Idea evolution … what's next?

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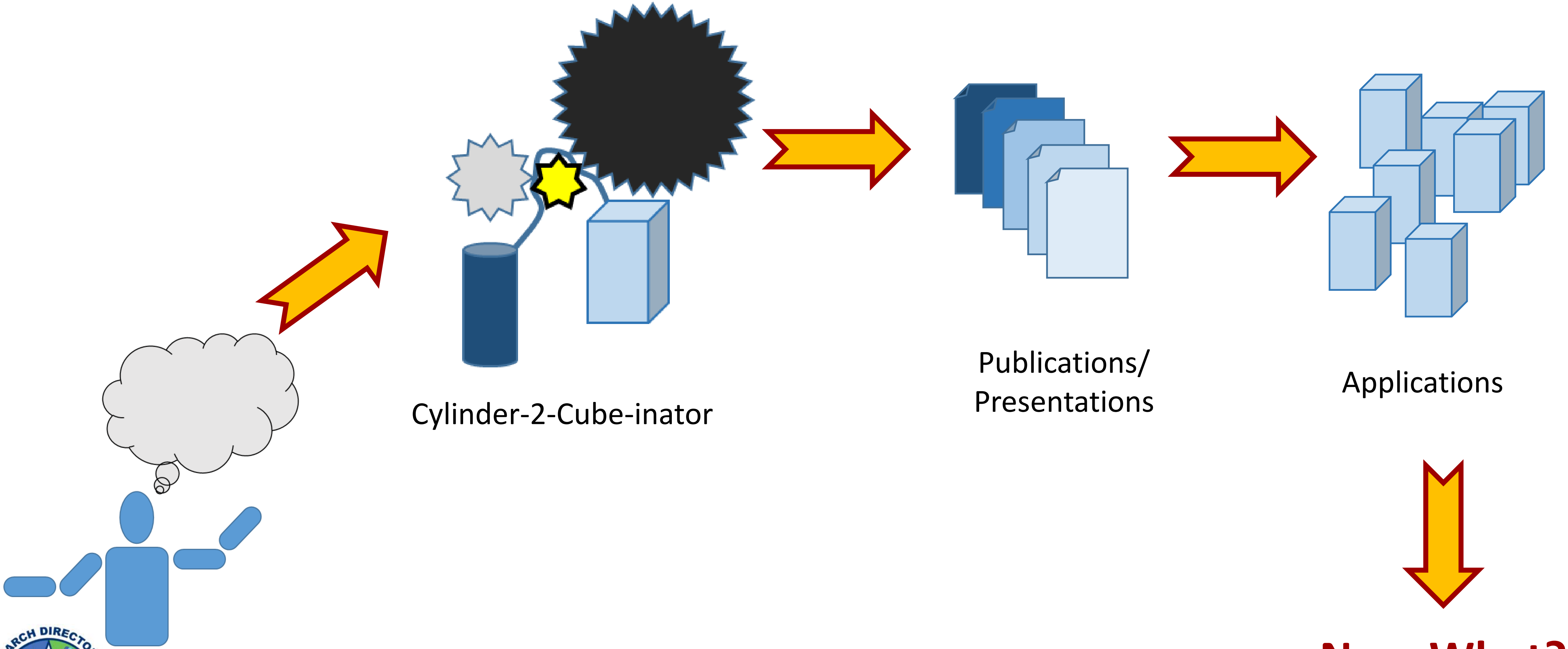
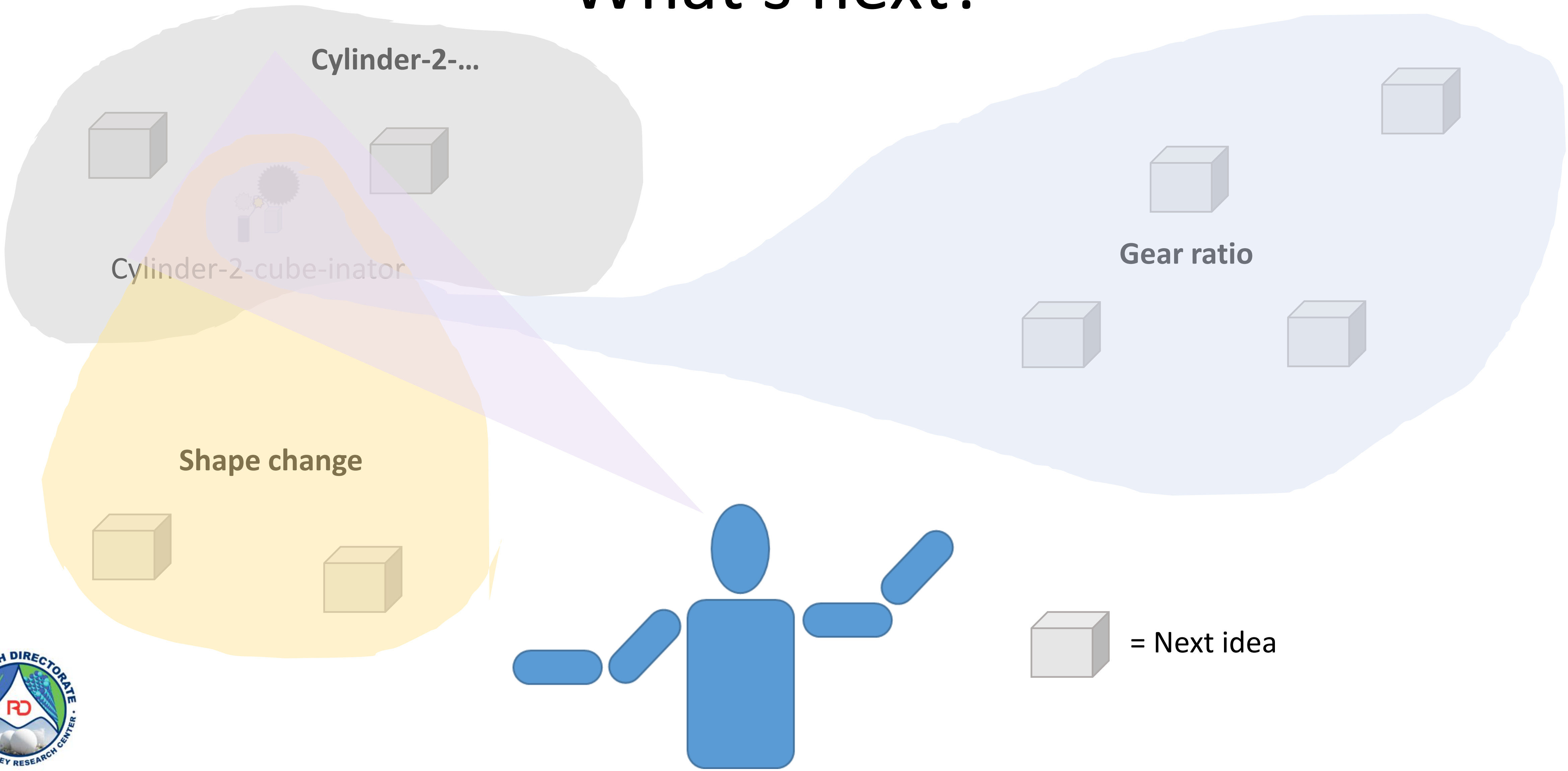
*Unless otherwise indicated, all images were generated or utilized from NASA sources

I have an idea …



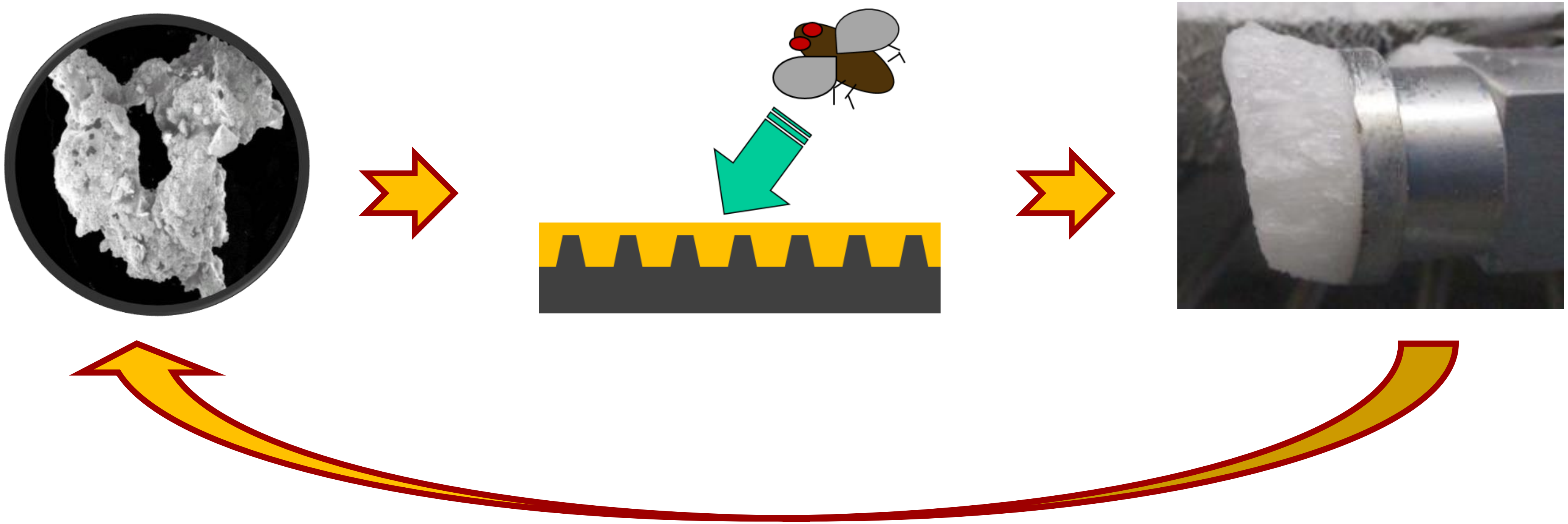
Now What?

What's next?


Cylinder-2-...
Cylinder-2-cube-inator
Gear ratio
Shape change
= Next idea

Case study

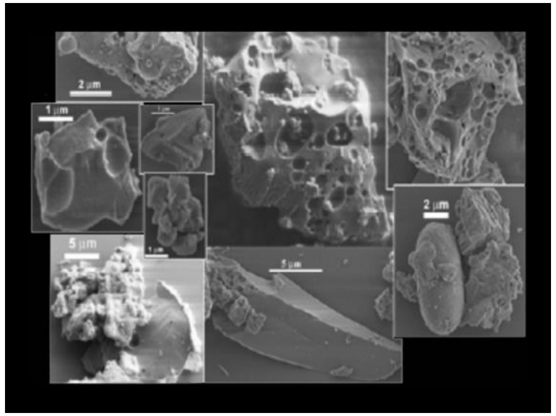
❖Engineered surfaces for contamination mitigation



Who knew lunar dust was a problem?

