



Insect Residue Contamination on Wing Leading Edge Surfaces: A Materials Investigation for Mitigation

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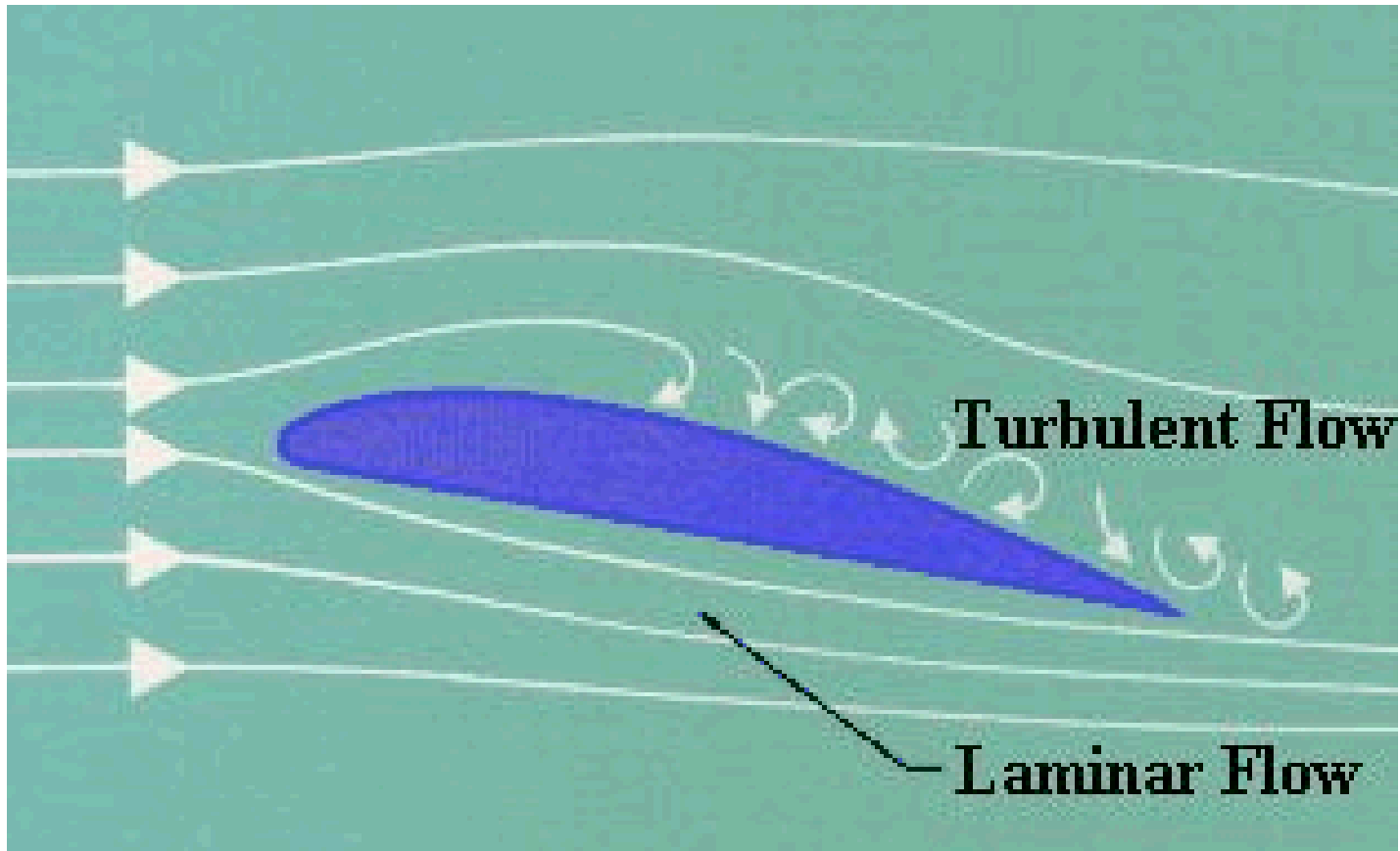
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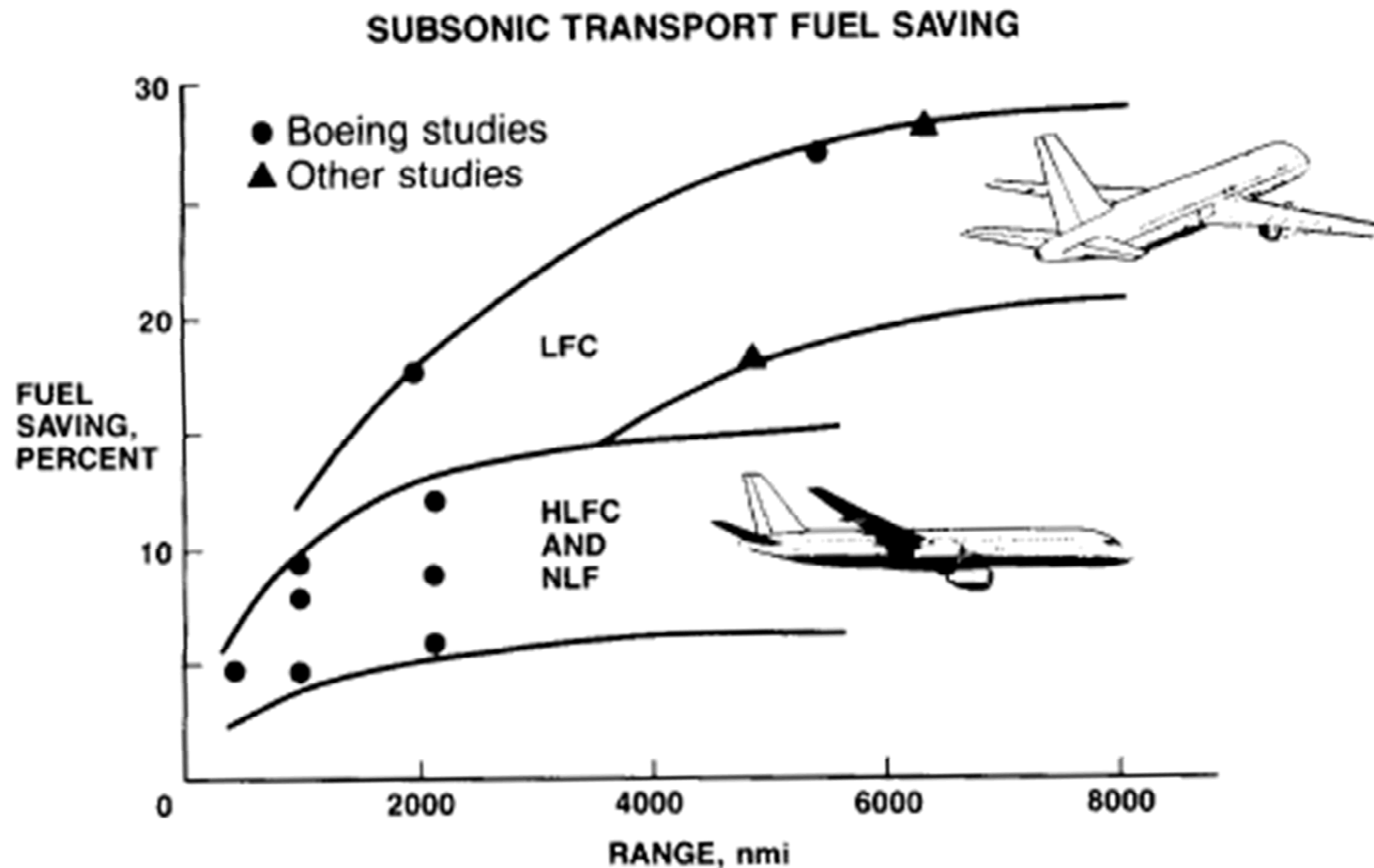
August 28, 2011



