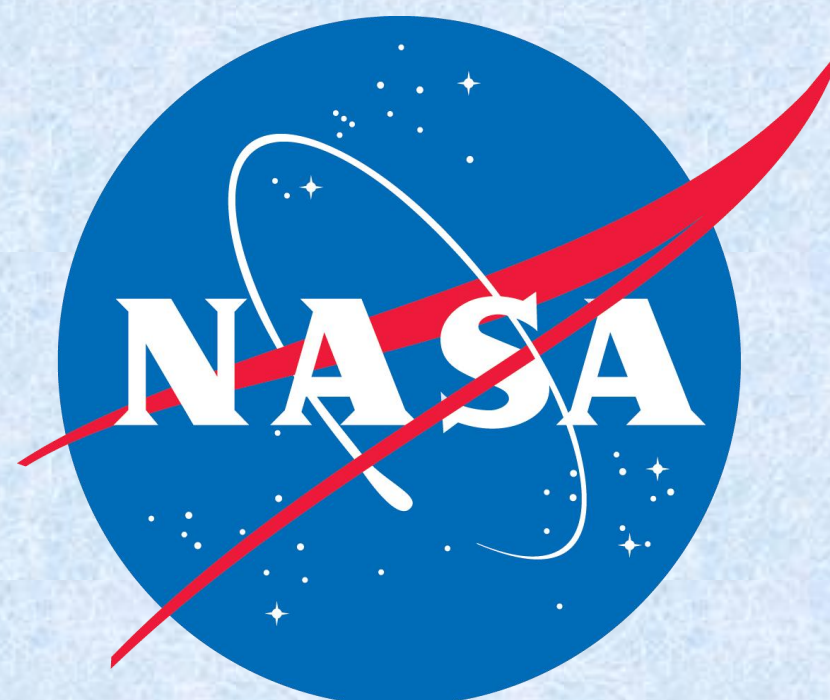
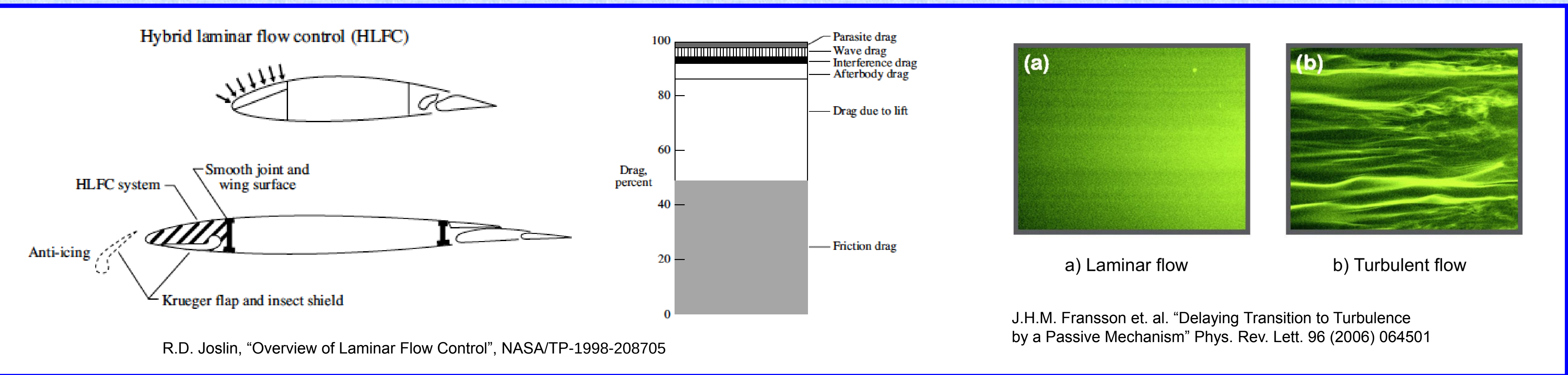


Mitigation of Insect Residue Contamination on Hybrid Laminar Flow Control Leading Edge Surfaces: Part 1. An Investigation of Commercially Available Materials