Apollo astronauts learned the hard way

- **Lunar dust interfered with several different aspects of the Apollo missions:**
  - Vision obscuration
  - False instrument readings
  - Loss of foot traction
  - Inhalation hazards
  - Seal failures and clogging
  - Thermal control issues
- **Lunar dust characteristics:**
  - Abrasive, jagged edges
  - Chemically reactive
  - Electrostatically charged
  - Sometimes magnetic
  - Strongly adheres to surfaces

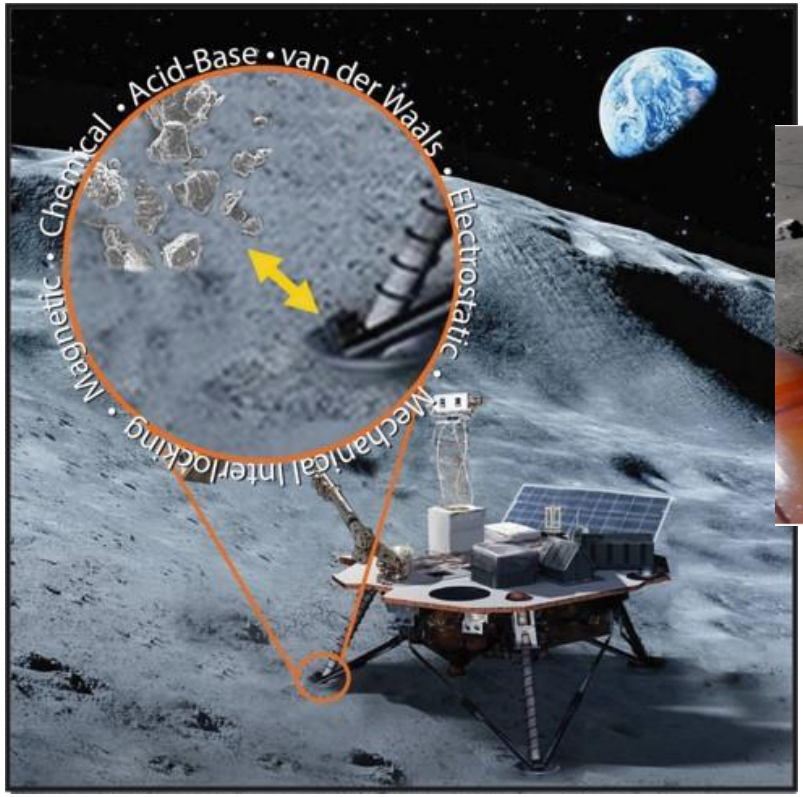


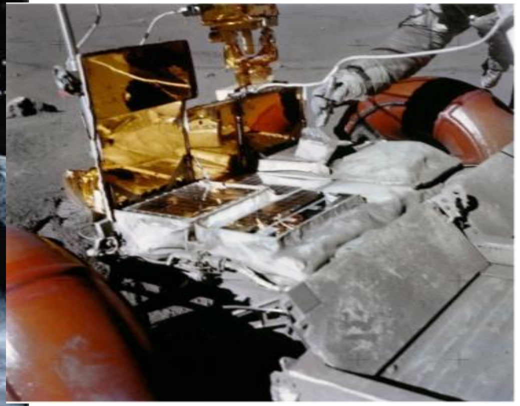
Where do we need lunar dust mitigation?

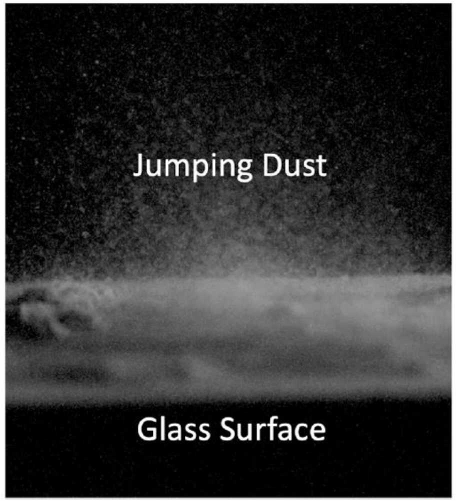
- ❖ Space suits - fabric, unique mechanisms
- ❖ Lunar habitat - outer surfaces, seals
- ❖ Lunar lander - wheels, bearings, gears
- ❖ Instruments - sensors, electronics, motors
- ❖ Thermal control surfaces - radiators
- ❖ Optical surfaces – visors, solar cells, windows

What dust mitigation strategies are there?

- ❖Lunar dust adhesion can be attributed to a variety of forces:
  - ❖ Mechanical interlocking
  - ❖ Van der Waals forces
  - ❖ Magnetic forces
  - ❖ Chemical bonding
  - ❖ Electrostatic and coulombic interactions



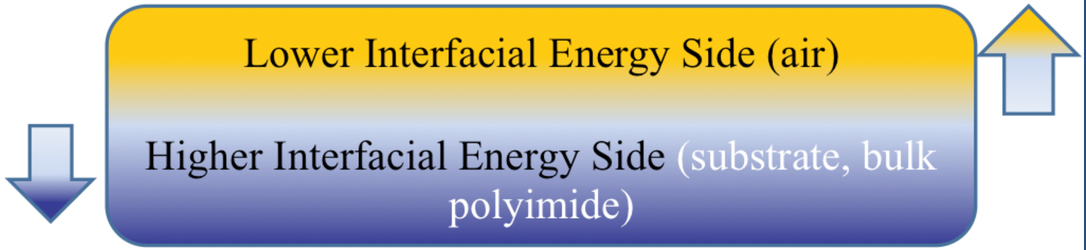




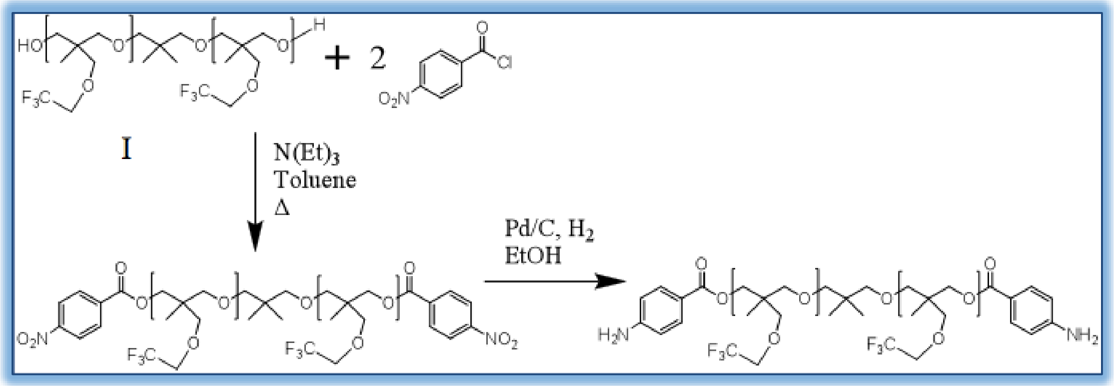
- ❖3 strategies to minimize lunar dust adhesion:
- ❖ active - e.g., mechanically powered brushes
- ❖ passive – e.g., low surface energy coatings
- ❖ combination of active and passive

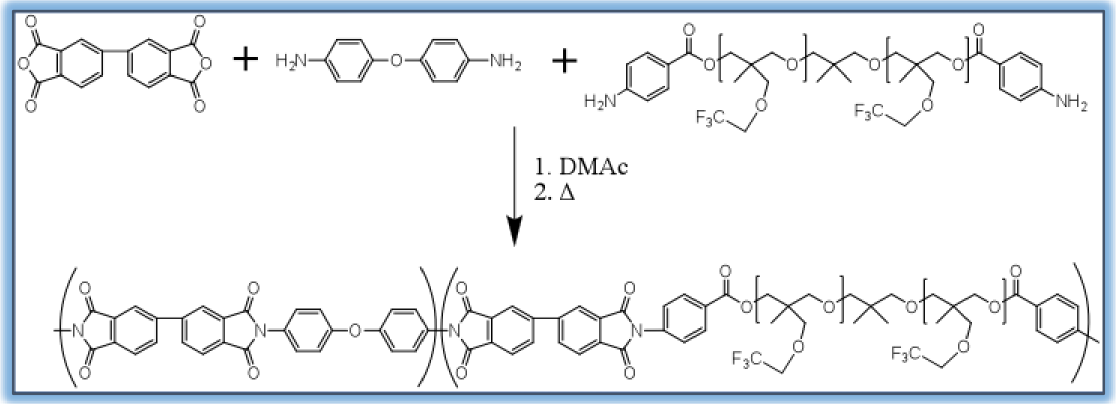
Where did we start? Surface Modifying Agents (SMA)s

Thermodynamic Response of SMA



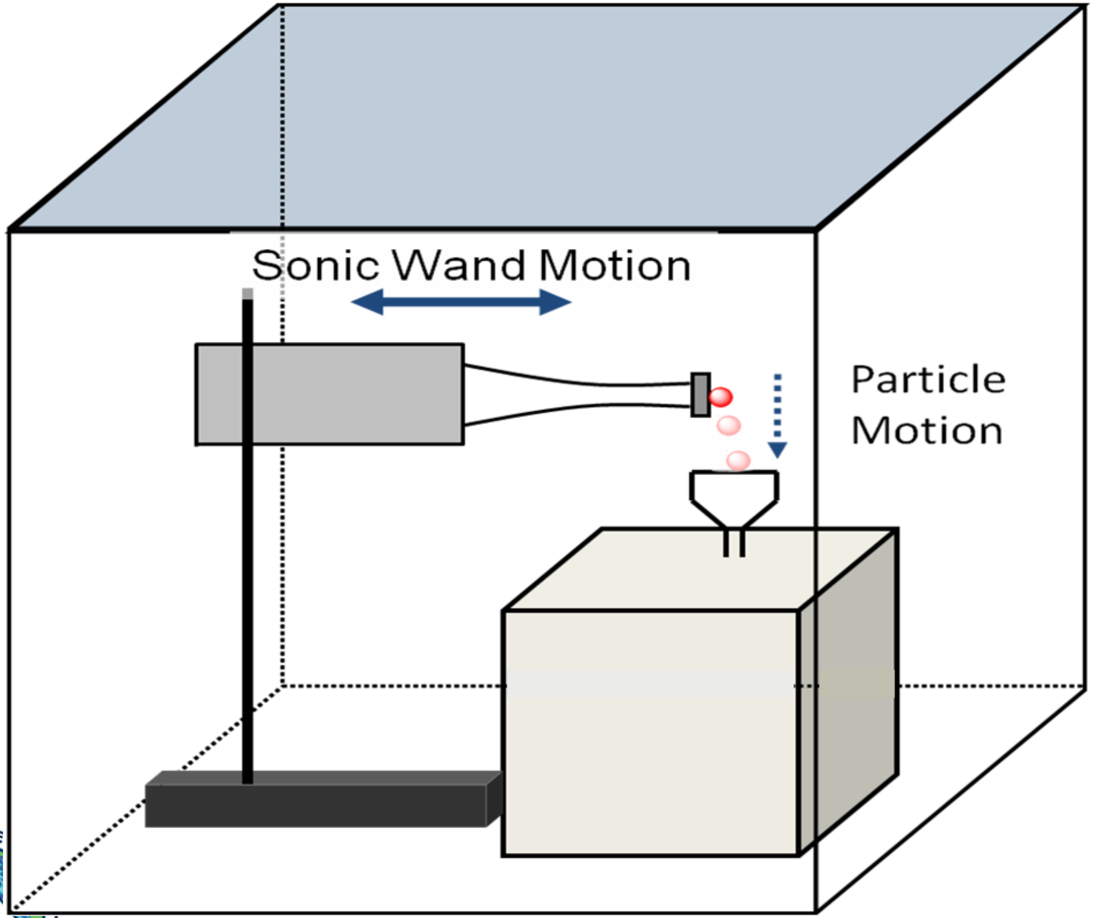
Arrows indicate enthalpy-driven migration of LOW and HIGH surface energy components.

