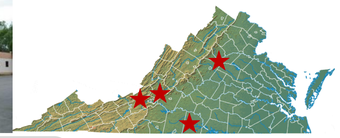
Hybrid, Ultra-Low VOC, Non-HAP Rain Erosion Coatings

Luna Innovations Inc. 706 Forest St. Suite A, Charlottesville, VA 22903 // SERDP BAA W912HQ-16-P-0007

Luna Innovations Overview



Luna Innovations Incorporated occupies more than 104,000 square feet of research, development, manufacturing and administrative space throughout Virginia for the development of healthcare, telecommunications, energy and defense solutions. Luna has over 60 scientists and engineers with expertise in chemistry, physics, materials science, optics, and a variety of engineering disciplines.

Objectives

Luna's limited scope program is focusing on the development of a rapid curing glycidyl carbamate (GC) based rain erosion coating system that has low volatile organic content (VOC), is hazardous air pollutant (HAP) free via the use of exempt solvent technologies, and does not contain any free isocyanates. We are requiring the data necessary to demonstrate proof-of-concept via validation testing (e.g. rain erosion testing at UDRI) against requirements in SAE AMS-C-83231A for application to radome composites and leading edges.

Luna's effort covers 12 months and involves four primary tasks:

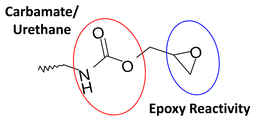
- coating design to achieve desired low/zero VOC and HAP-free formulation
- coating performance characterization testing
- rain erosion demonstration testing at UDRI
- next-step coating optimization, characterization, and transition planning

Project Overview

- Limited scope, 12-month duration
- Tasks focused on coating formulation, performance demonstration to SAE AMS-C-83231, and rain erosion testing (UDRI)
- Prepare formulation, processing, and EHS documentation
- Planning for full-scope project and DoD transition

Milestones of this program includes passing relevant specifications, such as SAE AMS-C-83231A and MIL-PRF-32239, demonstrating rapid application and reduced handling costs associated with a reduction in VOCs, HAPs and by eliminating free isocyanates from the coating formulation, and development of an extensive scale-up and qualification plan for a follow-on full-scope project to facilitate DoD transition with appropriate SERDP and Air Force personnel.

GC Chemistry



Luna's GC resin combines flexibility of polyurethane with epoxy functionality with no free isocyanates

Luna's Coating System Key Features

- Based on unique GC resin chemistry
- Rapid epoxy-type reactivity/cure
- Performance typical of urethanes
- Excellent durability, UV resistance, and chemical resistance
- Targeted VOC content of <100 g/L
- HAPs-free formulation
- No hazardous isocyanates

Objective 1: Formulate rain erosion coatings based on GC technology with ultra-low VOC and non-HAP materials
Rain erosion coatings will be formulated having both a primer and topcoat using the GC resin technology. The system will exhibit excellent adhesion to aircraft radome composites and other substrates (e.g. aluminum) and will provide maximum corrosion protection, hydrolytic stability, and rain erosion durability while being microwave transmissive.

Objective 2: Demonstrate that the coatings meet base relevant performance specification requirements
Rain erosion coating formulations will be evaluated against metrics in AMS-C-83231A and MIL-PRF-32239. Variants will be initially screened via rain erosion assessment using a custom ultrasonic cavitation stand built by Luna.

Objective 3: Demonstrate technology efficacy via rain erosion testing
Down selected coating systems will be tested at UDRI for rain erosion resistance on AFRL's specialized test rig in accordance with SAE AMS-C-83231A requirements. Coating system variants will be compared to relevant qualified rain erosion coatings.

Rain Erosion Protection Technologies

Rain erosion protection is needed in two areas to increase operational readiness of aircraft:

Leading Edges: Left unprotected, rain, wind, dust, sand and F.O.D. can erode the paint and primer. Eventually the substrate and/or the integrity of the leading edge can be damaged.

Radomes: Damage to radomes can result in the loss of radar transmission capabilities, communication in aircraft and an increase in drag in both aircraft and missiles.

Method	Advantages	Disadvantages
Urethane Coatings	- Compatible with traditional spray methods in depots and in the field - Specialized for different applications: leading edges vs. radomes - Historical data suggests 2-3 year longevity of many COTS coatings	- COTS coatings do not pass 180 minutes of testing at UDRI per SAE AMS-C-83231 - Wet adhesion and UV stability issues - Very thick films (10-14 mil) required - High in VOCs and Isocyanates
Protective Tapes	- Fast, safe and easy application - Doesn't require spray or long dry times, reducing applicator man hours - Can significantly reduce maintenance, repair and overhaul costs and extend service life	- Difficult to apply to odd shapes, interfaces, fasteners and seams - Frequent replacements and material costs - Noise and drag generation
Surface Engineered Coatings	- Nanometer thick, extremely durable ceramic or metal coatings - High strength coatings reduce weight compared to paints or tapes - A wide variety of erosion resistant thin films for metal substrates	- Time and energy intensive coating processes - Expensive ceramics, metals, and alloys - Difficult field application and repair

Rain Erosion Tapes for Leading Edges

Coated vs. Uncoated Leading Edges

Flexibility and Toughness

Engineers at Luna have determined that a combination of flexibility and toughness, combined with excellent adhesion and hydrolytic stability, can lead to increased durability in rain erosion coatings for radome composites and leading edges.

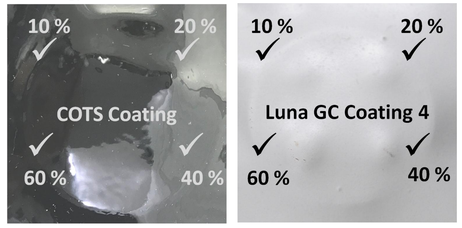
Fast, lab scale testing to evaluate coating properties will allow for the down selection of rain erosion formulation variants.