Introduction

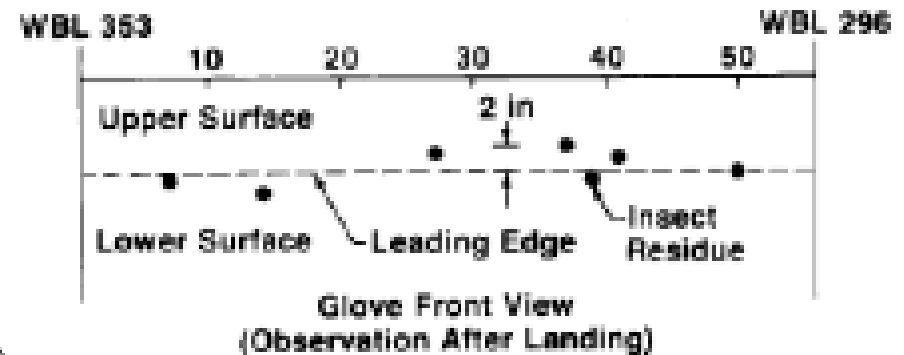
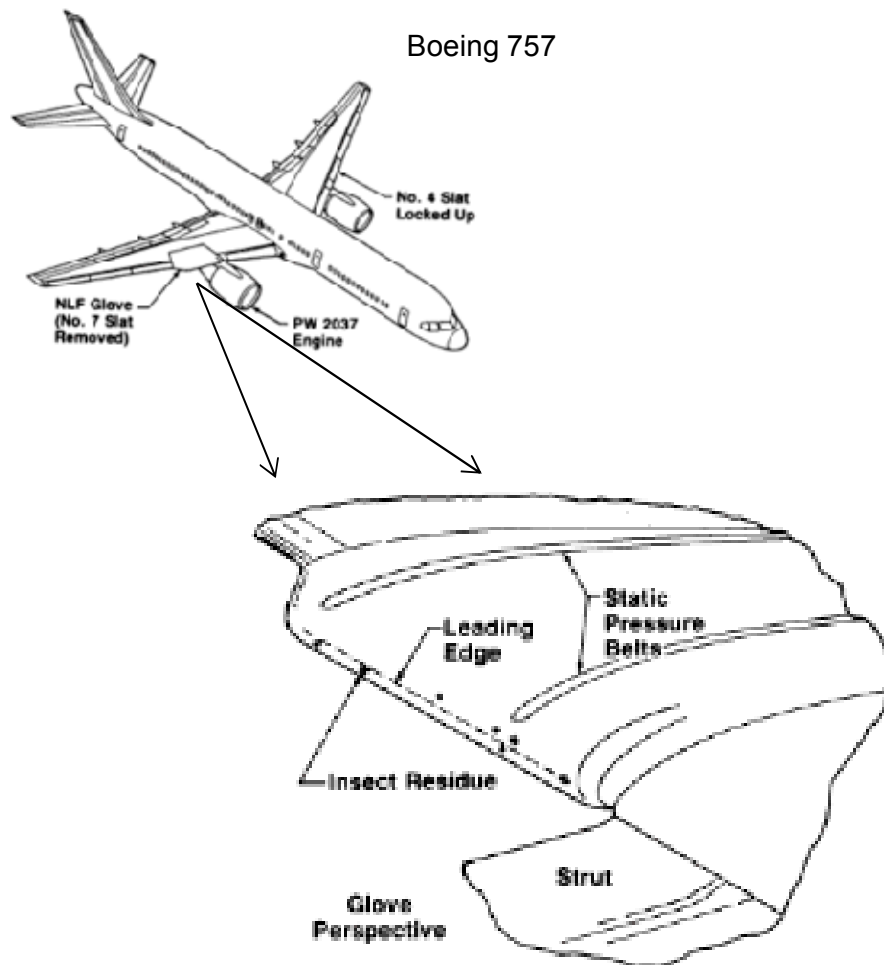


