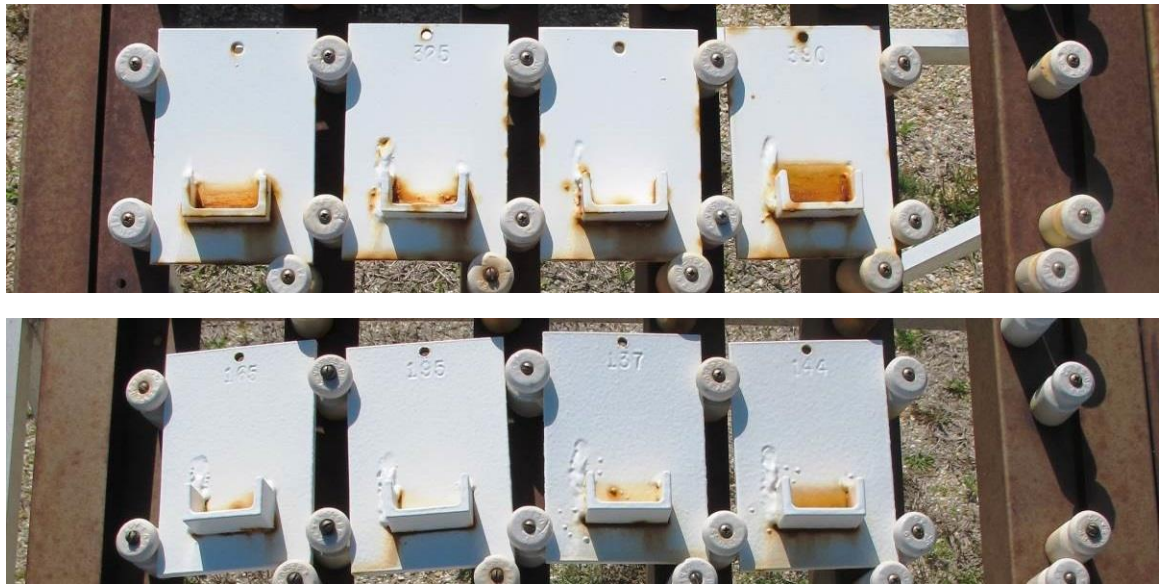


Summary

- Four (4) coating systems passed the minimum criteria set forth in the KSC NASA-STD-5008B; Carboline, Polyset, PPG, and Sherwin Williams. Test coupons will remain at the KSC Beach Atmospheric Test Site and be re-evaluated at 60 months.

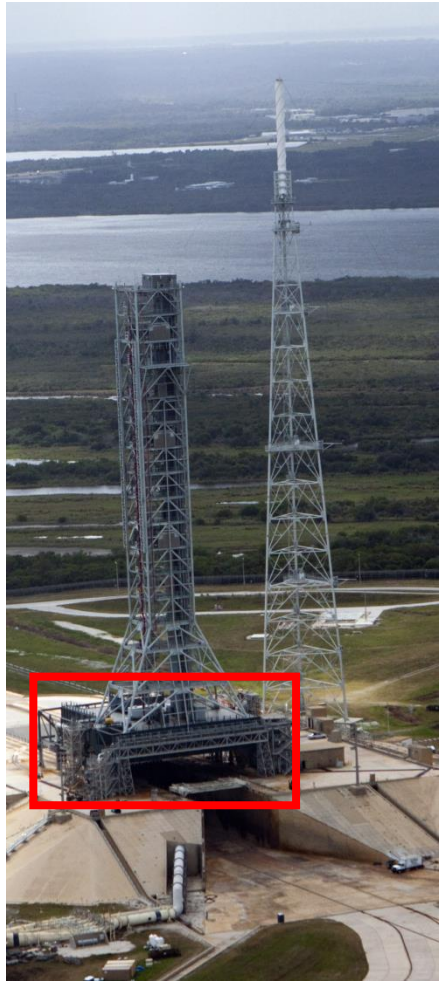
Manufacturer	Type	Primer	Intermediate	Topcoat	Pot Life	Ease of Application	Surface Appearance	Atmospheric Exposure Test					Primer Heat Adhesion	Hypergol Compatibility	Cure Time	Adhesion	Removability	Reparability	Mandrel Bend
								Corrosion	Blistering	Scribe	Color	Gloss							
Carboline	Isocyanate Free	Carbozinc 11 WB	Carbotherm 3300	Carbocyrlic 3359	PASS	PASS	PASS	Equal	Equal	Equal	Equal	PASS	Equal	PASS	FAIL	FAIL	FAIL	FAIL[1]	PASS
Polyset	Isocyanate Free	Ply-Zinc WB 18	N/A	Ply-Guard ME	PASS	PASS	PASS	PASS	Equal	Equal	Equal	FAIL	Equal	PASS	FAIL	PASS	PASS	PASS	FAIL
PPG	Isocyanate Free with Zinc	Dimetcote® 21-5 Water-based Epoxy Primer	N/A	PSX 700 Polysiloxane Finish	PASS	PASS	PASS	Equal	Equal	Equal	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS
Sherwin Williams	Contains Isocyanate with Zinc	Zinc Clad II+	646-100	Hi-Solids Polyurethane - 250	PASS	PASS	PASS	Equal	Equal	Equal	FAIL	FAIL	PASS	PASS	PASS	PASS	PASS	PASS	PASS