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Introduction



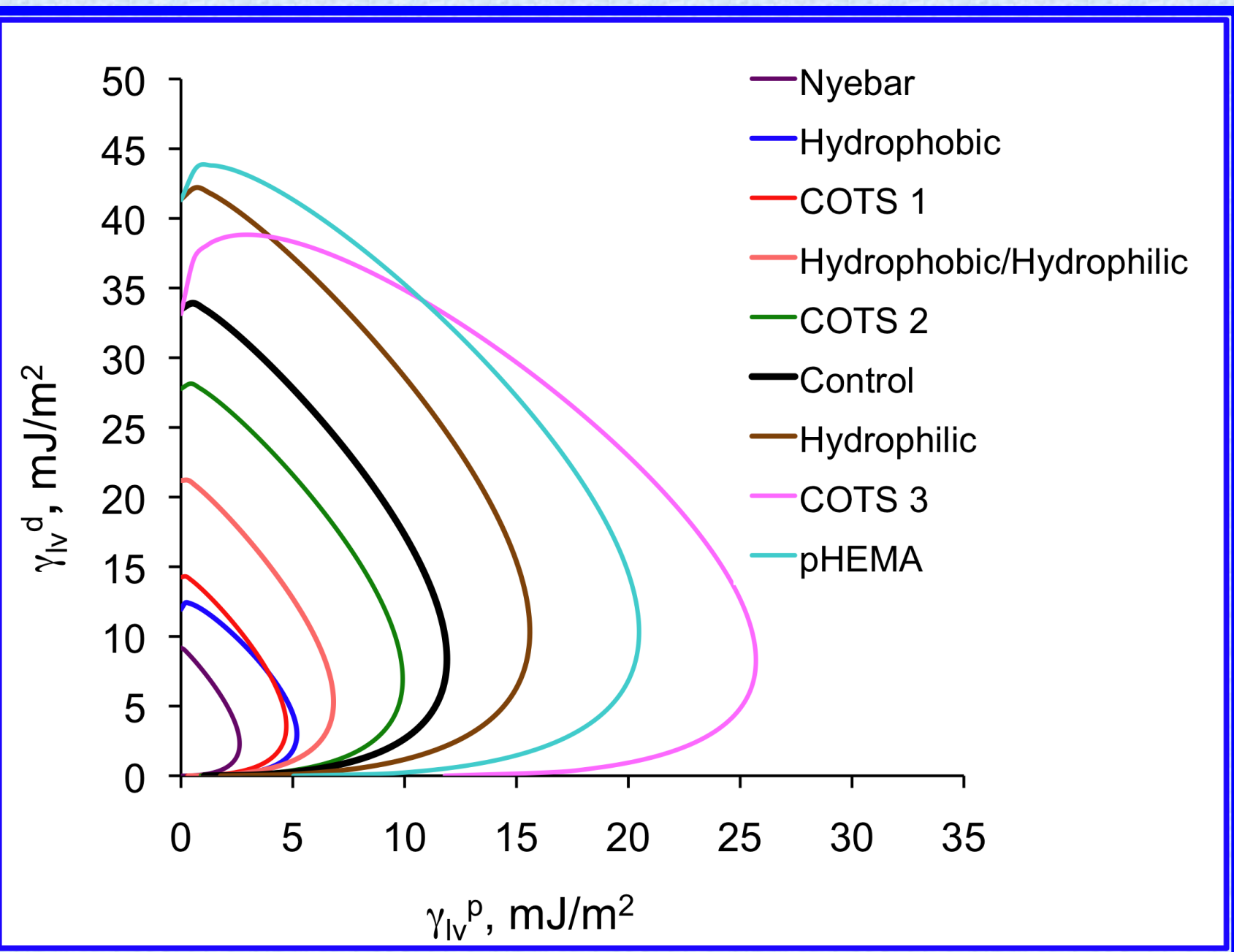
Flight tests have demonstrated that in many operational environments, insect residue buildup on the leading edge of an aircraft wing can cause the loss of laminar flow. The airborne insect threat occurs between ground level and 152.4 m with the highest population concentration occurring during light winds (2.6 – 5.1 m/s), high humidity, and temperatures between 21-29° C. Under these conditions, mitigation is needed during takeoff, initial climb, approach, and landing. When insect fouling reaches a critical height, laminar flow is disrupted leading to increased drag and hence additional fuel consumption for the duration of the flight. This critical height is highly dependent upon the airfoil and Reynold's number. Several techniques (e.g. paper, scrapers, surfactants, flexible surfaces, etc.) investigated to date have the potential to mitigate this problem; however, implementation has proven to be impractical thus limiting their utility. For example, the Krueger flap (illustrated above) has been shown to negate insect excrescence from the wing leading edge while also improving lift during takeoff. However its complexity and physical discontinuities may induce early boundary layer transition on the lower surface.