Motivation for Laminar Flow Control



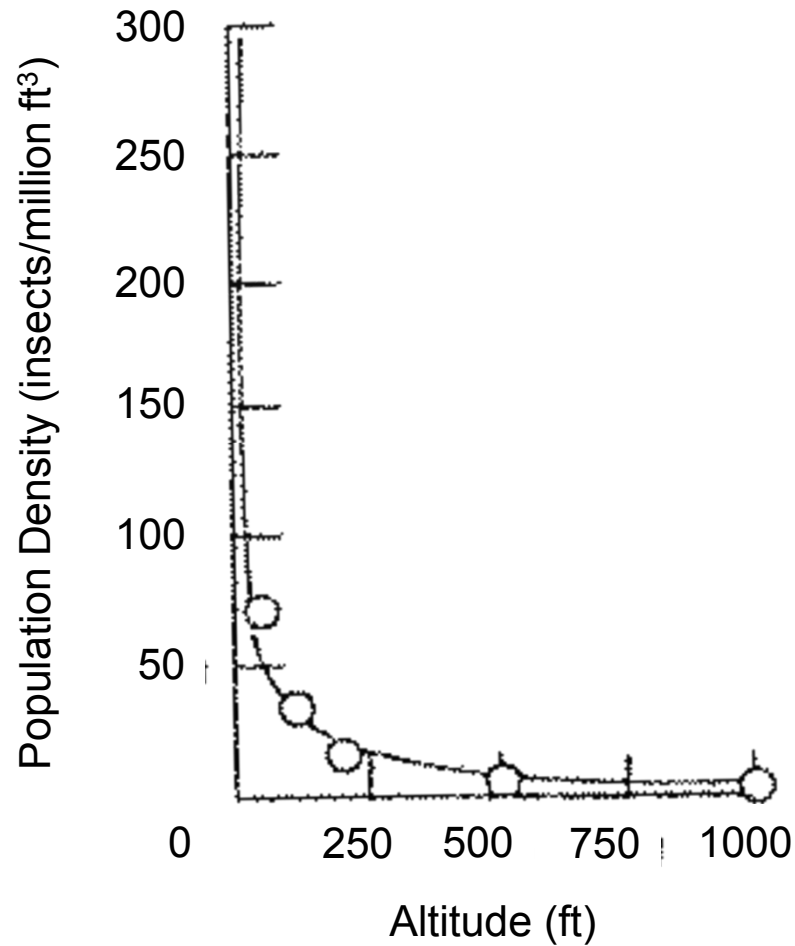
M.E. Kirchner: "Laminar Flow: Challenge and Potential", in Research in Natural Laminar Flow and Laminar-Flow Control, J. N. Hefner and F. Sabo, compilers, NASA CP-2487, Part 1, pp. 24-44 (1987).

The Problem with Insects



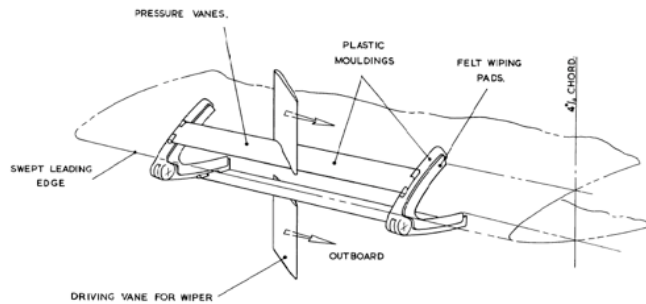
L. J. Runyan, G. W. Bielak, R. Behbehani, A. W. Chen, and R. A. Rozendaal, "757 NLF GLOVE FLIGHT TEST RESULTS", In Research in Natural Laminar Flow and Laminar-Flow Control, J. N. Hefner and F. Sabo, compilers, NASA CP-2487, Part 3, pp. 795-818 (1987).

The Problem with Insects



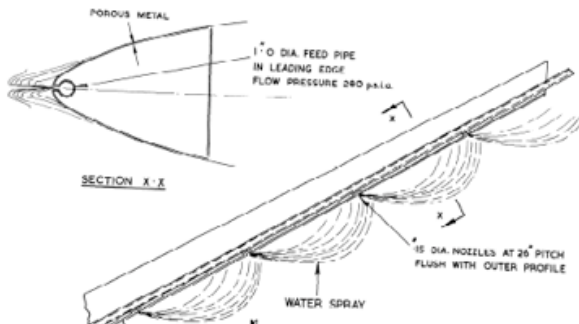
M. B. Bragg and J. L. Maresh, "The Role of Airfoil Geometry in Minimizing the Effect of Insect Contamination of Laminar Flow Sections", AIAA Paper no. 84-2170 (1984).

Prior Research



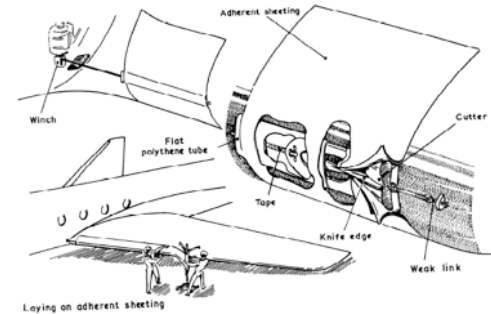
Mechanical scrapers

W.S. Coleman, "Roughness Due To Insects" in "Boundary Layer and Flow Control", ed. G.V. Lachman, Pergamon Press, 1961, pp. 682-747



Continuous Liquid Discharge

G.V. Lachman, "Aspects of Insect Contamination in Relation to Laminar Flow Aircraft", Ministry of Aviation Aeronautical Research Council, A.R.C. Technical Report, C.P. No. 484 (1960)

