FLIGHT TESTING SURFACES ENGINEERED FOR MITIGATING INSECT RESIDUE ADHESION ON A FALCON HU-25C

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Introduction

Insect residue contamination on aircraft wings can decrease fuel efficiency in aircraft designed for natural laminar flow. This contamination can cause a premature transition to turbulent flow, increasing fuel burn rate and making the aircraft less environmentally friendly. In the past, researchers have addressed this issue using various innovations including mechanical scrapers, protective coverings, and active liquid discharge systems.[1] However, these methods have not been implemented commercially due to increased operational complexity and added weight.

Coatings offer several advantages. In addition to being lightweight, they are a passive mitigation technology. In prior work, it was determined that most commercially available materials were not effective at mitigating insect residue adhesion.[2] In this effort, eight engineered surfaces were chosen for evaluation of insect residue mitigation effectiveness using a Falcon HU-25C aircraft based on laboratory characterization and wind tunnel testing using fruit flies.[3]

Figure 1: Photograph of the HU-25C with research and control panels installed prior to flight test 2.

Experimental

Aluminum (Al) 1100 (.08 mm [0.003"] thickness) was used as the test substrate. The entire 2 m (7 ft) long outboard slat on both wings of the HU-25C Falcon was covered with Al 1100 panels that were cut to fit the airfoil shape. This area was divided into four evenly spaced regions, span-wise, resulting in a total of eight panels for each test flight. Four of the eight panels were spray-coated with select materials and the remaining four were left uncoated to serve as controls. The panels were arranged so each test flight would have control panels (i.e. bare Al 1100) next to each experimental coated surface. This arrangement was chosen in an attempt to the address the variability of insect species and density throughout the flight testing period.

The Al panels were spray-coated with eight different compositions consisting of a series of research copolyimides and epoxies, and two commercial-off-the-shelf (COTS) products (Table 1). These coatings were selected due to promising results observed in bench-top and large (the Basic Aerodynamics Research Tunnel [BART] located at NASA Langley Research Center) wind tunnel testing.

Table 1: Coatings evaluated on the Falcon HU-25 flight test

	Composition	Roughness, R_a (µm)	Sessile Water Contact Angle (°)
1	Copolyimide with MoS_2	12.3	134
2	Research Epoxy with MoS_2 and SiO_2	1.0	109
3	Copolyimide with SiO_2	7.0	117
4	Copolyimide with MoS_2, SiO_2, Ni, $ZnFe_4O_4$	5.5	84
5	Research Epoxy	0.4	99
6	COTS 1	0.3	110
7	Research Epoxy with MoS_2	0.9	107
8	COTS 2	8.0	134

The panels were mounted to the wing leading edge using 50 mm (2") wide 3M™ Al Foil Tape, with coated and control surfaces mounted in an alternating configuration. Two cameras were installed in the aircraft to record insect impacts. A Nikon D800 camera was used to capture still images (resolution of 1200 by 800 pixels) at 10 s intervals throughout the test flight. A Phantom 300 camera was used to capture high speed video at 5000 frames per second (Figure 2). Due to the large file size and prolonged data download time from the Phantom camera, 1.5 second duration videos were collected on an event-triggered basis, such as during initial take-off, during decent, or upon observation of a particularly large insect impact within the viewing area. Recording half of the frames before the manual record triggering enabled capture of an impact event after it was observed in real time.

Figure 2: Camera mount used for flight testing.

The aircraft flew at altitudes ≤300 m (1000 ft.) to assure high insect density[4] along flight paths in the tidewater regions of Virginia and North Carolina in August, 2013. The aircraft was flown at 1.3 V_{stall} (the velocity at which the aircraft would stall) with slats fully deployed to represent take-off and landing slat positions. Flight operations included flying at 300 m (1000 ft.), low approaches, touch-and-goes, and landing with a full stop at the completion of the flight test.

For all panels, the insect residues were counted and numbered. The chord position, measured as distance from the stagnation line, was recorded for each insect residue. A representative leading edge section was then cut from the panels which consisted of an 80 mm (3") strip surrounding the stagnation line in order to measure height and areal coverage for each insect residue within this region.

