NASA Aeronautics Mission Directorate FY11 Seedling Phase I Technical Seminar

NARI

Nano-Rod Piezoelectrics for Icephobic Surfaces

Frederick Dynys (NASA-GRC), Eric Kreeger (NASA-GRC) & Alp Sehirlioglu (CWRU)

Objectives

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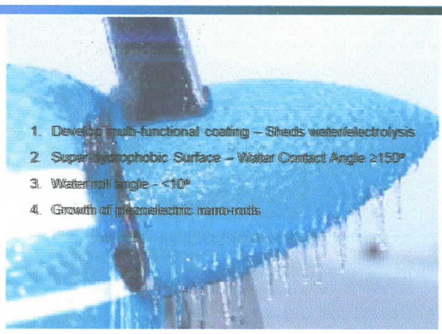

1. Develop multi-functional coating – Sheds water/electrolysis
2. Super-hydrophobic Surface – Water Contact Angle ≥150°
3. Water roll angle - <10°
4. Growth of piezoelectric nano-rods

Weather Related Accidents

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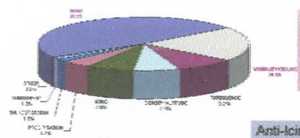
NTSB Weather Related Accidents 1994 - 2003



- Ice accredition disrupts airflow reducing lift and increasing drag
- Ice also can form in the engine intake, blocking air flow to the engine

•19,562 total accidents

•4,159 (21.3%) weather related

•291 (7%) cause by icing

Anti-Icing

Preemptive before the flight enters icing conditions: thermal heat, prop heat, pitot heat, fuel vent heat, windshield heat, and fluid surface de-icers

De-Icing

Reactive -ice build up

Includes surface de-ice equipment such as boots, weeping wing systems, and heated wings

Flight Operations

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•Icing Conditions Disrupt Flight Schedules
- ➢ Average cost for idling aircraft ~ $85/minute
- ➢ Flight delays cost the airline industry ~ $19 billion/yr

•On Ground Airframe De-icing
- ➢ 200-600 million gallons of Aircraft Deicing Fluid (ADF)/yr
- ➢ ADF cost is $11-$18/gallon
- ➢ ADF environmental pollutant – 22 million gallons release
- ➢ EPA imposing effluent discharge standards
- ➢ Corrosion of aircraft parts
- ➢ Deterioration of carbon brakes

Basics of Wetting

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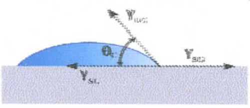
Equilibrium Contact Angle



γ_{SL} : solid-liquid surface tension

γ_{SG} : solid-gas surface tension

γ_{LG} : liquid-gas surface tension

Young Dupré relation

$$\gamma_{SV} - \gamma_{SL} = \gamma_{LV} \cos\theta$$

Smooth surfaces exhibit maximum contact angles ~ 120° – 130°

Wetting Regimes

Hydrophilic	Partially Wetting	Hydrophobic	Super-Hydrophobic
θ=0°	θ < 90°	θ>90°	θ>150°

Basics of Wetting

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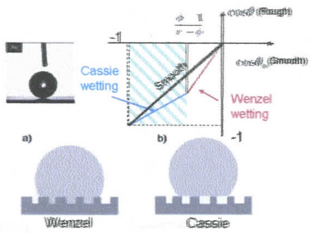


•Surface roughness enhances hydrophobicity

R. N. Wenzel, 1936

$\cos\Theta_w = r \cos\Theta$

Θ_w :CA on the rough surface

Θ :CA on the smooth surface

r :roughness factor ($r > 1$)

Real Area/Flat Area

A. B. D. Cassie, 1948

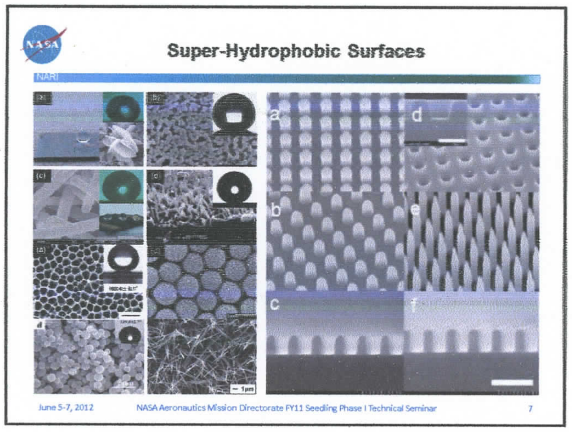
$\cos\theta_c = f_1 \cos\theta - f_2$

Θ_C :CA on the rough surface

Θ :CA on the smooth surface

f_1 :fraction of solid

f_2 :fraction of air ($f_1 + f_2 = 1$)