Next Step

- Evaluate coatings for use in Zone 1 = surfaces that are directly exposed to rocket motor exhaust



Manufacturer	Contains Zinc	Contains Isocyanates	Primer	VOC (g/l)	Intermediate	VOC (g/l)	Topcoat	VOC (g/l)
Carboline	YES	NO	Carbozinc 11 WB water-based inorganic-zinc	0	N/A	N/A	N/A	N/A
Carboline	YES	NO	Thermaline 4765	480	Thermaline 4001	407	Thermaline 4001	407
Dampney	YES	NO	Endcor 835 IOZ	358	N/A	N/A	230C silicone	372
GE	NO	NO	N/A	N/A	N/A	N/A	SCM3500 silicone roof coating	< 24
GE	NO	NO	Zinc Clad II+ inorganic ethyl silicate, zinc rich	< 320	N/A	N/A	SCM3500 silicone roof coating	< 24
International	NO	NO	N/A	N/A	Interbond 1202UPC	420	Interbond 1202UPC	420
International	YES	NO	Interzinc 22HS	290	Interbond 1202UPC	420	Interbond 1202UPC	420
PPG	YES	NO	Dimetcote 21-5 water-based inorganic-zinc silicate	0	Amerlock 2 VOC high solids epoxy	< 100	Pitt-Tech Plus 100% acrylic waterborne enamel	< 100
PPG	YES	NO	Dimetcote 21-5 water-based inorganic-zinc silicate	0	Amerlock 2 VOC high solids epoxy	< 100	PSX 700 epoxy siloxane	< 100
PPG	YES	NO	Amercoat 68HS Zinc Rich Epoxy	288	PSX 700 epoxy siloxane	< 100	PSX 700 epoxy siloxane (clear)	< 100
PPG	NO	NO	HI TEMP 1027	420	N/A	N/A	HI TEMP 1000VS	420
Sherwin-Williams	YES	YES	Zinc Clad II+ inorganic ethyl silicate, zinc rich	< 320	Macropoxy 646-100 Fast Cure Epoxy	< 100	Envirolastic 980	< 300

System that is expected to pass NASA-STD-5008B primer heat adhesion test; but the topcoat contains isocyanate