Insect residue height and area were measured using a FRT of America optical surface profilometer (Microprof 100). The insect residues were scanned using a resolution of 5 µm between data points and 20 µm between scan lines. Surface roughness was determined from scanned regions not containing insect residues. Contact angle measurements were collected using an FTA1000B goniometer (First Ten Angstroms). Measurements were collected using 8 µL water droplets and a minimum of three measurements was taken.

Results and Discussion

Through visual inspection, the number of residues counted on the engineered surfaces was lower than the untreated Al control surfaces flown concurrently, with the exception of coating 6. Figure 3 shows the number of insect strikes on the coated surfaces in relation to the control panels, for both the leading edge and the whole panel.

Although coatings 1 and 8 had the largest percent reduction in number of insect strikes, the coatings did not adhere well to the Al surface and could be readily removed with mild abrasion. This indicated that, although they might be beneficial as sacrificial coatings, they did not have the necessary durability to operate as a persistent coating in a commercial application. Coatings 3 and 4 were also shown to have this durability issue.

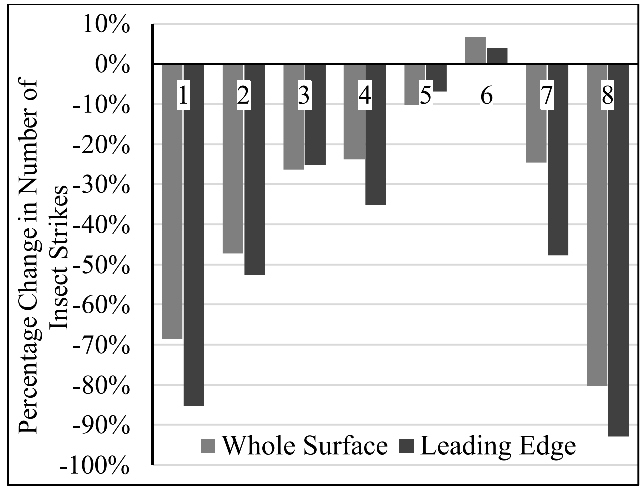

Figure 3: Change in number of bug strikes for the whole surface and leading edge compared to control

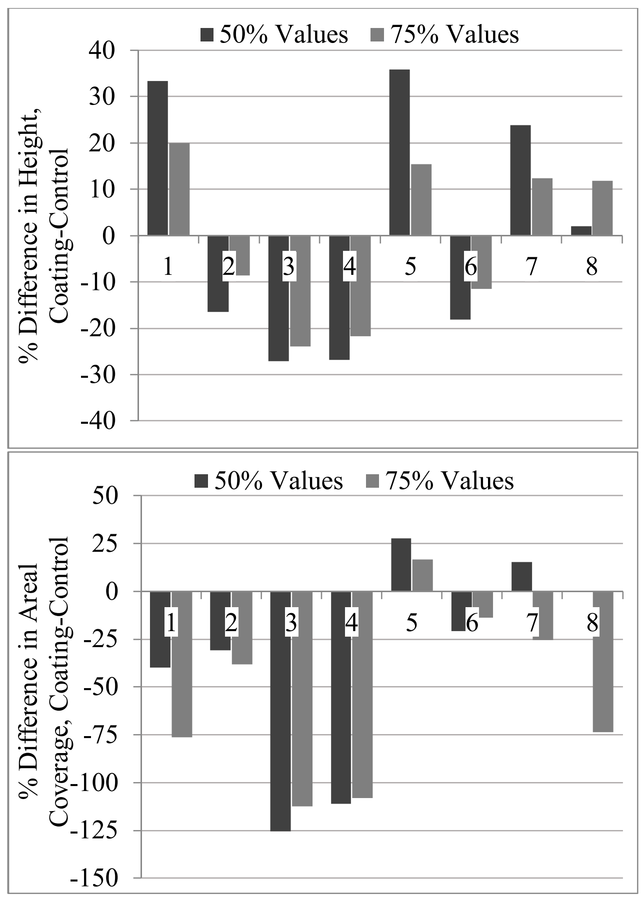

Figure 4: Median and third quartile height (top) and area (bottom) changes

Height and area were measured for insect residues seen within the leading edge region. Because of the variability in the data collected, i.e., differences in insect size, angle of attack, aircraft speed, etc., a strict comparison of height and areal coverage was determined to be inconclusive. Figure 4 shows a comparison between the coated and uncoated surfaces for median and third quartile values of the insect residue height and areal coverage. Coatings 2, 3, and 4 had a visible reduction in number of residues (Figure 3), as well as a greater number of residues with lower height and areal coverage relative to the other coatings and control surfaces.