Super-Hydrophobic Surfaces
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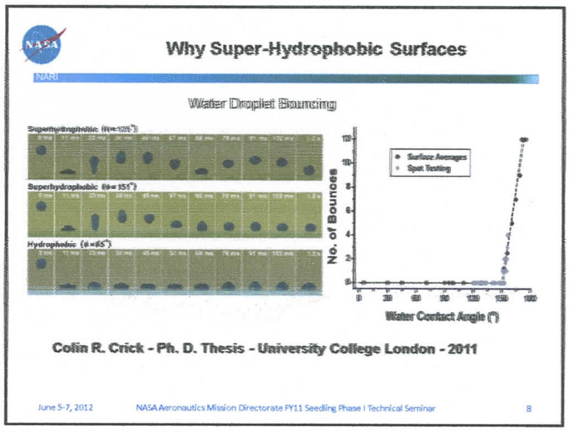
Why Super-Hydrophobic Surfaces
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Water Droplet Bouncing
Superhydrophobic
Hydrophobic
No. of Bounces
Surface Averages
Spot Testing
Water Contact Angle (°)
Colin R. Crick - Ph. D. Thesis - University College London - 2011
June 5-7, 2012
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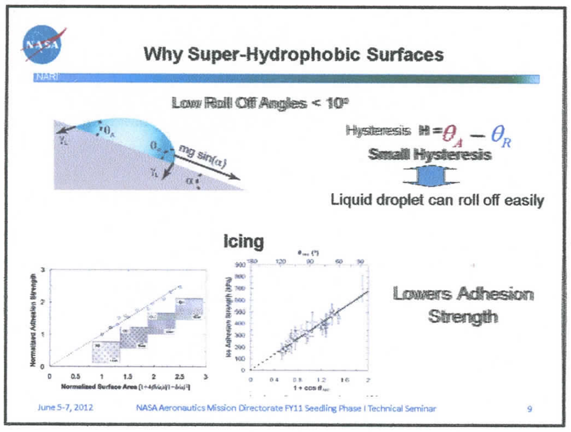
Why Super-Hydrophobic Surfaces
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Low Roll Off Angles < 10°
mg sin(α)
Hysteresis H = $\theta_A - \theta_R$
Small Hysteresis
Liquid droplet can roll off easily
Icing
Lowers Adhesion Strength
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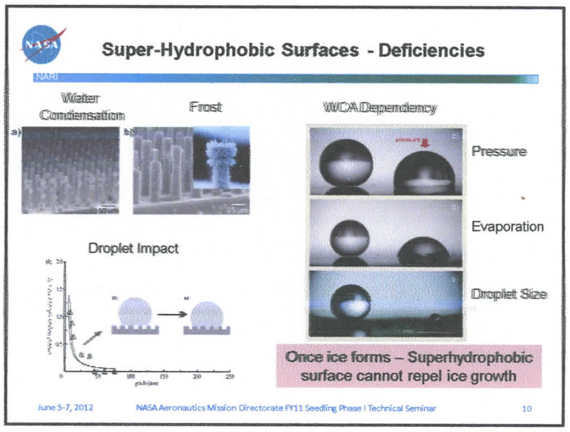
Super-Hydrophobic Surfaces - Deficiencies
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Water Condensation
Frost
WCA Dependency
Pressure
Evaporation
Droplet Size
Droplet Impact
Once ice forms – Superhydrophobic surface cannot repel ice growth
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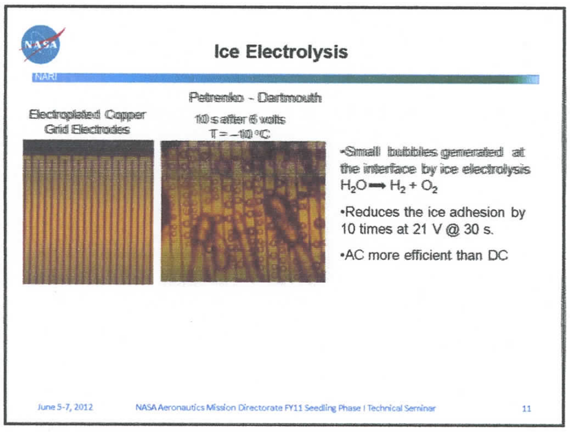
Ice Electrolysis