Approved per NASA-STD-5008B

Passed NASA TEERM / GSDOP testing

Coatings used at SSC in recent refurbishment project

Designed for operating temperatures up to 1,200 degrees F

KSC Corrosion Technology Lab Testing

Test	Test Specimen	Acceptance Criteria	Requirement	Test Methodology References
Pot Life	Mixed Coating System	Based on Applicator Evaluation: Equal to or better than control coating	NASA-STD-5008B	None
Ease of Application	Coupon	Based on Applicator Evaluation: Smooth coat, with acceptable appearance, no runs, bubbles or sags; Ability to cover the properly prepared/primed substrate with a single coat (one-coat hiding ability); Measure Dry Film Thickness.	NASA-STD-5008B	SSPC-PA-2
Surface Appearance	Coupon	Based on Applicator Evaluation: No streaks, blistering, voids, air bubbles, cratering, lifting, blushing, or other surface defects/irregularities; No micro-cracks observable at 10X magnification	NASA-STD-5008B	ASTM D 523 ASTM D 2244
Atmospheric Exposure	Coupon	Attain a rating of not less than 8 in accordance with ASTM D610; 18 months initial acceptance, 5 years for final acceptance	NASA-STD-5008B	ASTM D 610, ASTM D 714
Atmospheric Exposure	Coupon	Retain gloss and color on prolonged outdoor exposure	NASA-STD-5008B	ASTM D 523
Primer Heat Adhesion	Coupon	No loss of adhesion after heating @ 400 °C (750 °F) for 24 hours	NASA-STD-5008B	ASTM D 4541

KSC Corrosion Technology Lab Test Results

Manufacturer	Primer	Intermediate	Topcoat	Pot Life	Surface Appearance	Ease of Application	Primer Heat Adhesion
Carboline	Carbozinc 11 WB water-based inorganic-zinc	N/A	N/A	PASS	PASS	PASS	PASS
Carboline	Thermaline 4765	Thermaline 4001	Thermaline 4001	PASS	PASS	PASS	FAIL
Dampney	Endcor 835 IOZ	N/A	230C silicone	PASS	PASS	PASS	PASS
GE	N/A	N/A	SCM3500 silicone roof coating	PASS	PASS	PASS	N/A
GE	Zinc Clad II+ inorganic ethyl silicate, zinc rich	N/A	SCM3500 silicone roof coating	PASS	PASS	PASS	N/A
International	N/A	Interbond 1202UPC	Interbond 1202UPC	PASS	PASS	PASS	FAIL
International	Interzinc 22HS	Interbond 1202UPC	Interbond 1202UPC	PASS	PASS	PASS	PASS
PPG	Dimetcote 21-5 water-based inorganic-zinc silicate	Amerlock 2 VOC high solids epoxy	Pitt-Tech Plus 100% acrylic waterborne enamel	PASS	PASS	PASS	PASS
PPG	Dimetcote 21-5 water-based inorganic-zinc silicate	Amerlock 2 VOC high solids epoxy	PSX 700 epoxy siloxane	PASS	PASS	PASS	PASS
PPG	Amercoat 68HS Zinc Rich Epoxy	PSX 700 epoxy siloxane	PSX 700 epoxy siloxane (clear)	PASS	PASS	PASS	FAIL
PPG	HI TEMP 1027	N/A	HI TEMP 1000VS	PASS	PASS	PASS	FAIL
Sherwin-Williams	Zinc Clad II+ inorganic ethyl silicate, zinc rich	Macropoxy 646-100 Fast Cure Epoxy	Envirolastic 980	PASS	PASS	PASS	FAIL