Experimental

Coated Al 2024 Sessile Drop Surface Energies, mJ/m²

Coating	γ^d	γ^p	γ^-	γ^+	γ^{total}
	Dispersive	Polar	Base	Acid	Total
Nyebar	9.2	0.0	1.0	0.0	9.2
Hydrophobic	12.0	0.9	0.8	0.3	12.9
COTS 1	14.3	0.3	2.4	0.0	14.5
Hydrophobic/Hydrophilic	21.2	0.3	8.8	0.0	21.5
COTS 2	27.8	0.9	3.4	0.1	28.6
Control	33.5	1.1	6.1	0.0	34.6
Hydrophilic	41.4	1.8	27.1	0.0	43.1
COTS 3	33.2	11.8	45.7	0.8	45.0
pHEMA	41.3	5.0	24.4	0.3	46.3

Wetting Envelopes For Coated Surfaces



Coatings can potentially prevent insect residue adhesion to the HLFC surface of the wing leading edge. Initial work focused on the evaluation of several commercially available products [Commercial Off The Shelf (COTS)], polymers, and substituted alkoxy silanes that were applied to aluminum (Al) 2024 substrates. Surface energies of these coatings were calculated from sessile drop contact angle data generated using water, ethylene glycol and methylene iodide obtained using a First Ten Angstroms FTA1000B Goniometer. Wetting envelopes generated from sessile drop surface energy data were used to determine the influence of surface energy on insect excrescence adhesion on coated Al substrates tested in a Bug Impact Facility. Similar surface energy and wetting envelope trends were observed for contact angle data based on the advancing and receding drops.

Grace's Insect Medium

Appearance (Turbidity) clear			
pH 6.1 - 6.5			
Osmolality, mOs/kg 355 - 375			
Glucose Concentration, g/L 0.60 - 0.80			
Medium Components			
Amino Acids		Vitamins	
β -Alanine	L-Isoleucine	p-Aminobenzoic Acid	Niacin
L-Alanine	L-Leucine	D-Biotin	D-Pantothenic Acid 0.5 Ca
L-Arginine HCl	L-Lysine HCl	Choline Chloride	Pyridoxine HCl
L-Aspartic Acid	L-Methionine	Folic Acid	Riboflavin
L-Asparagine (anhyd)	L-Phenylalanine	myo-Inositol	Thiamine
L-Cytosine 2HCl	L-Proline		
L-Glutamic Acid	DL-Serine		
L-Glutamine	L-Threonine	Inorganic Salts	
Glycine	L-Tryptophan	CaCl ₂ (anhyd)	KCl
L-Histidine	L-Tyrosine 2Na	MgCl (anhyd)	NaHCO ₃
	L-Valine	MgSO ₄ (anhyd)	NaH ₂ PO ₄
Other			
		D(-)-Fructose	α -Ketoglutaric Acid
		Fumaric Acid, free acid	L(-)-Malic Acid, free acid
		D(+)-Glucose	Succinic Acid
			Sucrose