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Electroplated Copper Grid Electrodes
Petrenko - Dartmouth
10 s after 6 volts
T = −10 °C
•Small bubbles generated at the interface by ice electrolysis $H_2O \rightarrow H_2 + O_2$
•Reduces the ice adhesion by 10 times at 21 V @ 30 s.
•AC more efficient than DC
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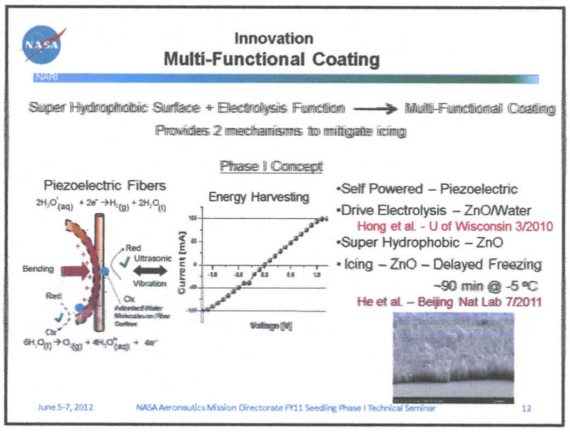
Innovation
Multi-Functional Coating
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Super Hydrophobic Surface + Electrolysis Function → Multi-Functional Coating
Provides 2 mechanisms to mitigate icing
Phase I Concept
Piezoelectric Fibers
Energy Harvesting
Bending
Ultrasonic Vibration
Current [mA]
Voltage [V]
•Self Powered – Piezoelectric
•Drive Electrolysis – ZnO/Water
Hong et al. - U of Wisconsin 3/2010
•Super Hydrophobic – ZnO
• Icing – ZnO – Delayed Freezing
~90 min @ -5 °C
He et al. – Beijing Nat Lab 7/2011
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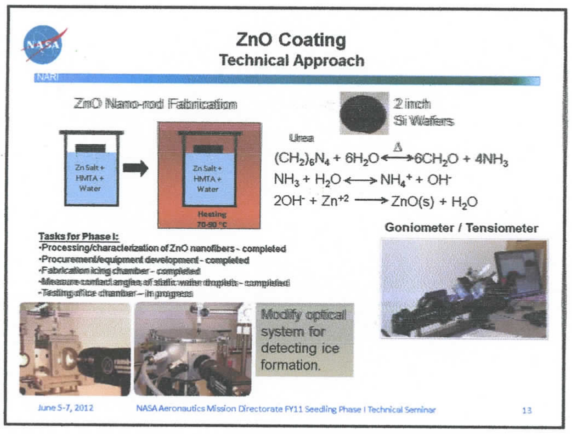
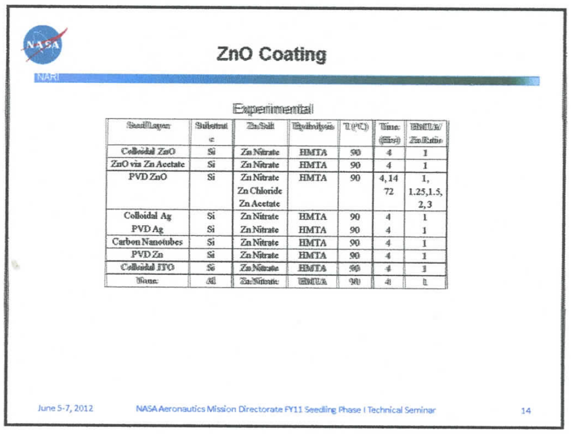
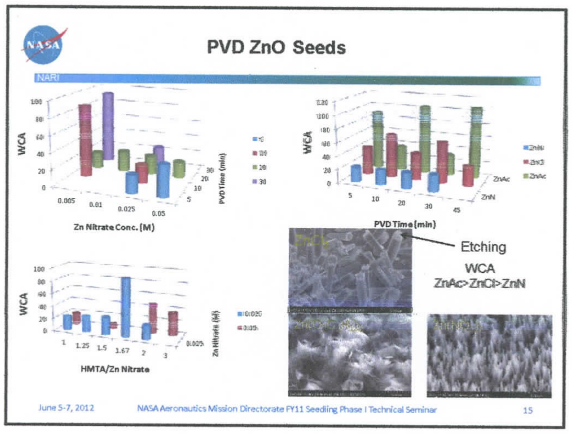
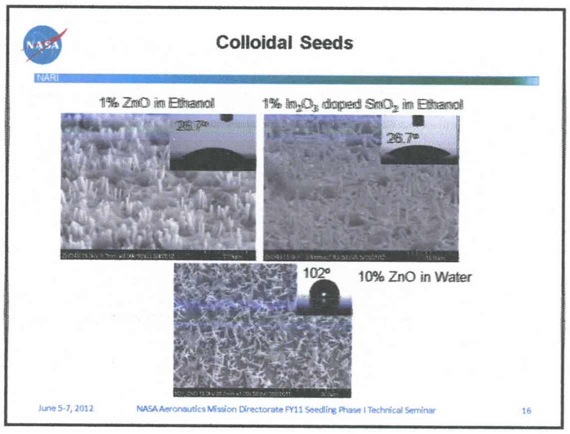
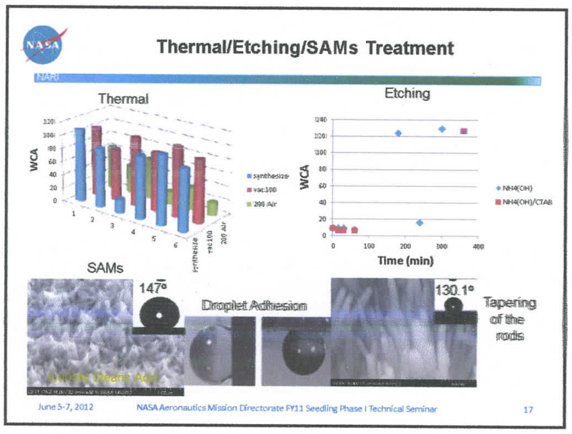