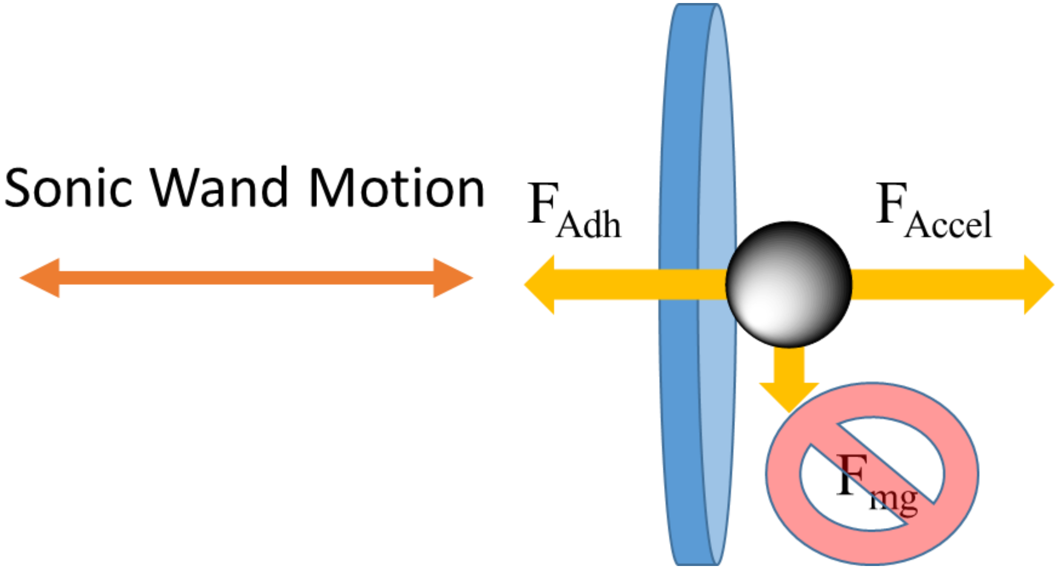




Copolyimide alkyl ethers

How do we test these materials?





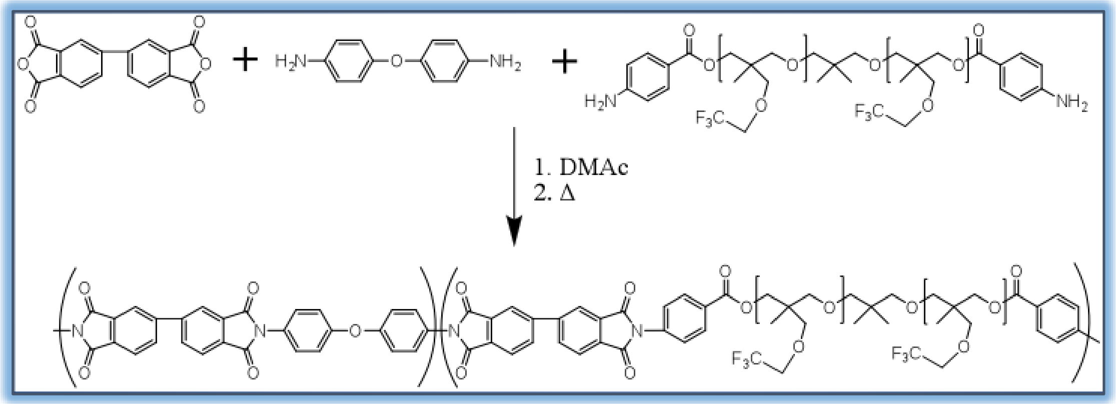
Particle will detach when F_{Accel} is ≥ F_{Adh}

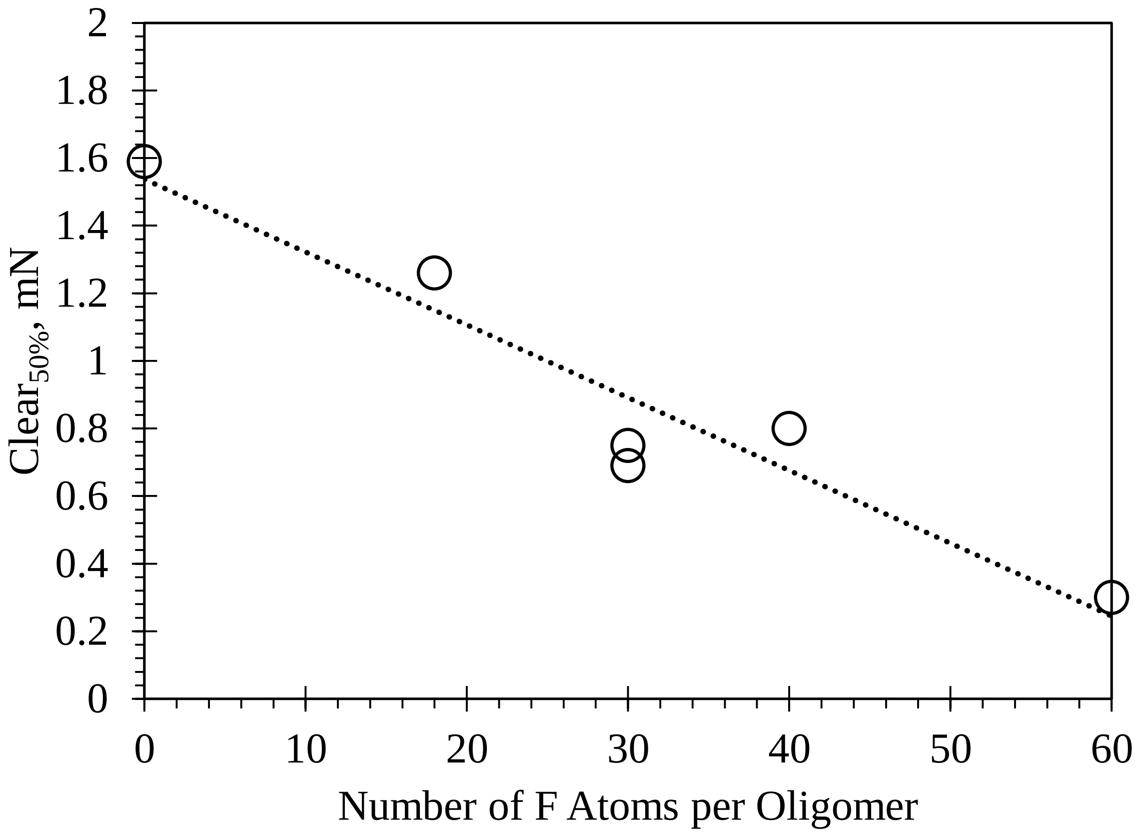
$$F_{Accel} = ma = m * 4\pi^2 * f^2 * A$$

m = particle mass
a = acceleration
f = sonic wand frequency
A = sonic wand amplitude

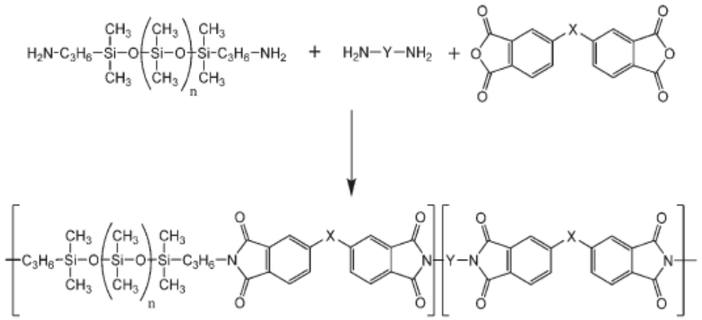
What did we learn from SMAs?

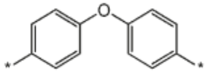
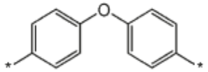
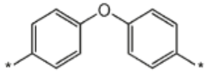
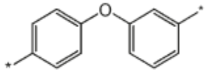
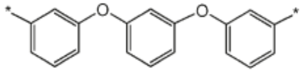
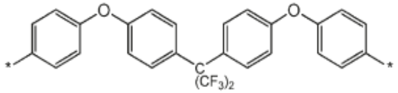
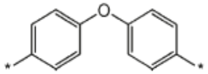
❖Dependence of adhesion force on fluorinated side chain