Comparison of Water and Grace's Medium

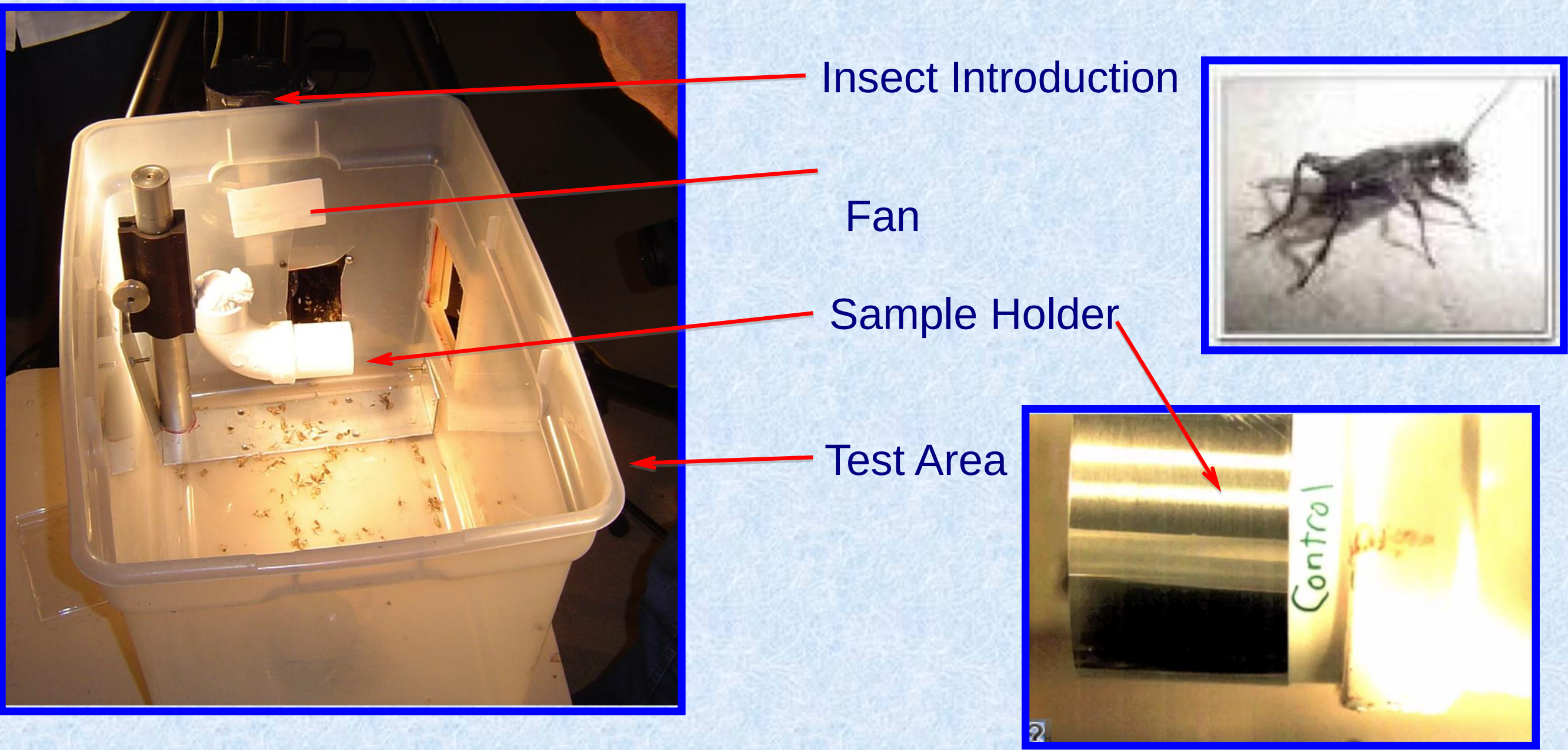
Surface	Condition	Grace's	Water
		Contact Angle, °	Contact Angle, °
Nyebar	Sessile	118.3 ± 0.8	117.8 ± 0.4
	Receding	99.7 ± 1.1	102.3 ± 2.5
	Advancing	122.8 ± 1.5	126.0 ± 3.9
COTS 1	Sessile	108.5 ± 1.3	106.6 ± 1.5
	Receding	90.1 ± 0.8	88.1 ± 1.9
	Advancing	112.0 ± 1.7	108.2 ± 1.6
Control	Sessile	95.9 ± 1.0	86.8 ± 3.1
	Receding	78.0 ± 1.1	72.9 ± 3.3
	Advancing	97.7 ± 1.0	91.2 ± 2.0
COTS 2	Sessile	97.0 ± 1.9	95.7 ± 0.7
	Receding	79.0 ± 2.7	75.2 ± 1.4
	Advancing	99.7 ± 1.3	99.5 ± 1.0
pHEMA	Sessile	49.3 ± 8.6	54.6 ± 7.2
	Receding	37.0 ± 7.4	34.2 ± 7.2
	Advancing	66.0 ± 6.8	68.3 ± 5.6

To gain a better understanding of the surface interactions influencing adhesion of insect excrescence to various coatings, contact angle measurements were also performed using an insect cell-growth medium (Grace's) designed to simulate insect (e.g. Australian emperor gum moth) hemolymph. The contact angle of the Grace's Insect Medium was found to be comparable to that of water on several of the surfaces even though it contained numerous components.