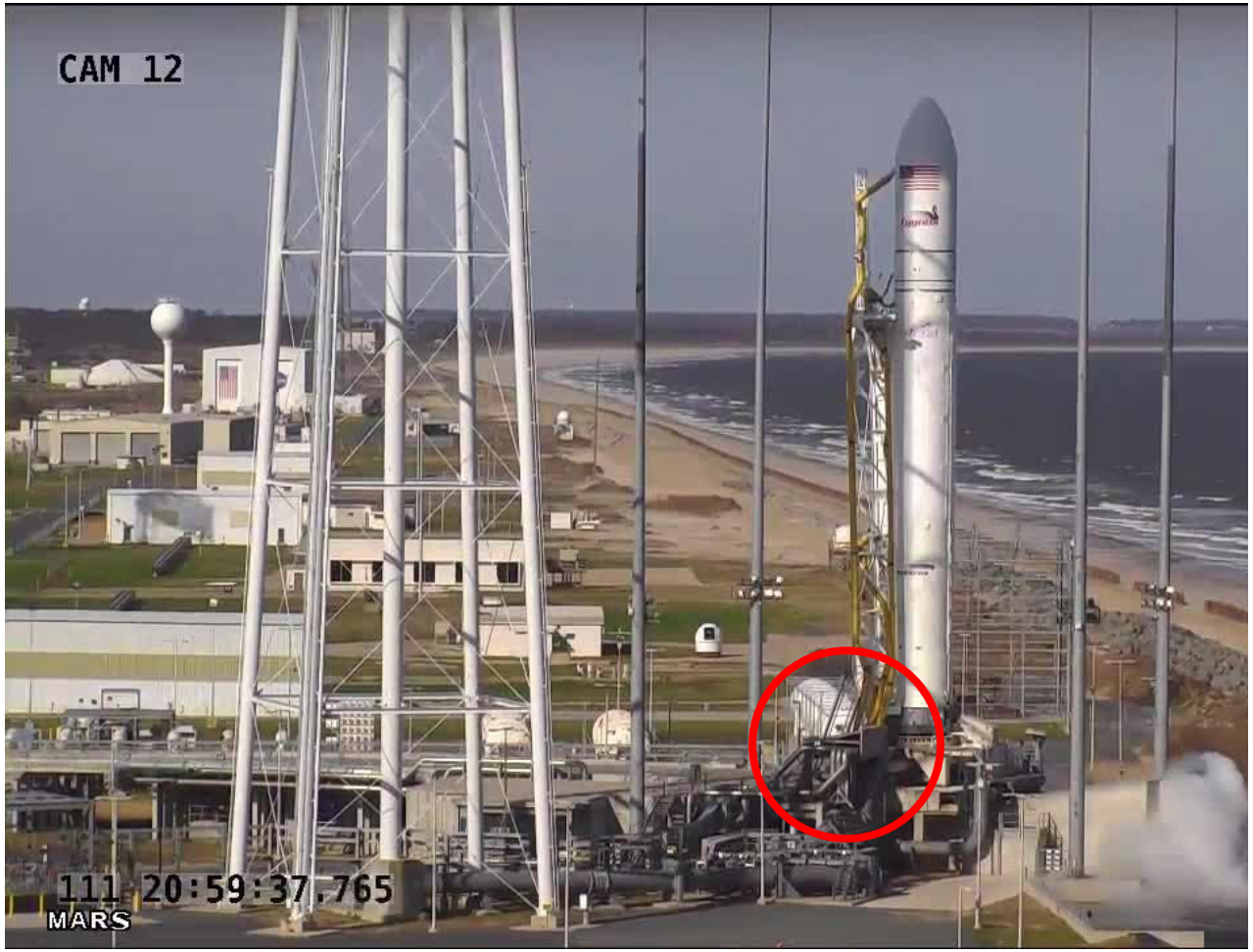
N/A - The adhesive used during testing did not adhere the dolly to the test panel

Wallops Flight Facility Field Testing

- Selected coatings designed for high temperature applications
- Testing primers only & primers with topcoats