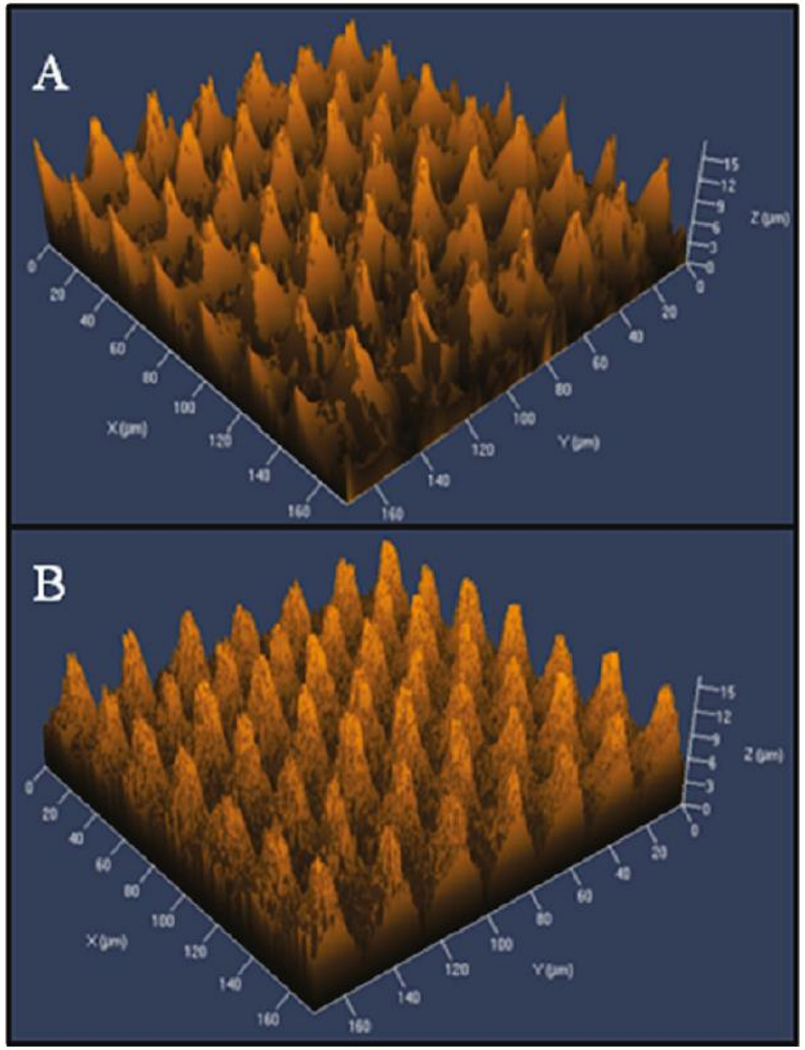




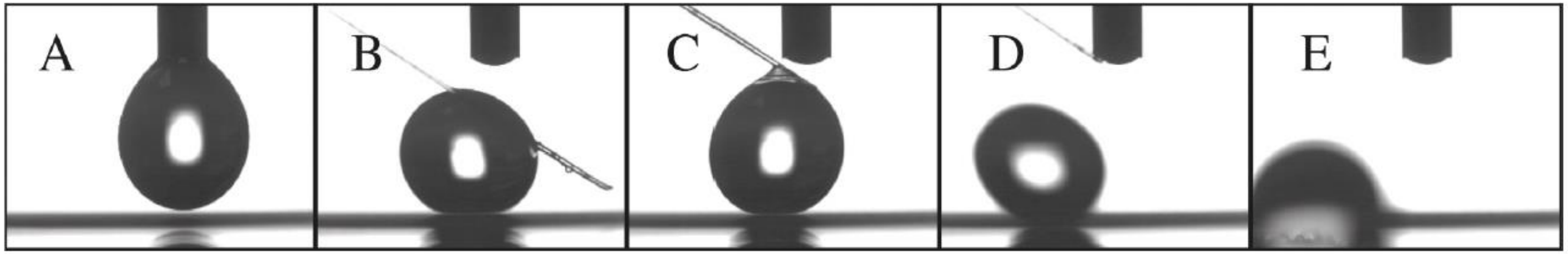
Next property: surface topography



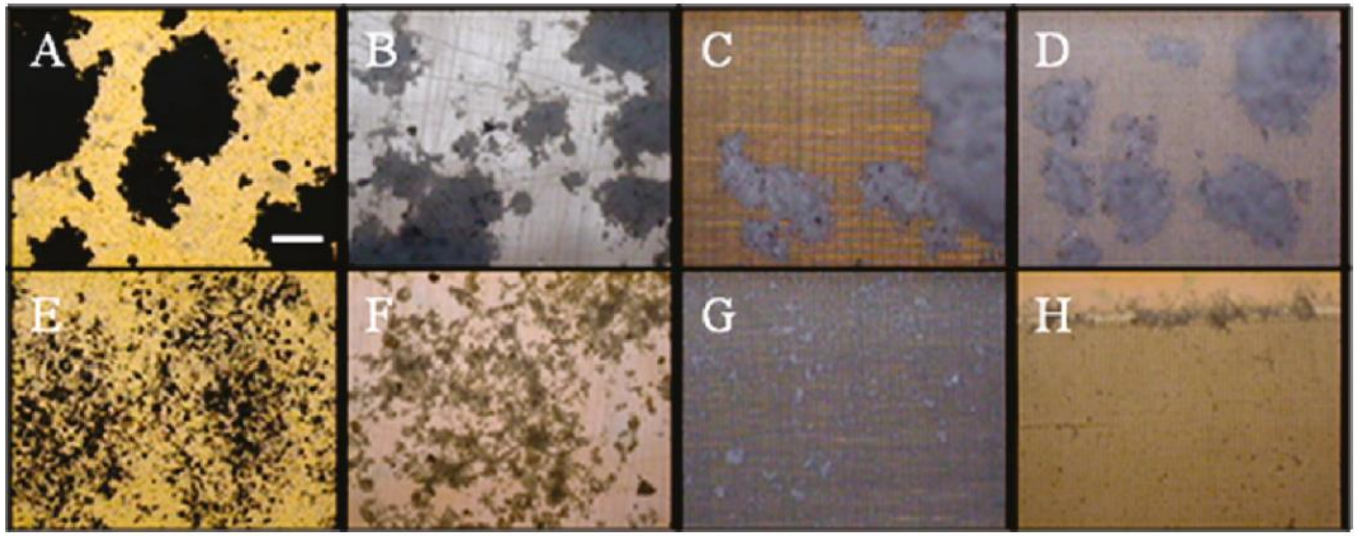
Polyimide Siloxane	PDMS wt. %[a]	X	Y
PIS-1	5	$C(CF_3)_2$	
PIS-2	10	$C(CF_3)_2$	
PIS-3	20	$C(CF_3)_2$	
PIS-4	10	$C(CF_3)_2$	
PIS-5	10	$C(CF_3)_2$	
PIS-6	10	$C(CF_3)_2$	
PIS-7	10	O	



Influence of topography on surface properties?



Droplet (8 μL) deposition on superhydrophobic surface

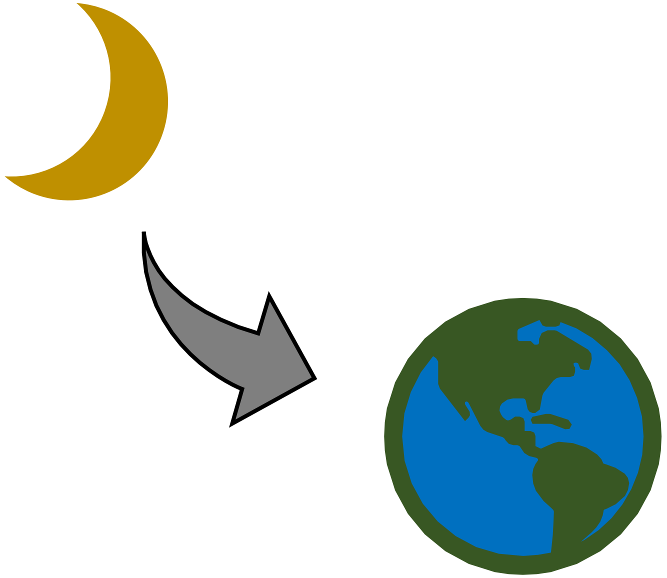


Images from lunar simulant tap testing. Upper and lower images are before and after tapping, respectively. The scale bar is 250 μm.

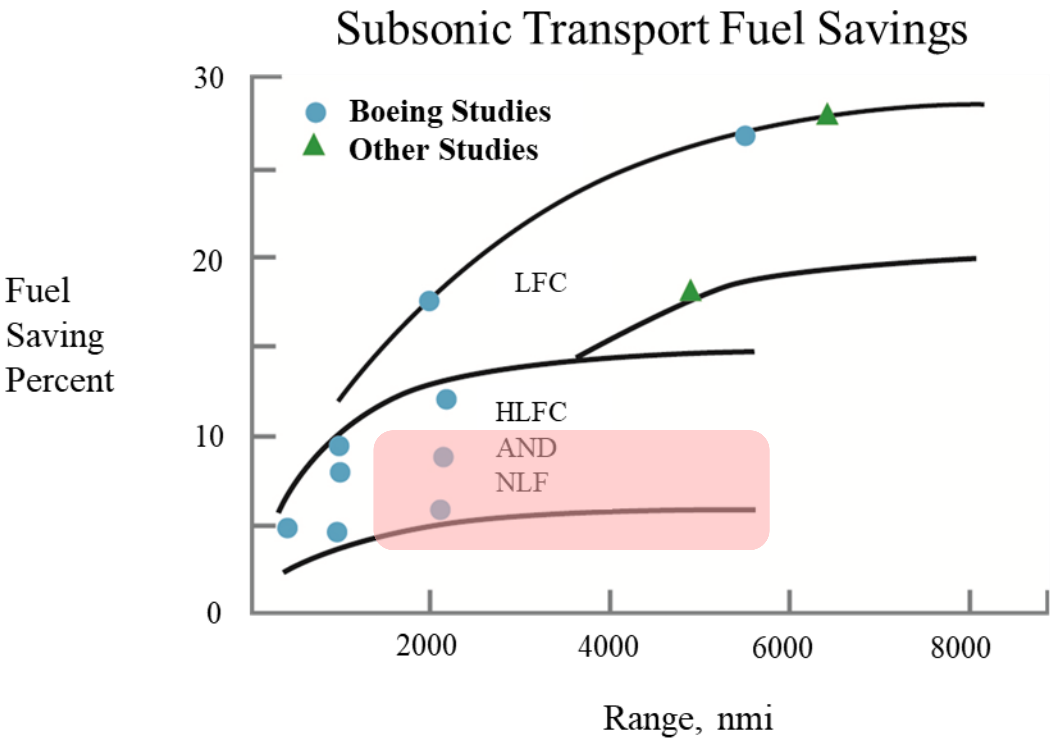
Then dust funding stopped …

- What can be done with this knowledge base of contaminant adhesion prevention/reduction?

- What do we move forward with?
  - Surface chemistry
  - Surface topography



Another extreme environment: commercial aircraft leading edges

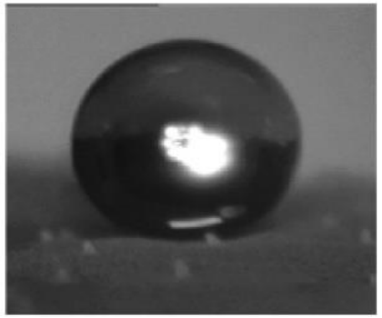


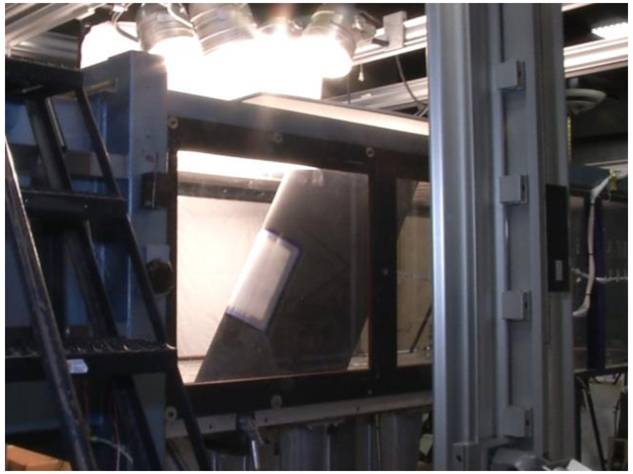
LFC = laminar flow control
HLFC = hybrid laminar flow control
NLF = natural laminar flow

Kirchner, M.E. NASA CP-2487, 1987, Part 1, pp. 24-44.

How do we approach studying aircraft wing contamination?