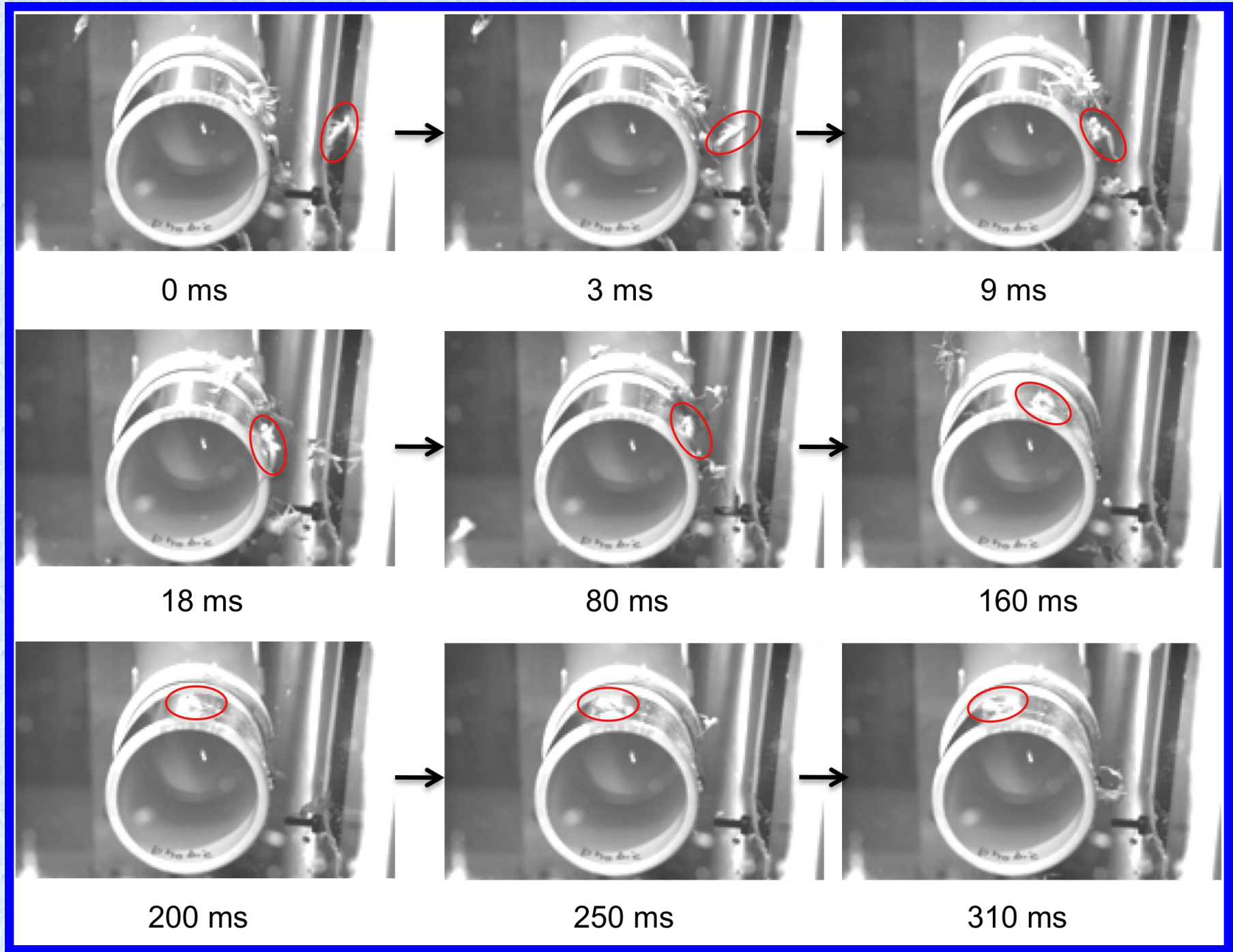
Testing

The coatings were applied to thin sheets of Al 6061 as stated by the manufacturer or by spray coating. The coated Al strips were subsequently mounted on a 5 cm diameter PVC pipe and placed in a Bug Impact Facility that was constructed in-house. The bug gun consisted of PVC piping and a fan operating at 3160 rpm. Test specimens were located approximately 2.54 cm from the bug gun muzzle. Testing was conducted at ambient temperature (~22° C) and 43-51 % relative humidity using bait crickets as the insect. Approximately 60 mL of crickets were poured through the gun barrel per shot. A majority of the insects were chopped by the gun fan prior to exiting the gun barrel and impacting the test article. The exit velocity of the insects ranged from 5 to 46 km/h with an average velocity of 21 km/h. High speed video was acquired during the test and static photographs were taken after the test was completed.