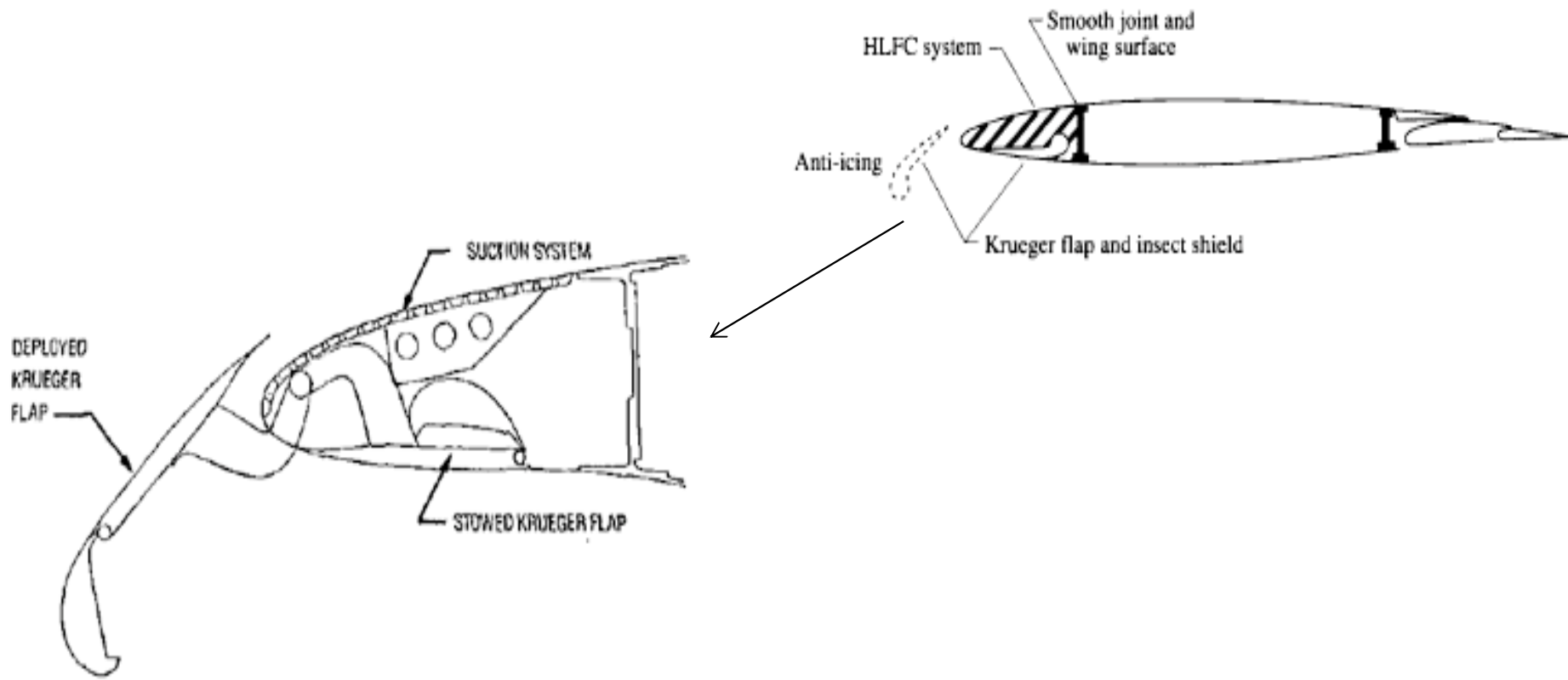


Paper & other coverings

G.V. Lachman, "Aspects of Insect Contamination in Relation to Laminar Flow Aircraft", Ministry of Aviation Aeronautical Research Council, A.R.C. Technical Report, C.P. No. 484 (1960)

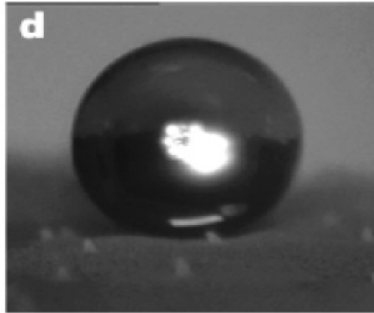
- Natural erosion
- Deflectors (i.e. Kreuger flap/shield)
- Elastic surfaces
- Coatings
- Soluble films and fluid covers

Krueger Flap

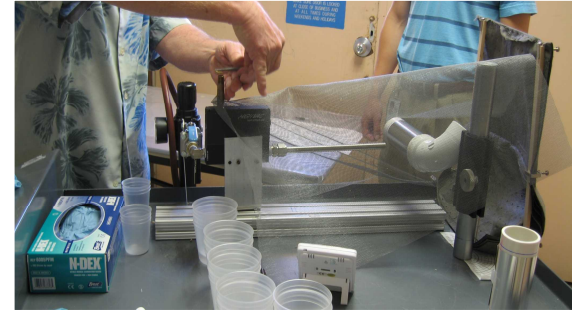


- ◆ To define an engineered surface that prevents insect excrescence adhesion under take-off and landing conditions

Approach



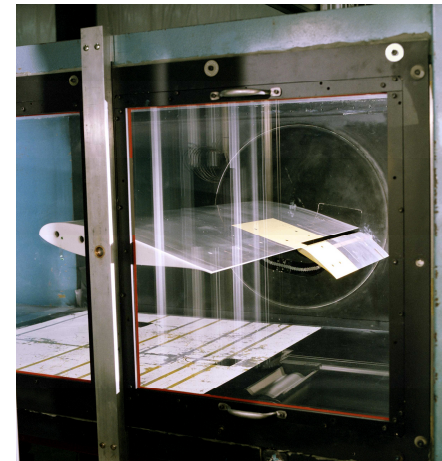
Screen commercial and experimental materials using contact angles.



Test coatings with simulated environment using "bug gun."