Screen commercial and experimental materials using contact angle goniometry





Downselect promising coatings for wind tunnel testing

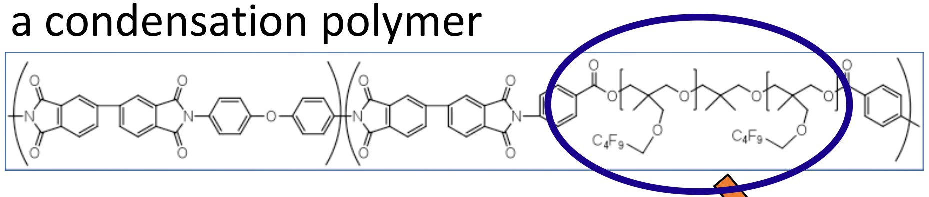
The Boeing Company

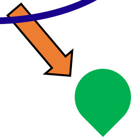
Flight test candidate coatings down-selected from wind tunnel tests

Starting from lunar dust lessons

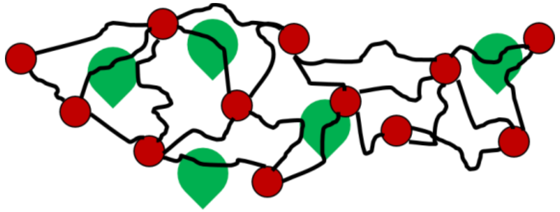
Varied surface chemistry

Surface modifying agent in
a condensation polymer

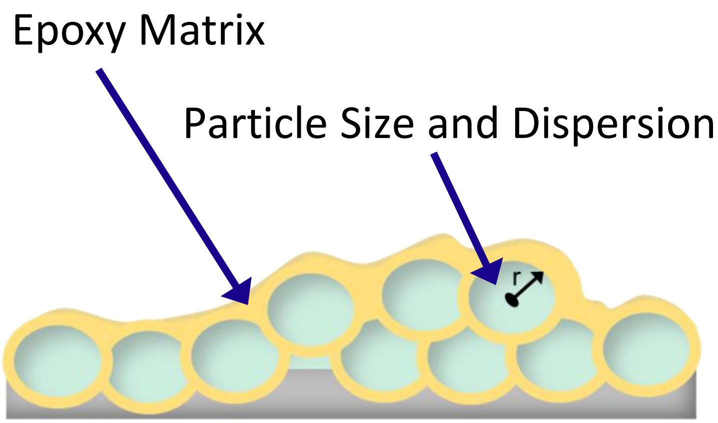




Surface modifying agent
in a cross-linked matrix



Varied surface topography



Particulate	Diameter, nm	Note
SiO_2	7	Fumed Silica, hydrophilic surface
MoS_2	2,000	Solid lubricant

Fast-forward to flight test campaign

Surface Chemical Change

Surface Topography Change

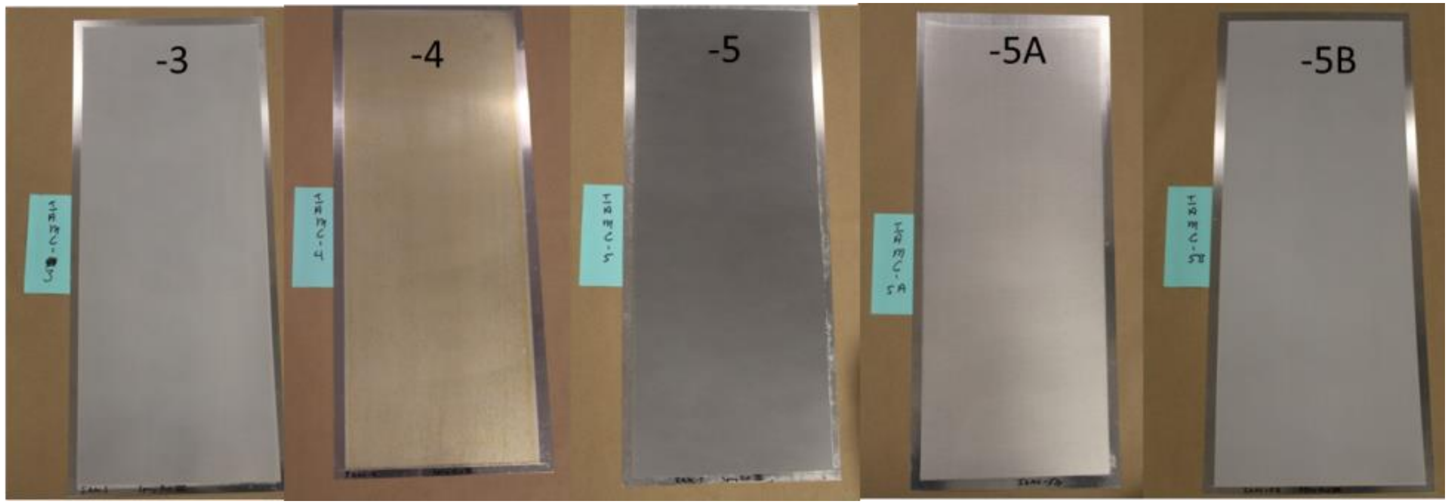
IAMC-5A
Modified COTS Epoxy

IAMC-4
Research Epoxy

IAMC-3
Research Urethane

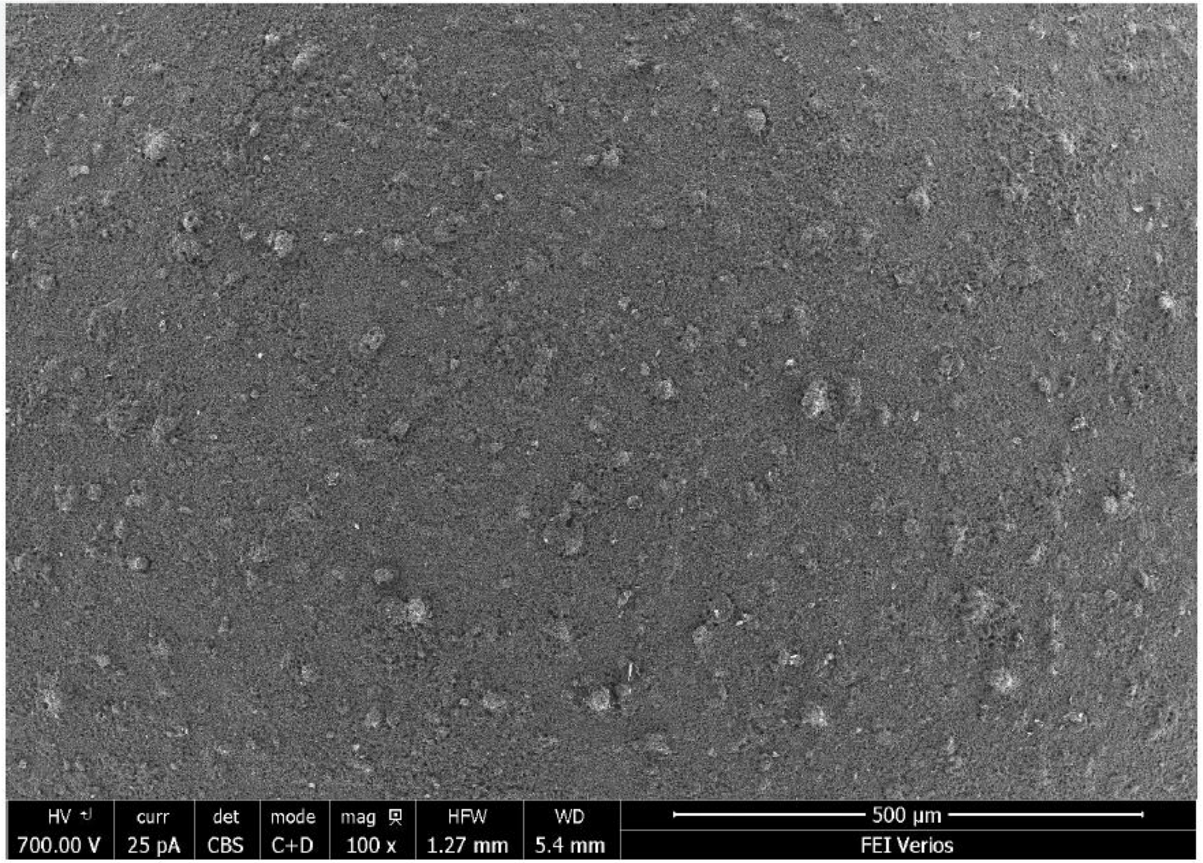
IAMC-5B
Modified COTS Epoxy/1 Filler

IAMC-5
Modified COTS Epoxy/2 Fillers



Images of the coatings

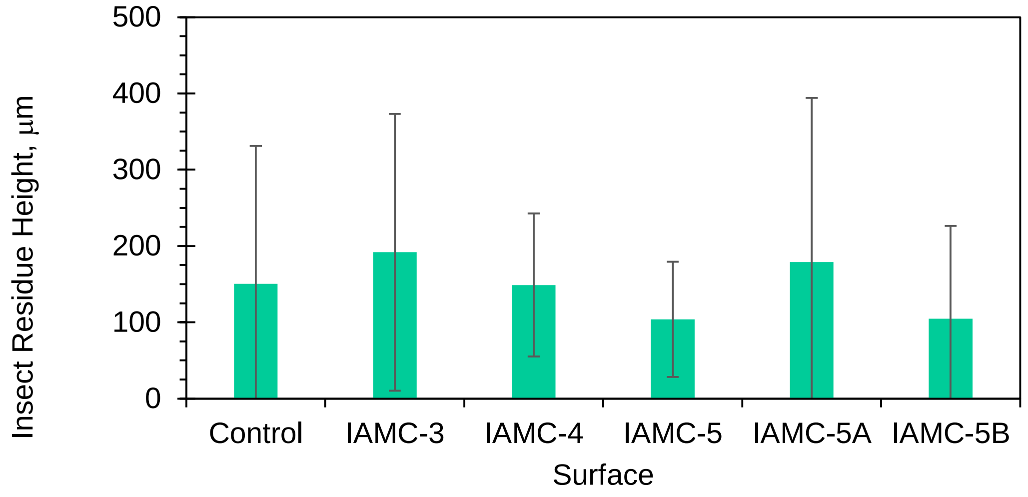
What did the topography look like?