Bug Impact Facility



High Speed Video



Results

Images of Post Test Specimens

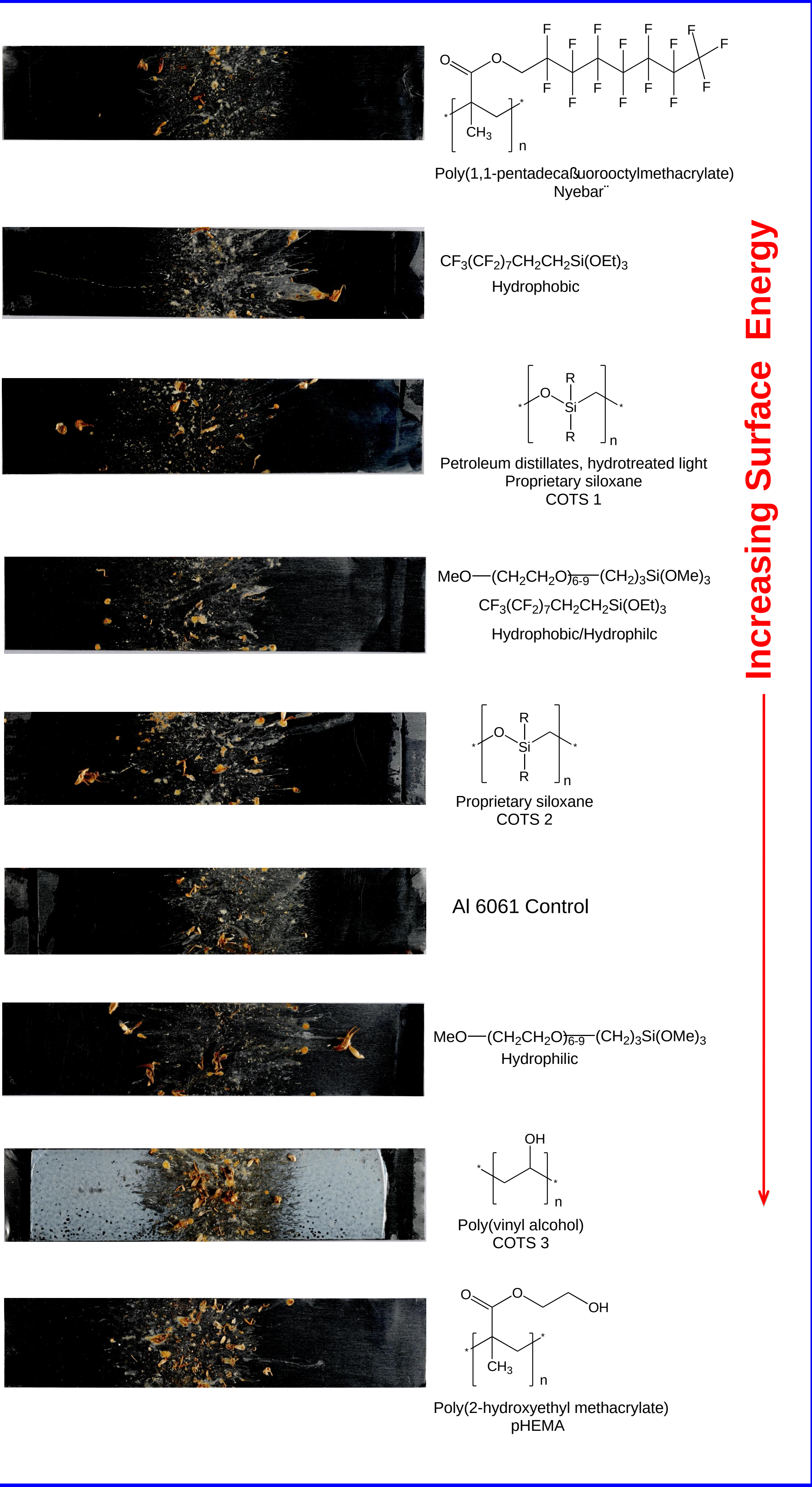
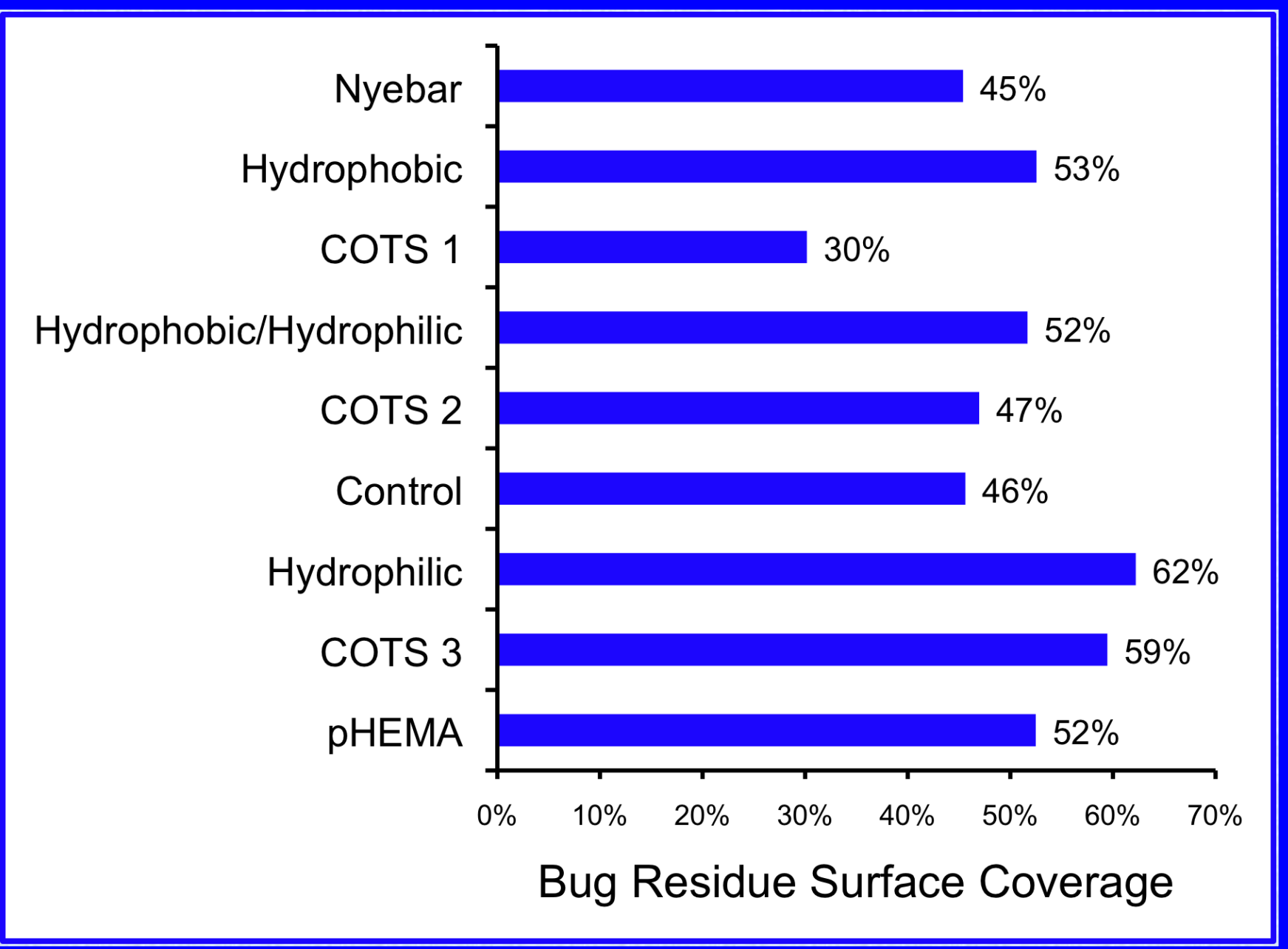
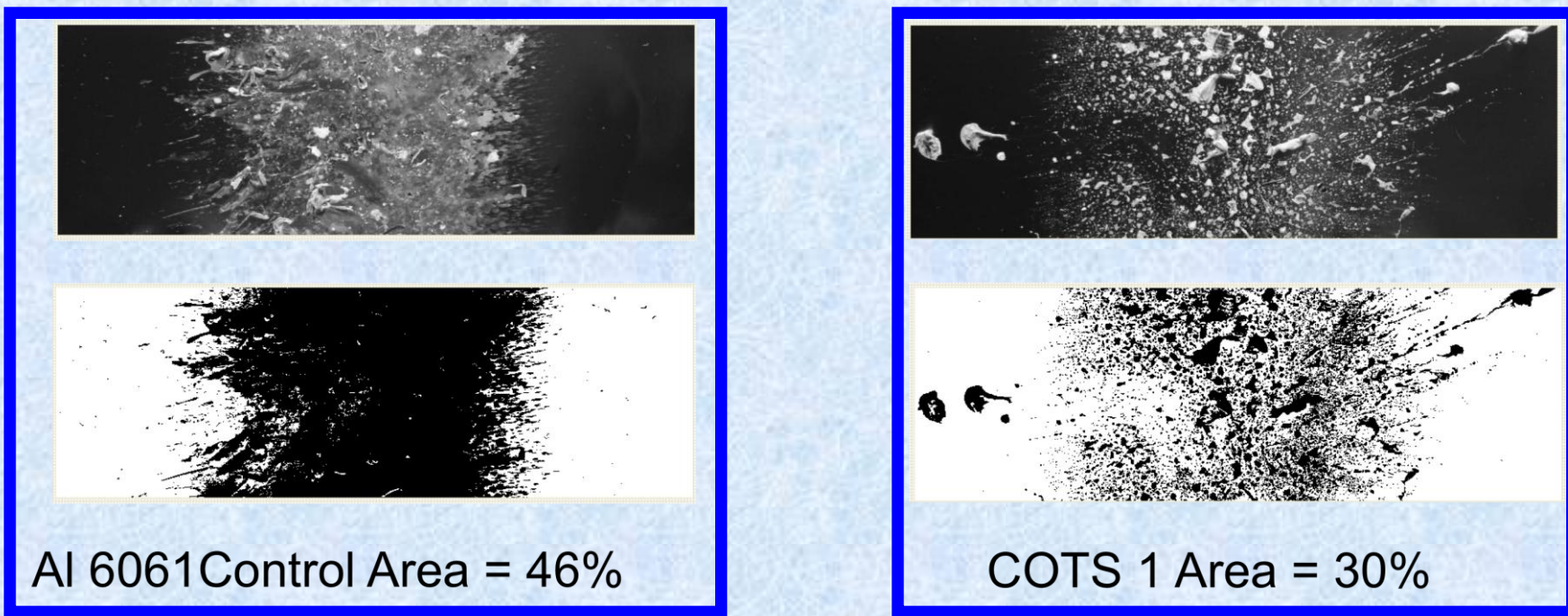


Image Processing

The per cent bug residue was determined by acquiring images using a UV flash bulb, extracting the green plane using XnView, and processing the images using IMAQ Vision Builder. The images were cropped to a standard size (same pixel area) and then run through a series of scripts to filter the image, converting it to binary, and calculating the areas (black and white). The per cent bug residue was then determined from the ratio of the black to white areas.



Conclusions and Future Work

- The surface energies of coated Al substrates were found to follow the expected trend based on chemical structure.
- Samples that had wetting envelopes less than the Al control (i.e. lower surface energy) tended to perform better.
- However all samples still accumulated significant residue regardless of surface energy implying that surface energy is only one of the factors contributing to reduced insect fouling.
- The per cent bug residue determined from image analysis of coated Al foils impacted with crickets correlated well with visual analysis for coverage. However the 2D image analysis did not take into account residue height which is critical to HLFC performance.
- Grace's bug medium, similar to insect hemolymph, was determined to exhibit similar contact angles as water even though it contained ~3% of added materials. Thus water is a good representative for surface screening.
- Future work will look into other approaches and 3D image analysis.

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