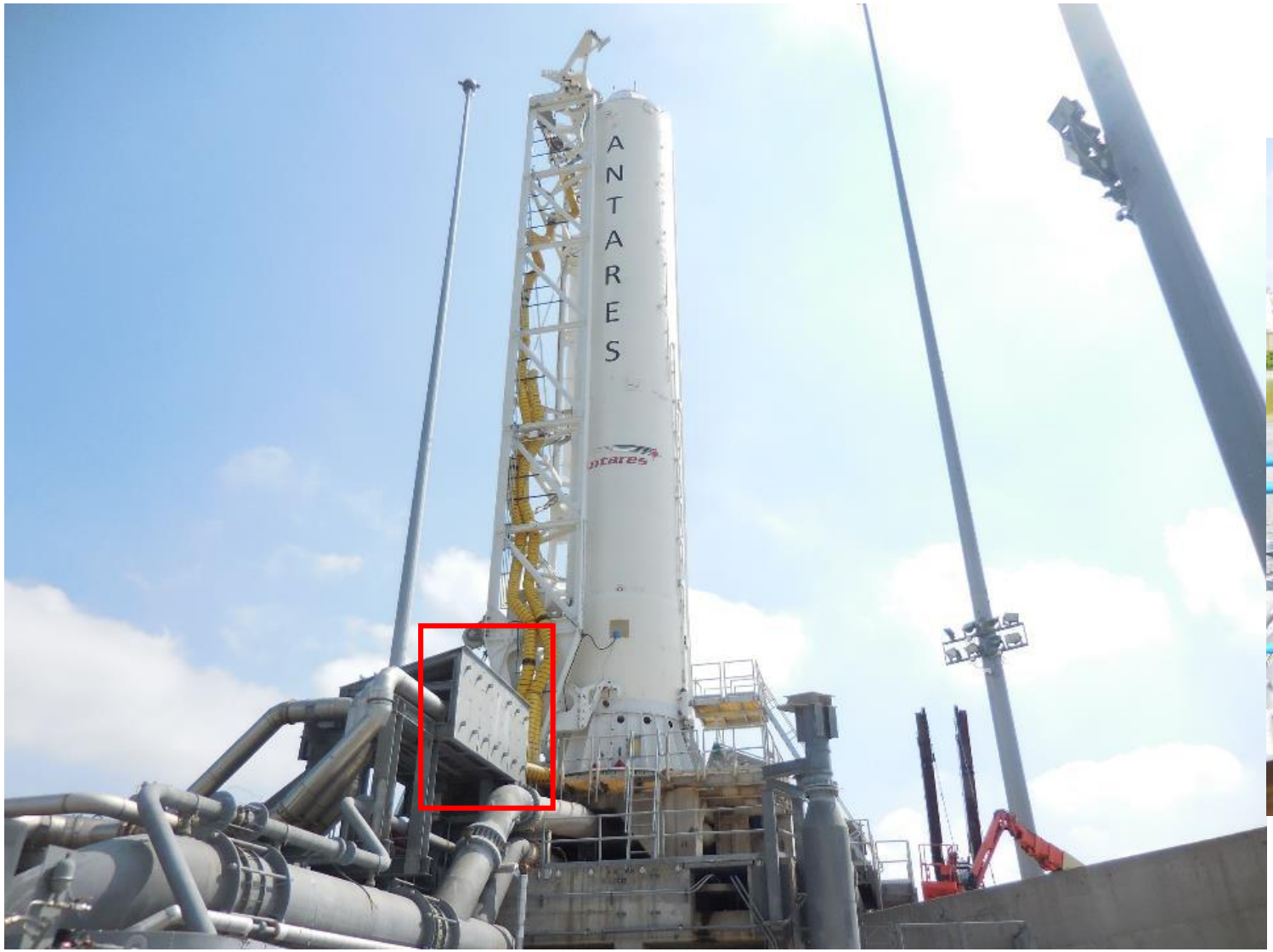
Manufacturer	Primer	Intermediate	Topcoat
Carboline	Thermaline 4765	N/A	N/A
		Thermaline 4001	Thermaline 4001
Dampney	Endcor 835 IOZ	N/A	N/A
			230C silicone
GE	N/A	N/A	SCM3500 silicone roof coating
International	Interzinc 22HS	N/A	N/A
		Interbond 1202UPC	Interbond 1202UPC

Wallops Flight Facility Field Testing – PAD 0A



Wallops Flight Facility Field Testing – PAD 0A

Wallops Flight Facility Field Testing – PAD 0A



Wallops Flight Facility Field Testing – PAD 0A; Corrosion Rate Analysis

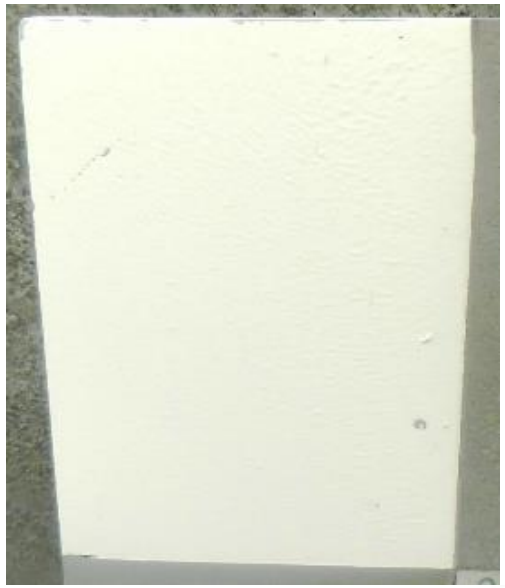
- 9 panels total; removed at 4 month intervals
- Looking at areas not directly impacted by rocket motor exhaust