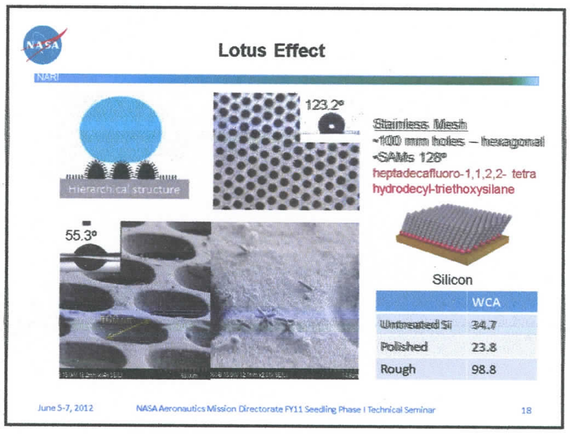


Seed/Layer	Substrate	Zn Salt	Hydrolysis	T (°C)	Time (Hrs)	HMTA/Zn Ratio
Colloidal ZnO	Si	Zn Nitrate	HMTA	90	4	1
ZnO via Zn Acetate	Si	Zn Nitrate	HMTA	90	4	1
PVD ZnO	Si	Zn Nitrate Zn Chloride Zn Acetate	HMTA	90	4, 14 72	1, 1.25,1.5, 2, 3
Colloidal Ag	Si	Zn Nitrate	HMTA	90	4	1
PVD Ag	Si	Zn Nitrate	HMTA	90	4	1
Carbon Nanotubes	Si	Zn Nitrate	HMTA	90	4	1
PVD Zn	Si	Zn Nitrate	HMTA	90	4	1
Colloidal ITO	Si	Zn Nitrate	HMTA	90	4	1
None	Al	Zn Nitrate	HMTA	90	4	1









Carbon Nanotubes

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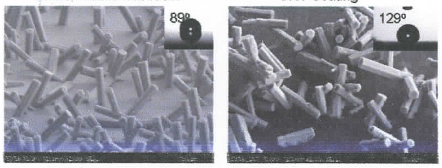
WCA for CNT Coating 143.2°

Metal Coated Substrate | CNT Coating



Metal Catalysis act as nuclei for ZnO Growth

Mechanical Robustness

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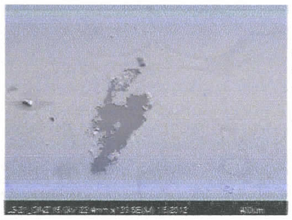

- Mechanical robustness – poor
- Film fails upon touching
- Films required gentle handling and washing
- Film porosity is needed for super hydrophobic structure

Phase II

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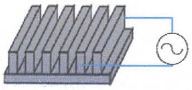
Super Hydrophobic Surface + Electrolysis Function ⟶ Multi-Functional Coating
Provide 2 mechanisms to mitigate ice

Improve mechanical properties ⟶ Carbon Nanotube/PEDOT:PSS composite
Poly(3,4-ethylenedioxythiophene) - poly(styrenesulfonate)

Printed Electrodes



Super Hydrophobic Electrode Pattern

Goals

- Structure Beads Water
- Structure Sheds Water
- Reduce Power Consumption
- Electrolysis of Ice/Water
- Mechanically Robust
- Easy to Fabricate

Summary

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- Proposed concept for multi-functional coating still valid
- Completed phase I tasks
- Successively Grown ZnO nano-rods
- Successively Characterized Wetting Behavior – 147°
- Environmental Chamber - -30°C/Humidity/WCA
- ZnO nano-rods exhibit poor mechanical properties
- Phase II re-focused on mechanical robustness of coating
- Technology – TRL 1 to TRL 2
- Information Dissemination – Conference, Publication