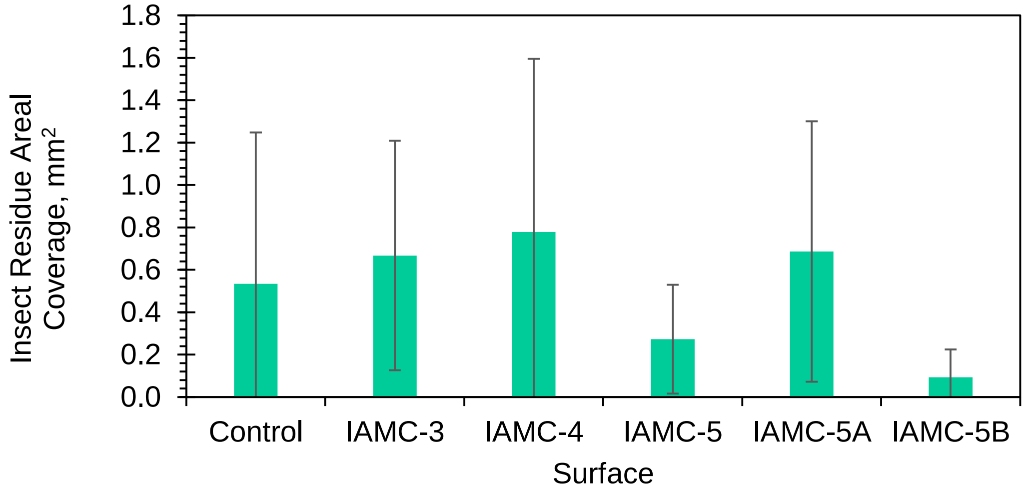


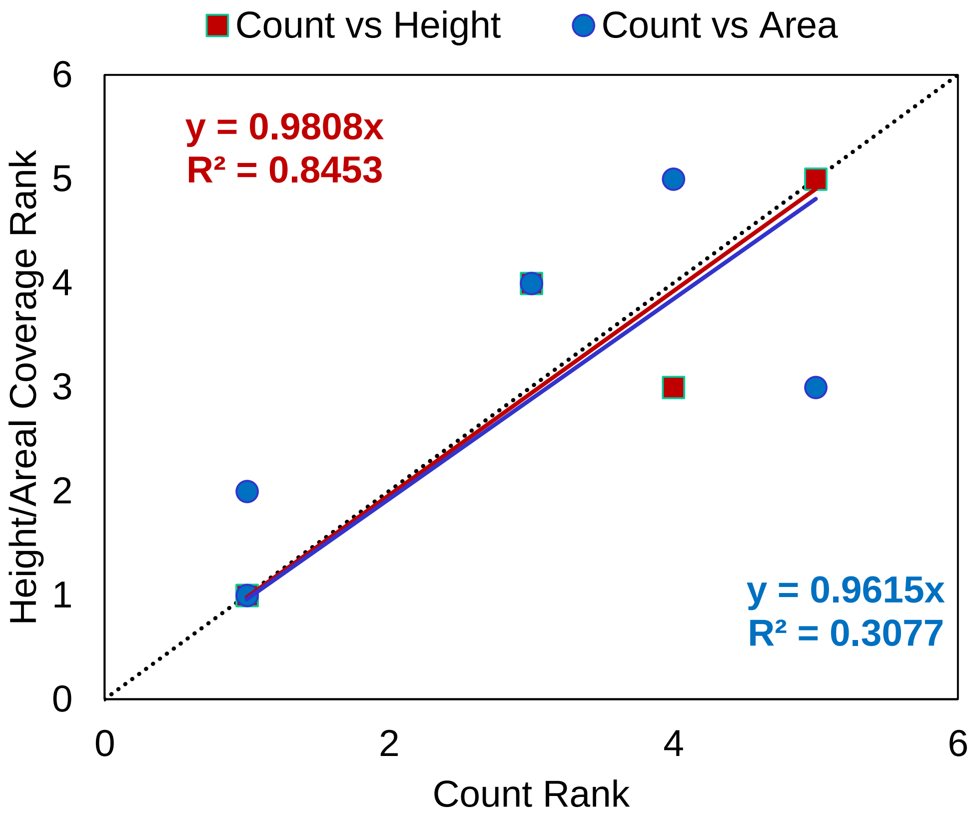
Representative mixed filler (MoS_2 and SiO_2) epoxy particulate composite

Images collected on the FEI Verios 460L compliments of FEI

How did the coatings perform?



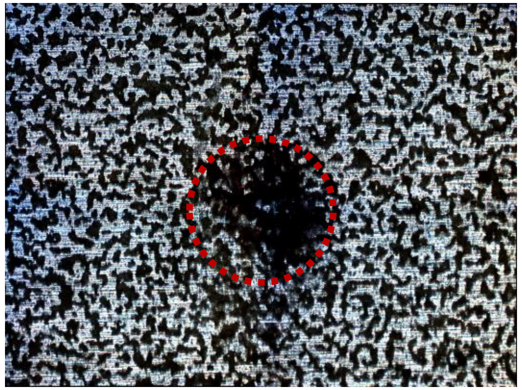


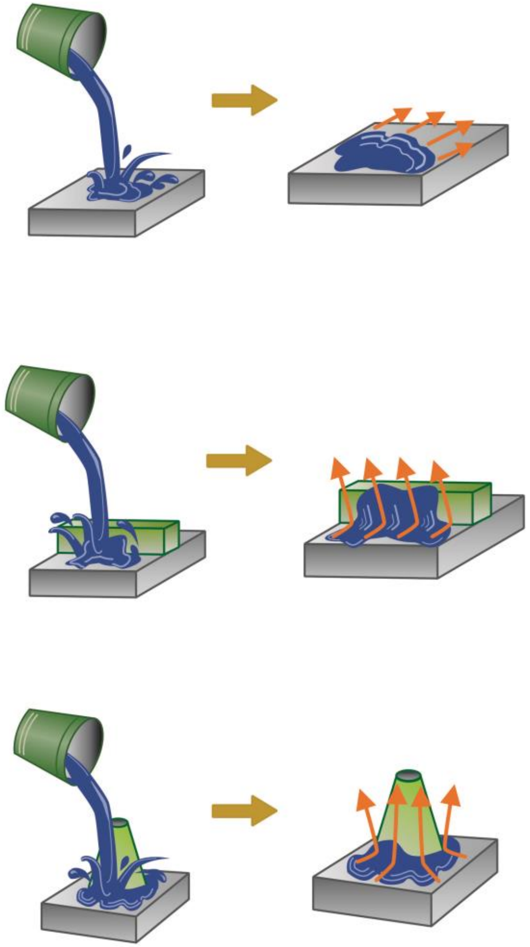


What new information did we gain? Roughness, dynamics, and lamella stability

Stable lamella expansion

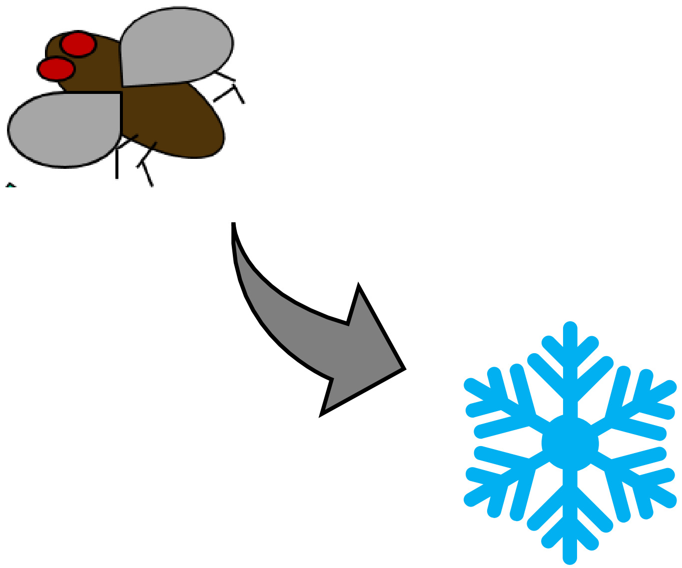
Unstable lamella expansion





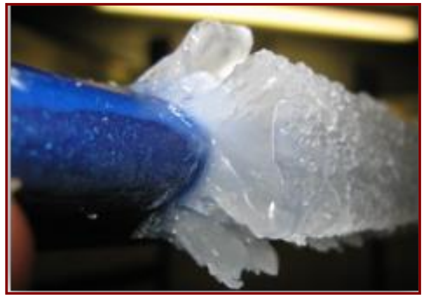
Then … insect accretion mitigation work ended

- Where do we pivot next?
- What do we move forward with?
  - Surface chemistry
  - Surface topography
  - Surface dynamics
  - Surface morphology



Aircraft impact icing

- ❖ In-flight issue year-round under certain atmospheric conditions
  - ❖ Air temperature (0 to -20°C)
  - ❖ Liquid water content (LWC, 0.3-0.6 g/m^3)
  - ❖ Droplet size [median volumetric diameter (MVD) of 15-40 mm]
- ❖ Result of supercooled water droplets impacting the aircraft surface
- ❖ Icing can range from glaze/clear to rime or a combination of the two



Glaze/Clear

Rime

Mixed

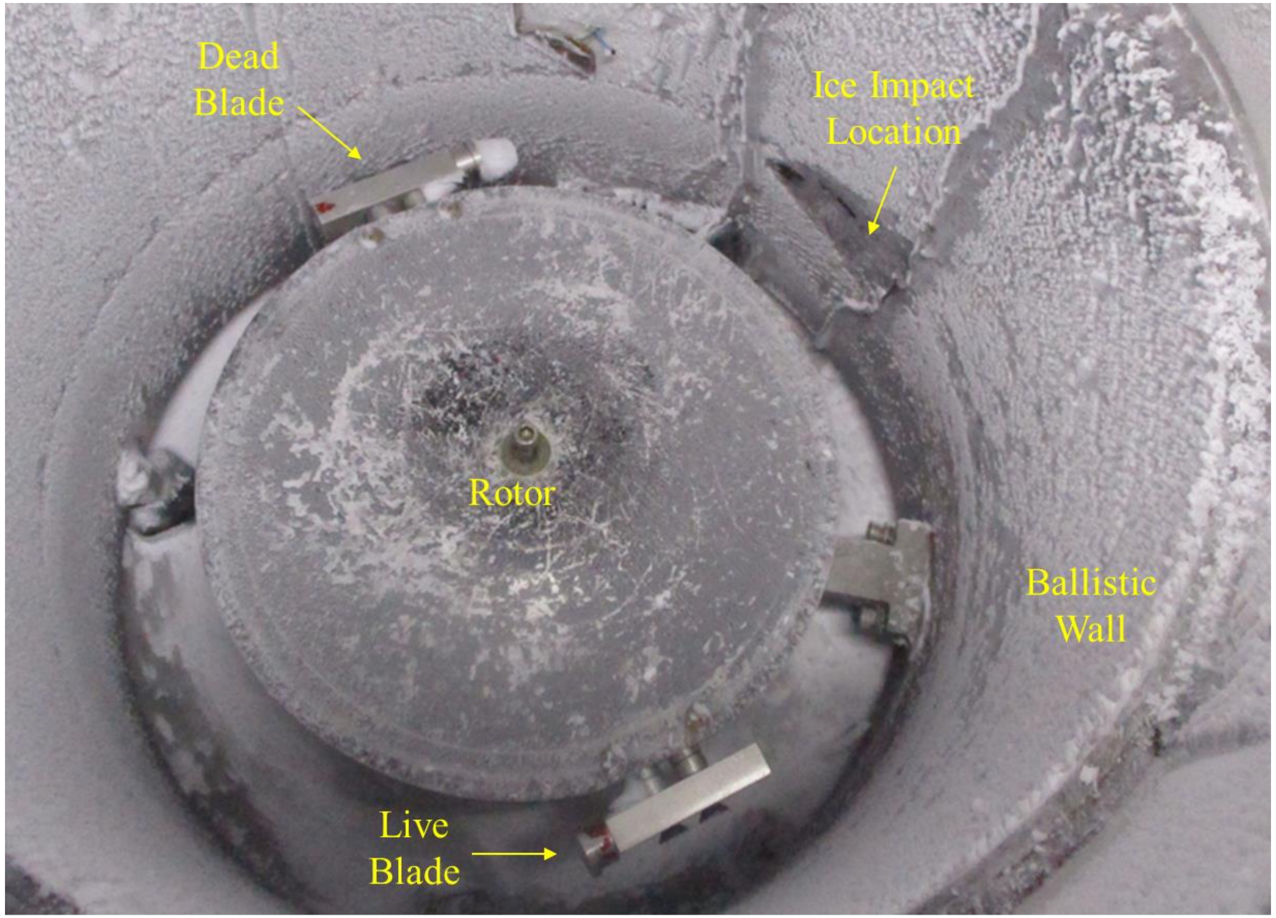
M.K. Politovich, "Aircraft Icing" in Encyclopedia of Atmospheric Sciences, Academic Press, Oxford, 2003, 68-75.
H.E Addy Jr., M.G. Potapczuk, and D.W. Sheldon, "Modern Airfoil Ice Accreations," NASA TM 107423, 1997.