A combination of GE Reverse Impact testing, low temperature mandrel bend, and both wet and dry adhesion will help determine the best coatings to evaluate via ultrasonic cavitation and full scale testing at UDRI's rain erosion test rig.

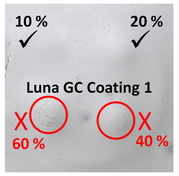
Impact Testing

Luna's GC Rain Erosion Coating 4 matches traditional COTS products (ASTM D6905):

- Pinhole free, 60% impact flexibility with a low VOC, non-HAPs coating
- Incorporation of adhesion promoters and highly flexible amine curatives boosts the performance properties of Luna's GC resin technology



Flexibility and Adhesion



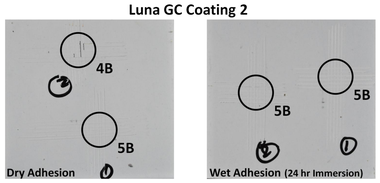
Room temperature and low temperature (-54 °C) mandrel bend testing demonstrates the flexible nature of both the COTS coating and Luna's GC Rain Erosion Coating 4 – ASTM D522

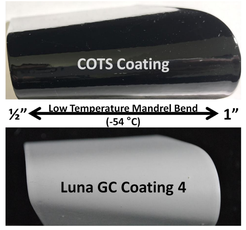
- Coated AA 2024 T0 Panels withstand 1" to ½" bends without delamination or failure
- Both room temperature and low temperature bending resulted in pinhole free coatings

Wet and dry adhesion cross hatch tape testing was performed on thin films of Luna's GC Rain Erosion Coatings (4-5 mil). Wet adhesion occurred after a 24 hr DI water soak – ASTM D3359

- Luna's GC Rain Erosion Coating 2 outperformed the more flexible Coating 4
- Luna has determined that there is a trade off between flexibility and adhesion

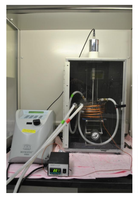
Luna GC Coating 2



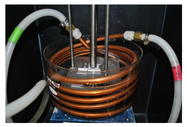


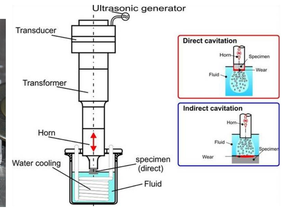
Rain Erosion Qualification

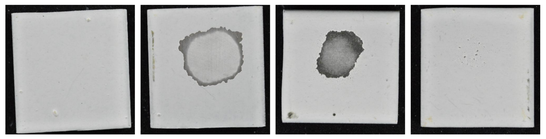
Ultrasonic Cavitation



Modified ASTM G32: Standard Test Method for Cavitation Erosion Using Vibratory Apparatus







Untested Coupon | 10 min, 0.5 mm | 10 min, 1.0 mm | 10 min, 3.0 mm

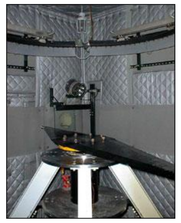
Luna is using ultrasonic cavitation (Modified ASTM G32 - Cavitation Erosion Using Vibratory Apparatus) as a rapid test method surrogate to formal rain erosion testing. By using the indirect method, Luna will create artificial cavitation/erosion conditions on the surface of the coated substrates. With appropriate conditions in place, this will allow formulations to be down selected and compared to the COTS rain erosion coating prior to full scale testing at UDRI. With success, Luna will attempt to correlate test parameters to full scale rain erosion testing on airfoils at UDRI.

Variables: Tip to coating distance, coating thickness, time, power output, substrate pretreatment

Rain Erosion Testing (UDRI)

The AFRL Particle Erosion Test Apparatus is capable of attaining constant velocities between 100 and 900 mph. Test specimens are exposed to a calibrated one inch per hour simulated rainfall. Raindrop impact is randomly distributed over the exposed surfaces of the test specimens.

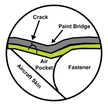
- 500 MPH, 12-14 mil thick coating, 150 minute survival (AMS-C-3231A)
- Luna's goal of 180 minutes under these conditions without coating removal, pitting, or delamination
- COTS coatings can only withstand approximately 120 minutes of testing



Projected Impact

Enhanced Protection

Luna's GC based coating systems are being designed to replace and outperform conventional polyurethane based rain erosion coatings for radomes and nose cones. Additionally, chrome-free GC coatings are being developed to replace conventional flexible primers for aircraft leadings edges, fasteners, and outer mold lines (Contract # FA8650-16-M-5063).



Luna's ultra-low VOC, non-HAP rain erosion coating is based on a unique hybrid resin chemistry that has been demonstrated to offer rapid epoxy-type reactivity and good adhesion combined with the excellent erosion, flexibility, weathering, and chemical resistance typical of polyurethanes. The coating contains little to no VOC content and is non-HAPs via the use of exempt solvent technologies. The excellent performance of the coating chemistry is achievable without the use of free isocyanates, thereby offering improvements in terms of applicator occupational safety.

Low VOC, Non-HAP Coatings

Protective coatings often contain large quantities of (VOCs), HAPs, and isocyanates which are hazardous and may be prohibited in the future under the Prohibited and Controlled Chemical List (PCCL). VOCs and HAPs are known to cause cancer and other serious health impacts. A drastic reduction in these hazardous compounds in coatings will lead to significant environmental and occupational safety improvements.

Source: Ozone Basic Information. U.S. EPA/Particulate Matter. Basic Information. U.S. EPA

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