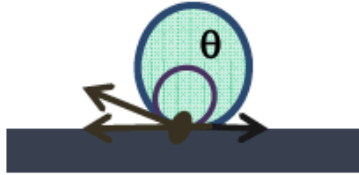
Flight test candidate coatings downselected from wind tunnel tests.



Downselect promising coatings for wind tunnel testing.

Surface Energy Determination



Classification	Contact Angle	Example
Hydrophilic	$\theta < 90$	
Hydrophobic	$150 > \theta > 90$	
Super-Hydrophobic	$\theta > 150$	

Large water contact angles indicate low surface energy which may be relatable to insect residue adhesion mitigation.

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

β -Alanine	L-Isoleucine
L-Alanine	L-Leucine
L-Arginine HCl	L-Lysine HCl
L-Aspartic Acid	L-Methionine
L-Asparagine (anhyd)	L-Phenylalanine
L-Cytosine 2HCl	L-Proline
L-Glutamic Acid	DL-Serine
L-Glutamine	L-Threonine
Glycine	L-Tryptophan
L-Histidine	L-Tyrosine 2Na
	L-Valine

Vitamins

p-Aminobenzoic Acid	Niacin
D-Biotin	D-Pantothenic Acid 0.5 Ca
Choline Chloride	Pyridoxine HCl
Folic Acid	Riboflavin
myo-Inositol	Thiamine

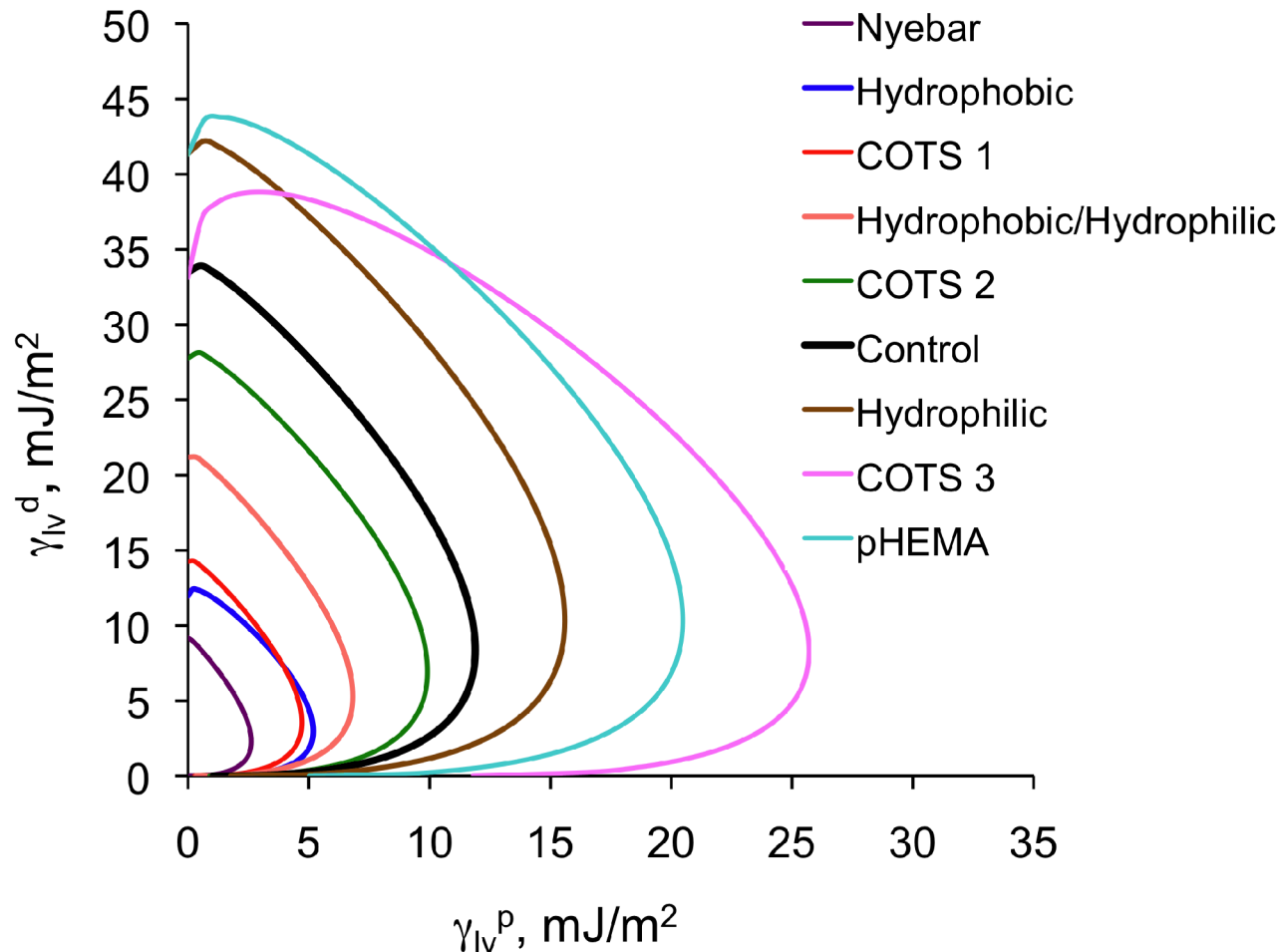
Inorganic Salts

CaCl ₂ (anhyd)	KCl
MgCl (anhyd)	NaHCO ₃
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

Wetting Envelopes For Coated Surfaces



$$\gamma_T = \gamma_D + \gamma_P$$

γ_T : total surface energy

γ_D : dispersive component

γ_P : polar component

Surface Tension Determination of Cricket Hemolymph



Surface	Water, °	Ethylene Glycol, °	Methylene Iodide, °	Cricket Hemolymph, °
Kapton® HN	77.0 ± 0.4	50.0 ± 0.4	32.0 ± 0.5	48.8 ± 3.5
Polypropylene	102.0 ± 0.6	72.3 ± 1.1	55.1 ± 2.2	88.5 ± 3.8
Teflon®	104.0 ± 0.2	92.1 ± 1.9	79.5 ± 6.4	91.1 ± 14.3