How are we going to study this?

- Simulates icing conditions within the FAR Part 25/29 Appendix C icing envelope
- Ice accumulation and subsequent shedding enables determination of IAS after data analysis
- Test conditions
  - Linear velocity ~ 93 m/s
  - LWC = 0.25 to 0.35 g/m^3
  - MVD of 20 mm

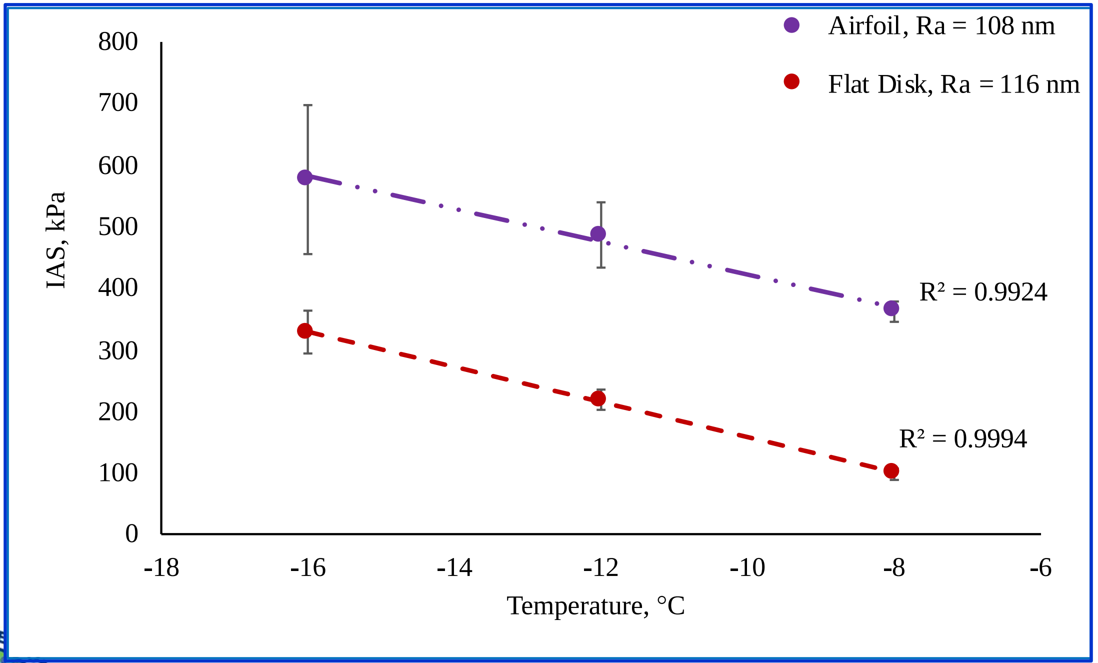
AERTS Jr. (Adverse Environment Rotary Test Stand) based on larger instrument at PSU, POC; Dr. Jose Palacios

How does AERTS Jr. work?

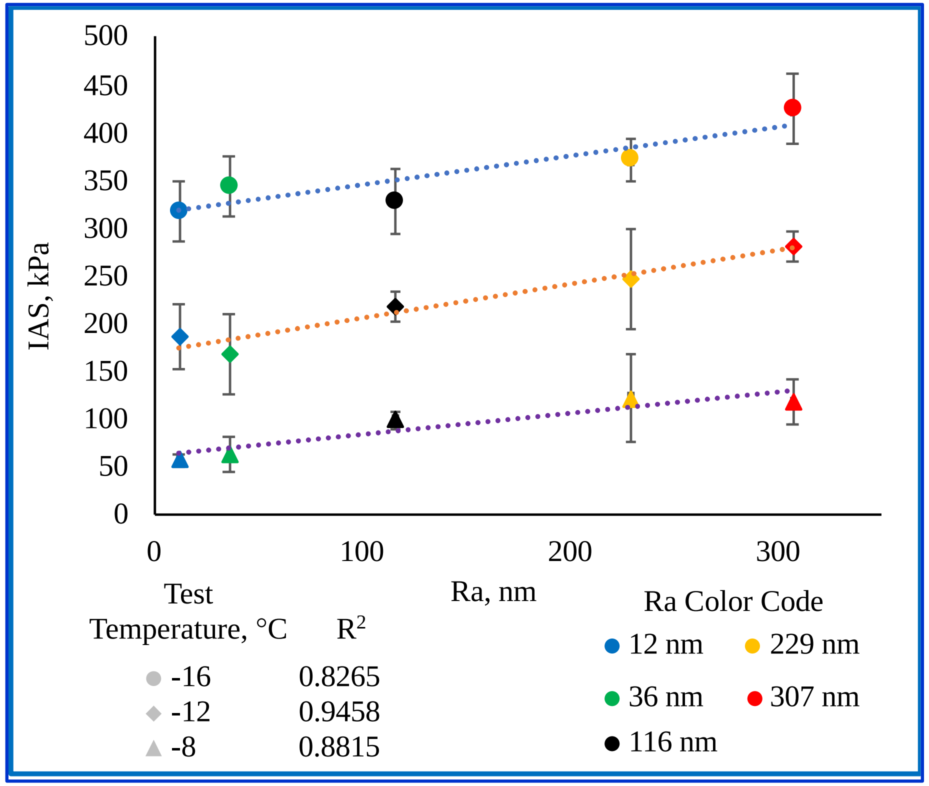


Improved understanding of fundamentals

Stainless steel (304) sample shape

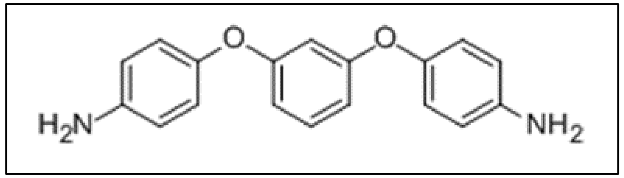


Stainless steel (304) roughness

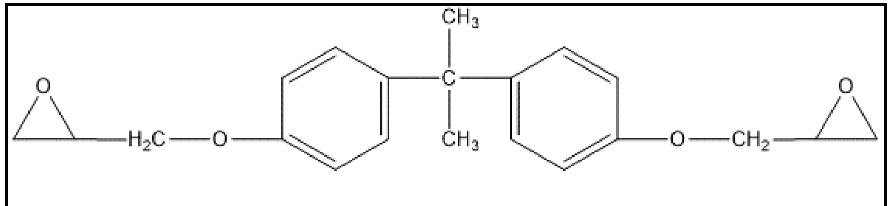


Apply working knowledge for coating development

- Aromatic system consisting of a diamine, a Bisphenol-A based epoxy, a diglycidyl ether, and a solvent
- **1, 3-Bis(4-aminophenoxy)benzene (1,3,4-APB)**

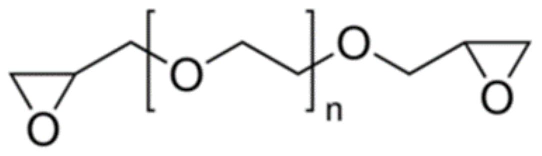


- **DER 331**

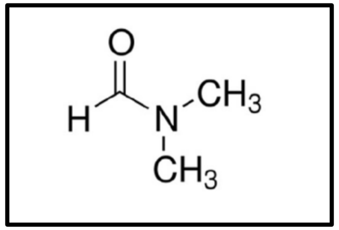


D.E.R. 331 Epoxy Equivalent Weight = 187.5
"Idealized Structure"

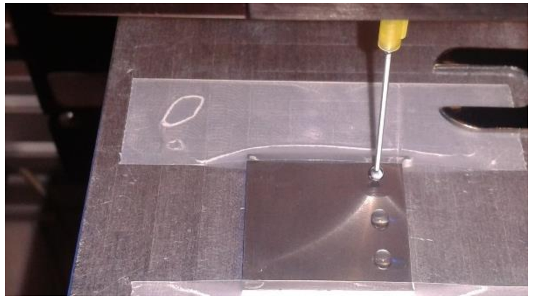
- **Poly(ethylene glycol) diglycidyl ether (PEG-DGE)**