Wallops Flight Facility Field Testing – Sounding Rocket MRL

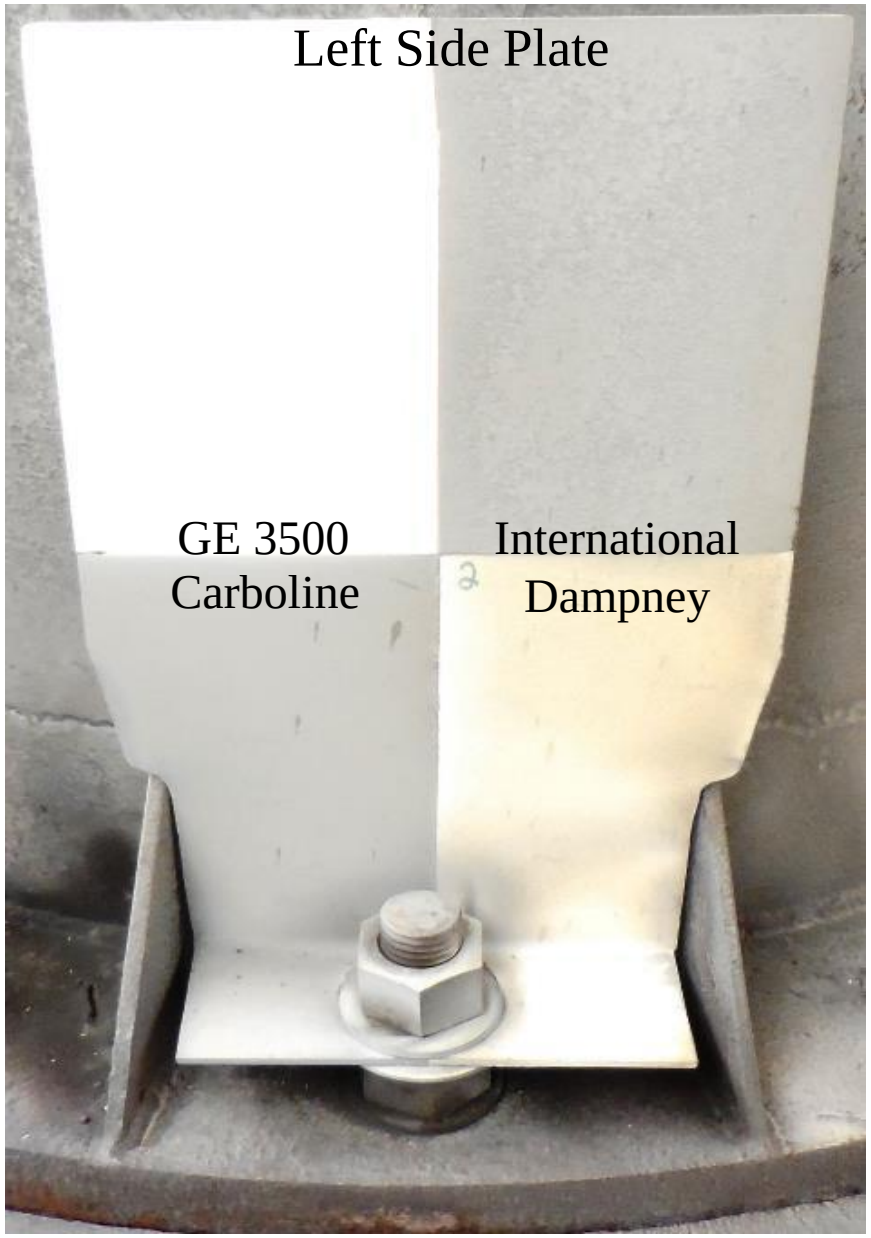
ID #	Manufacturer	Primer	Intermediate	Topcoat
1	Carboline	Thermaline 4765	Thermaline 4001	Thermaline 4001
2	Dampney	Endcor 835 IOZ	N/A	230C silicone
3	GE	N/A	N/A	SCM3500 silicone
4	International	Interzinc 22HS	Interbond 1202UPC	Interbond 1202UPC