Since coatings 2, 5, and 7 are comprised of the same resin and differ only by the fillers, additional comparisons can be made within this subset. The filler in coatings 2 and 7 was included to modify the surface topography with coating 7 containing MoS_2 filler (diameter ≤ 2 μm) and coating 2 containing both MoS_2 and SiO_2 (diameter ≤ 7 nm). These topographical modifications resulted in increased roughness (Table 1) and reduced insect residue adhesion. Coatings 2 and 7 also exhibited a larger reduction in the number of insect residues observed on the surface than coating 5. Based on previous experiments using high speed photography in small wind tunnel testing, these differences likely arise from reduced wetting of the surface by residues from insect impact events.

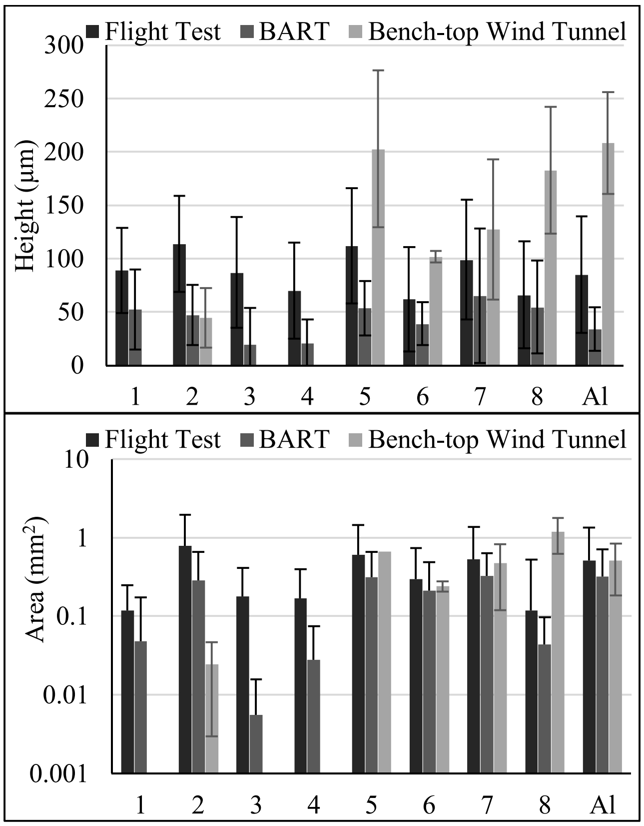

Figure 5: Height (top) and areal coverage (bottom) comparison of the coatings between levels of testing

Although it is difficult to validate conclusions from the coatings with low durability, a comparison due to surface topography can be made for coatings 1, 3, and 4, since these coatings were generated from the same copolyimide matrix. Coatings 1 and 4 show a larger reduction than coating 3 in the number of visible insect strikes on the leading edge. All three coatings performed well in reducing the area of the observed insect strikes in the leading edge region suggesting that the wetting properties of these coatings are different from the control.

The insect residue features from the flight test were also compared to those obtained from both bench-top wind tunnel and BART tests[3] (Figure 5). The average height and areal coverage of insect residues from flight testing does not directly correlate with results from ground testing experiments. This is likely due to the differences in flight conditions and types of insects encountered. Since the flight test best represents the anticipated operational environment for these coatings, this discrepancy with ground testing further validates the importance for future flight testing to properly evaluate coating performance.

Conclusion

Engineered coatings were flight tested to evaluate their effectiveness towards insect residue adhesion mitigation. Coatings with both controlled surface chemistry and topographies yielded a reduction in the number of visible insect residues, as well as reduced height and areal coverage of the residues relative to control surfaces. Differences in results between flight and laboratory test results validated the importance of testing in realistic use environments to evaluate the effectiveness of engineered surface designs.

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