Surface energy and surface tension were related using Extended Fowkes Theory.

$$(1 + \cos \theta) \frac{\gamma_L}{2(\gamma_L^d)^{0.5}} = (\gamma_s^d)^{0.5} + (\gamma_s^p)^{0.5} \left(\frac{\gamma_L^p}{\gamma_L^d} \right)^{0.5}$$

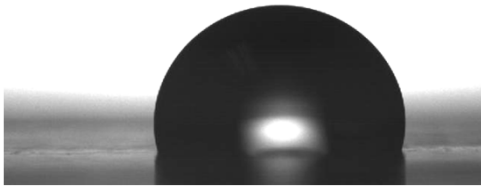
	γ_T , mN/m	γ_D , mN/m	γ_P , mN/m
Cricket Hemolymph	42	5	37
Ethylene Glycol	48	29	19

Cricket hemolymph has similar surface tension characteristics to ethylene glycol.

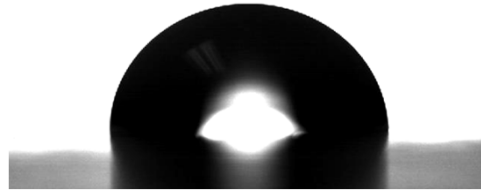
Solvent Contact Angles on Teflon[®]



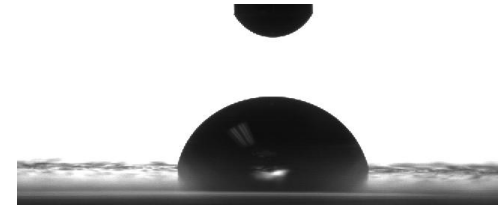
Water



Ethylene Glycol



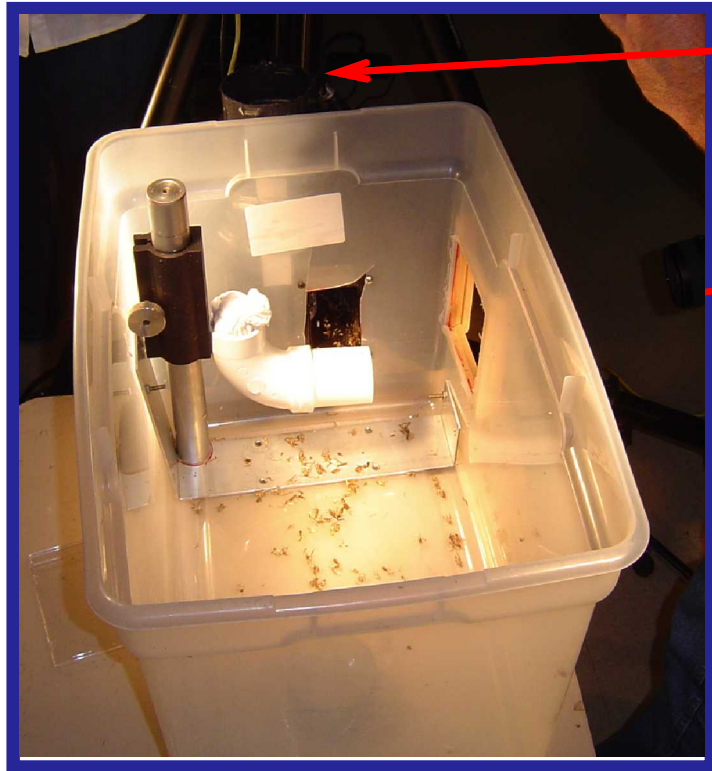
Methylene Iodide



Cricket Hemolymph



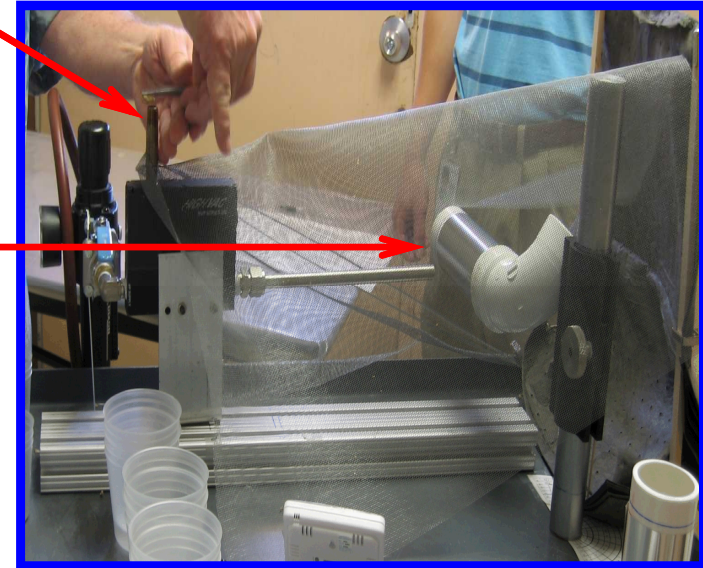
Bug Impact Apparatus



Generation 1

Insect Introduction

Sample Holder

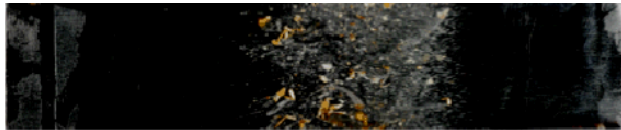
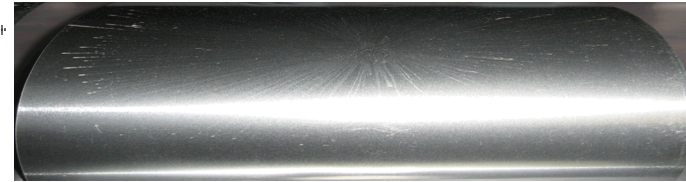
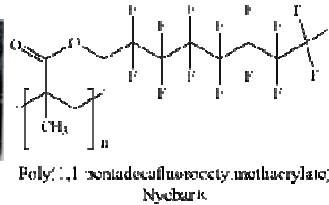
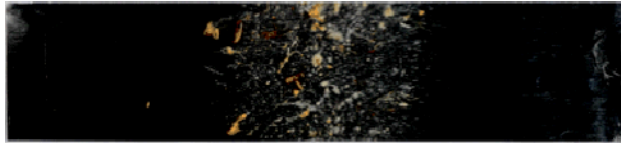