TEERM

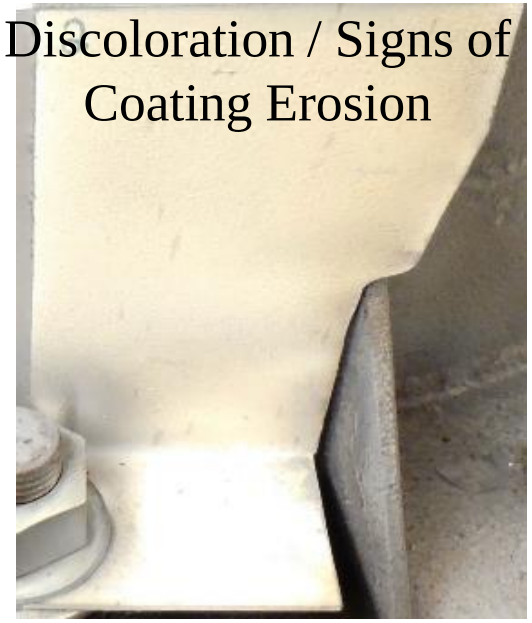
MK12 Terrier-Improved Orion rocket launched June 24, 2016




Limited Staining

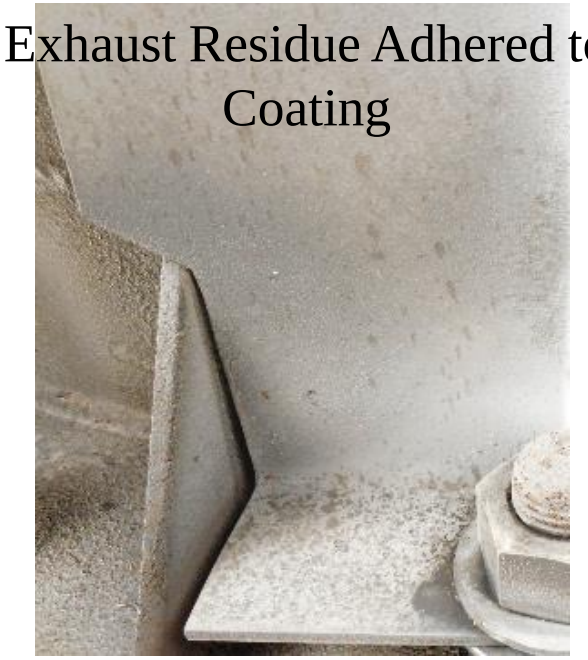

Left Side Plate
GE 3500
Carboline
International
Dampney


Coating Eroded


Discoloration / Signs of
Coating Erosion

Staining / Discoloration

Exhaust Residue Adhered to Coating



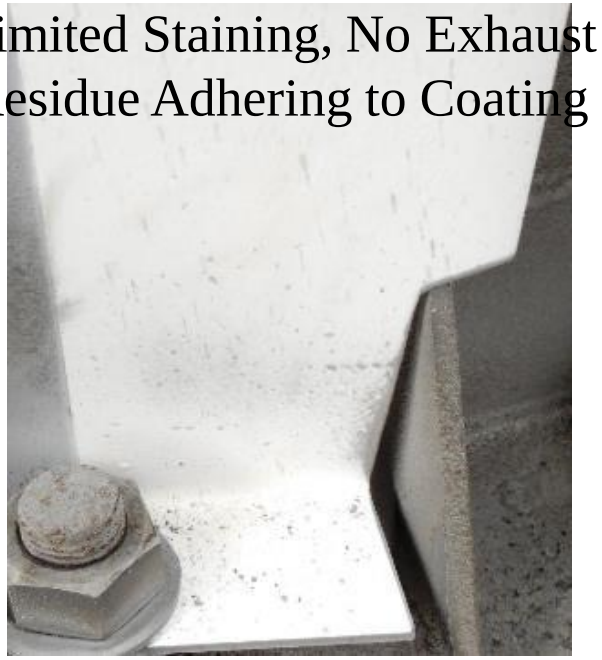
Right Side Plate

Dampney International

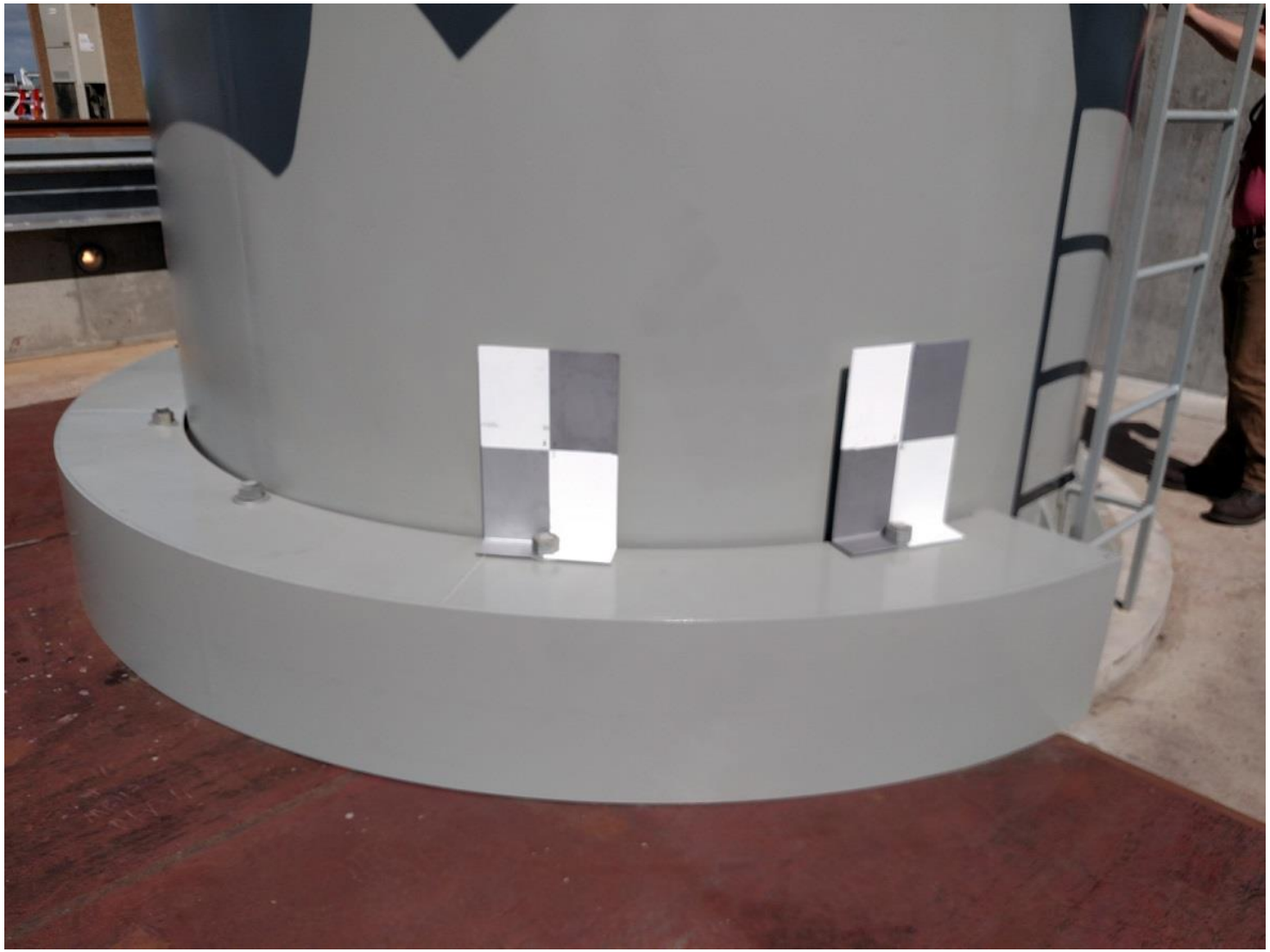
Carboline GE 3500

Staining

Limited Staining, No Exhaust Residue Adhering to Coating



Wallops Flight Facility Field Testing – Plates Secured to the New 50K Launcher



Questions?

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