Generation 2

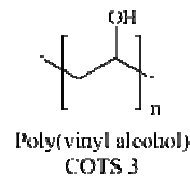
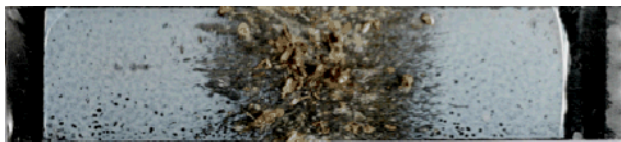
Images of Post-Test Specimens



Increasing Surface Energy
↓



Al 6061 Control

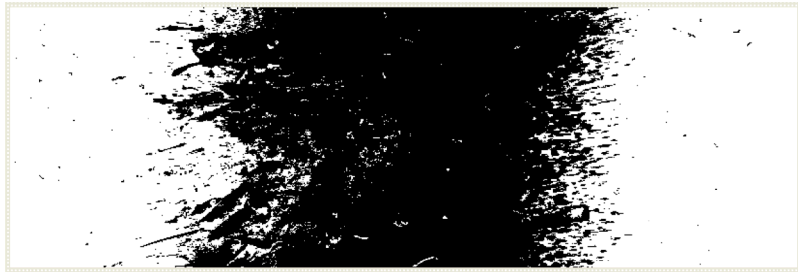
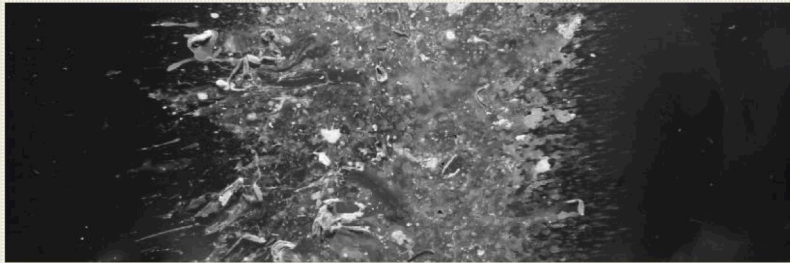


↑ Improving Apparent Performance

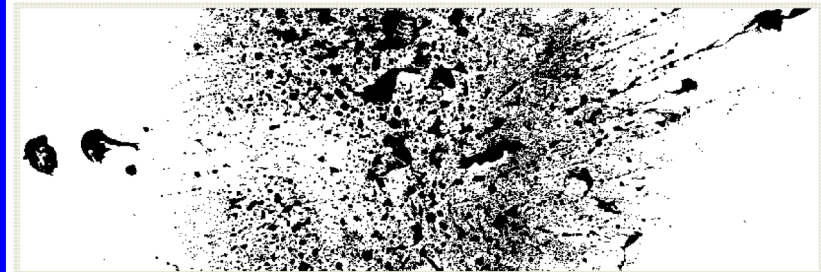
Multiple Insect Impacts
at Normal Incidence

Single Insect Impact
at Normal Incidence

Image Analysis of Insect Residue



AI 6061 Control Area = 46%



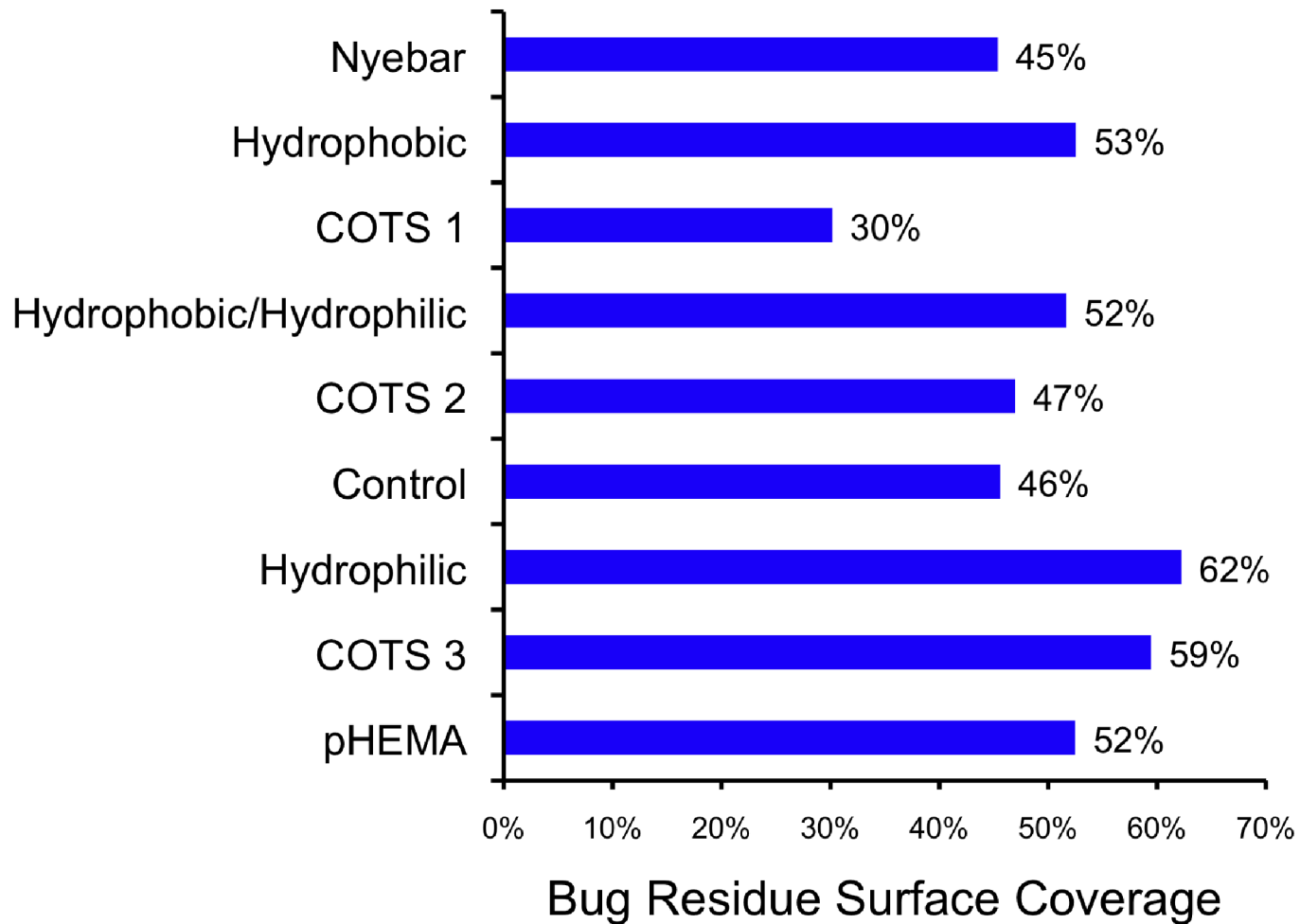
COTS 1 Area = 30%

Multiple Insect Impacts at Normal Incidence

Image Analysis Summary

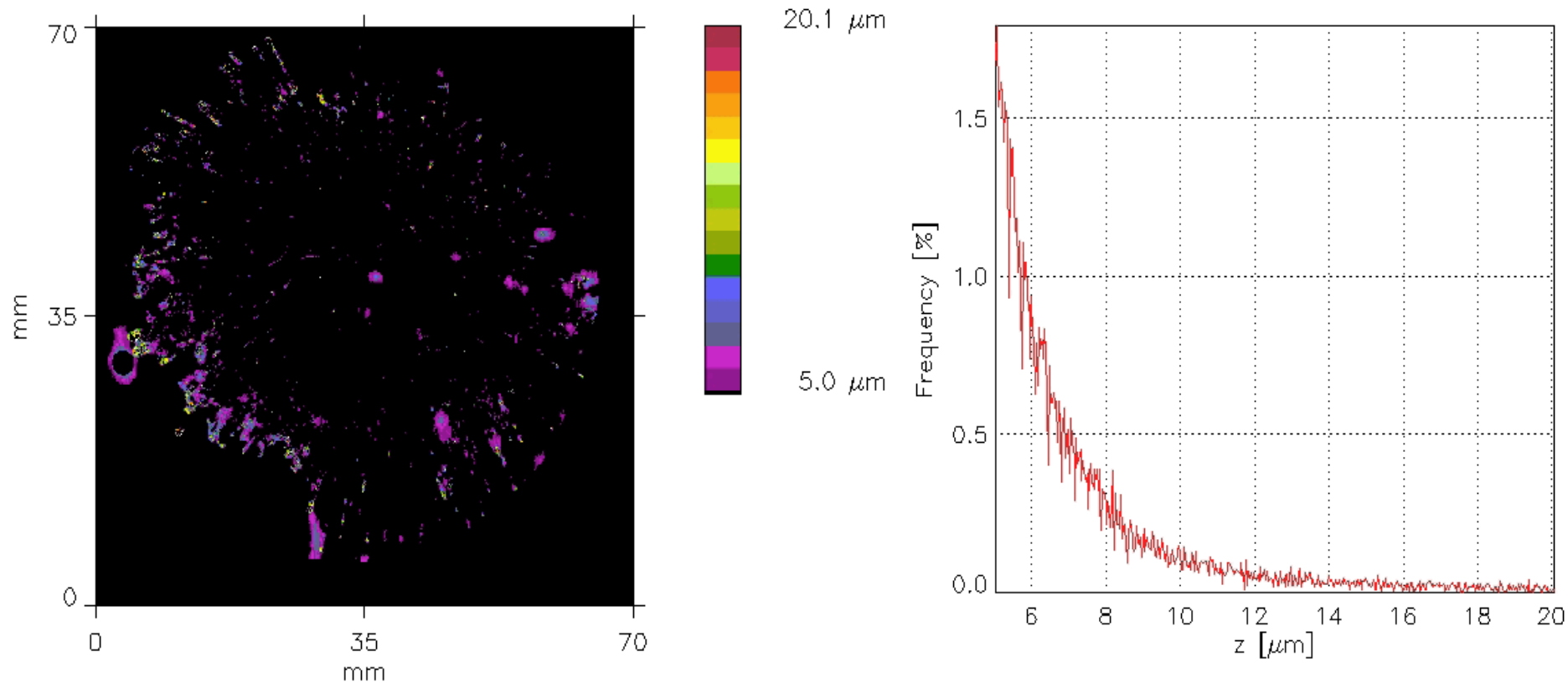


Increasing Surface Energy
↓



Multiple Insect Impacts at Normal Incidence

Excrecence Height Profilometry



Insect Impact at Normal Incidence on Aluminum

- ◆ **Contact angles provide an initial screen of insect excrement resistant surfaces**
- ◆ **Bug impact testing necessary due to influence of fluid characteristics on adhesion**
- ◆ **Hydrophobicity may not be the sole predictor of insect residue adhesion – static vs dynamic**
- ◆ **Testing with single insect provides a more accurate picture of surface performance**

Acknowledgements



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