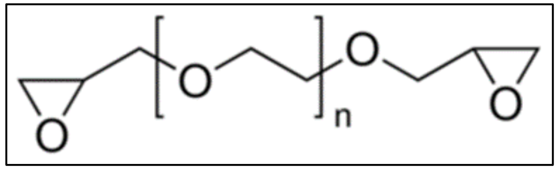


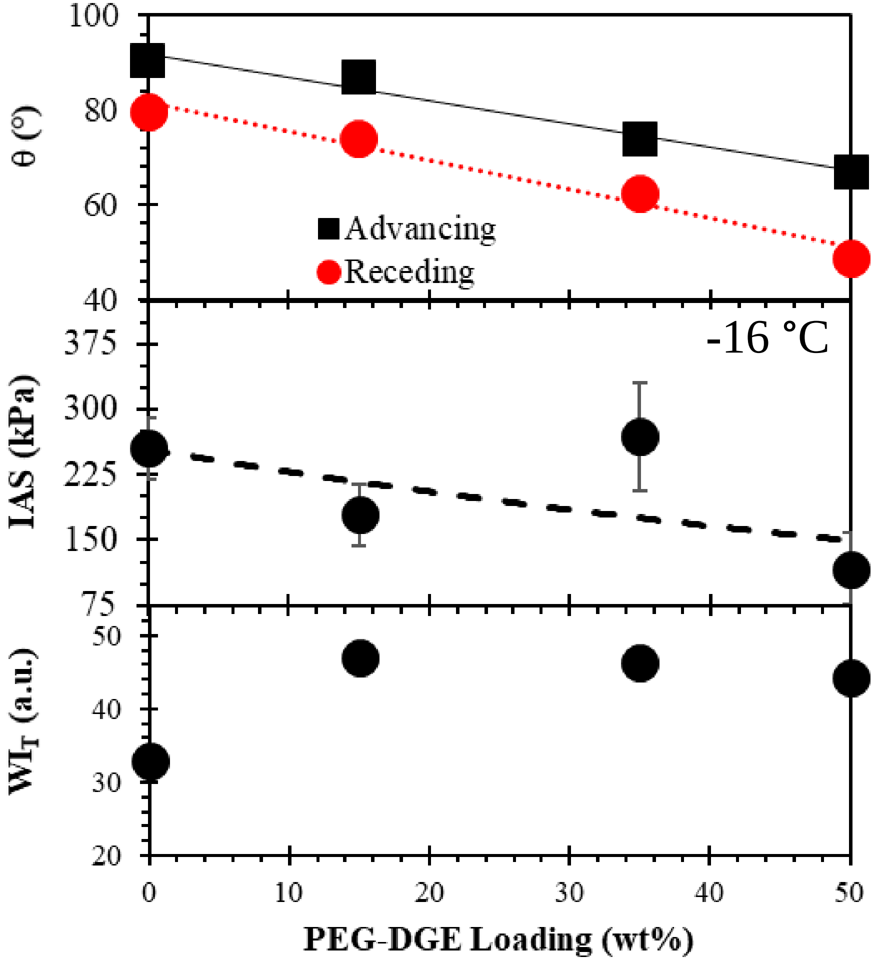
- **N, N'-dimethylformamide (DMF)**



Base resin performance … with PEG-DGE variation







Taber abrasion test
ASTM D4060*
*Modified for thickness dependent response

$$WI_T = \frac{(W_0 - W_{1200})1000}{C} - \alpha_T T$$

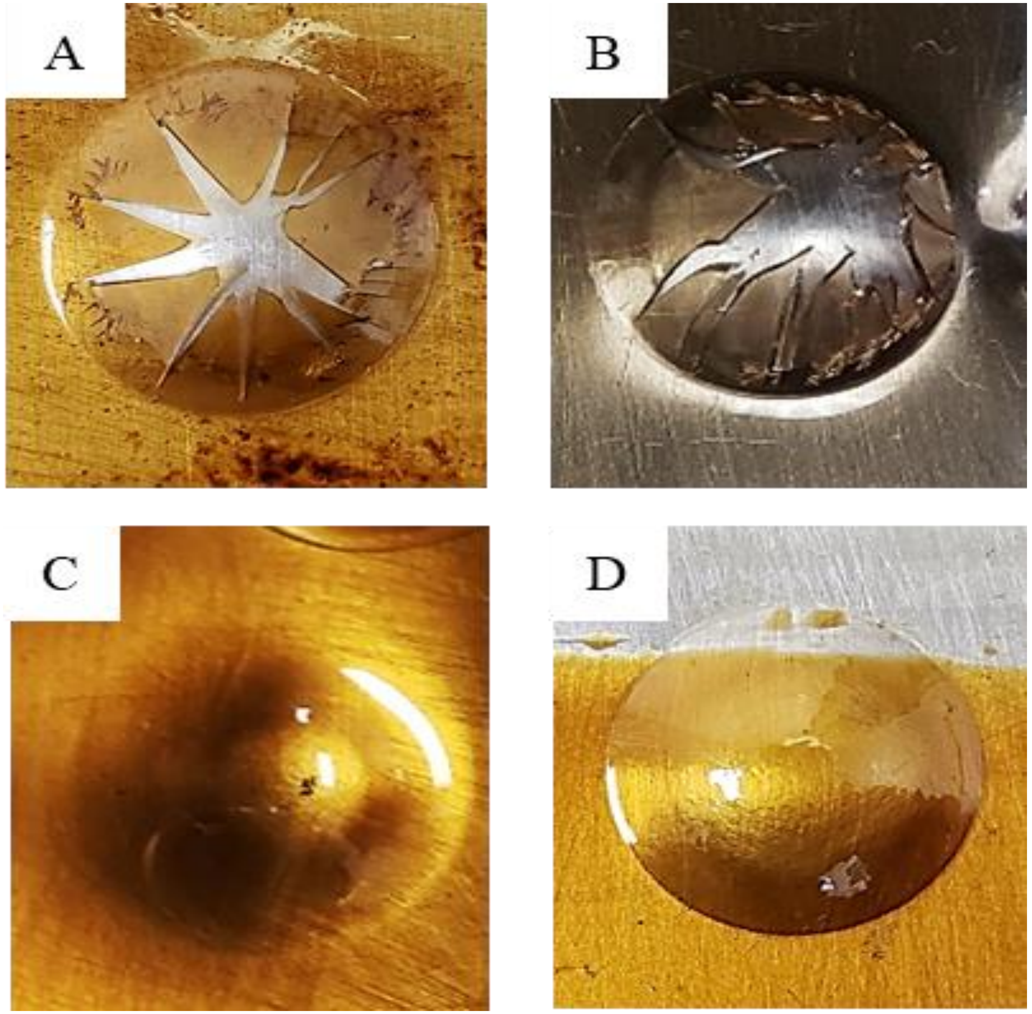
Base resin performance … with PEG-DGE variation

Impact testing

ASTM D2794

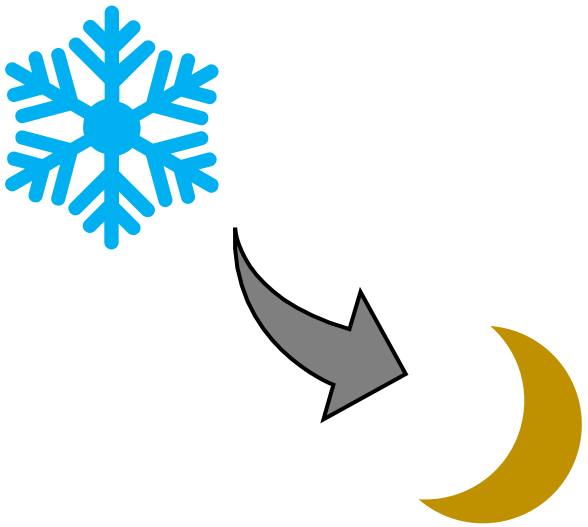
- 1 kg drop weight
- 40 cm drop height
- 15.9 mm radius impact surface

Figure	PEG Loading (wt%)
A	0
B	15
C	35
D	50



Lessons from studying ice adhesion prevention

- What do we move forward with?
  - Surface chemistry
  - Surface topography
  - Surface dynamics
  - Surface morphology
  - Surface mechanical properties
  - Durability



Then came ARTEMIS …

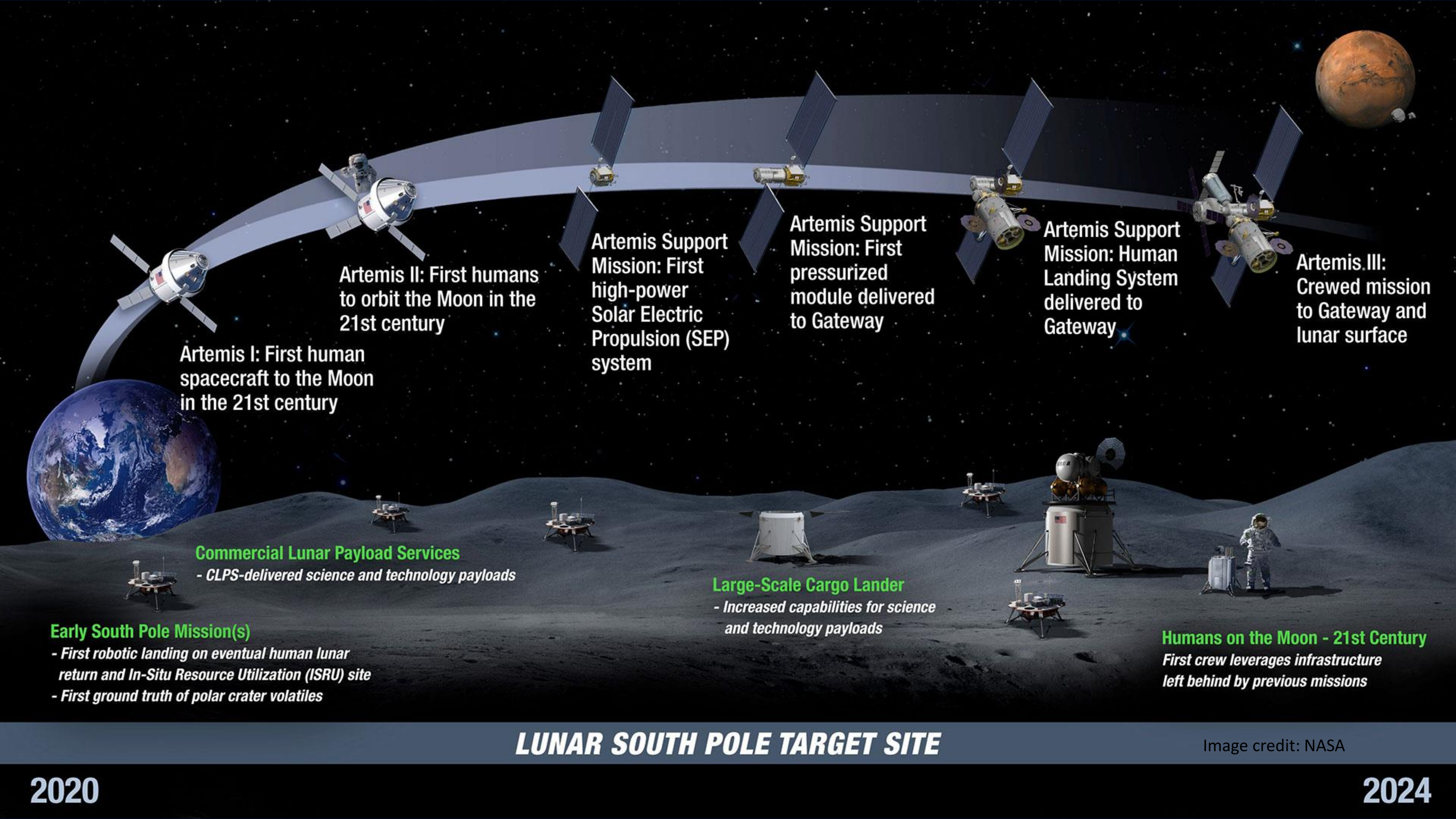
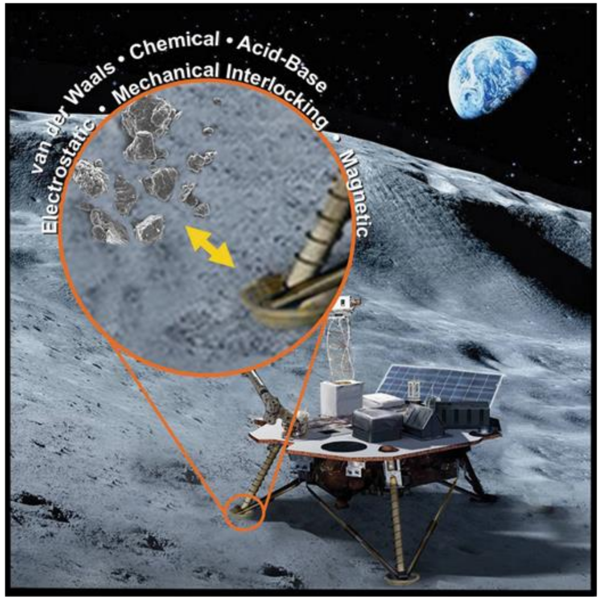


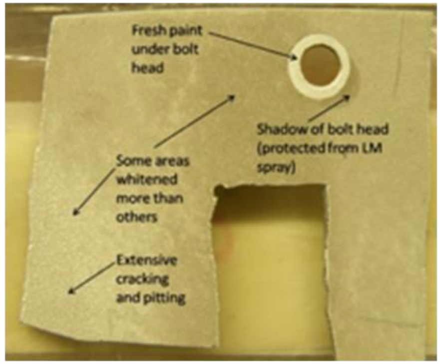
Image credit: NASA

What lessons are we bringing back to lunar dust?

Dust Mitigation-
Must Remove



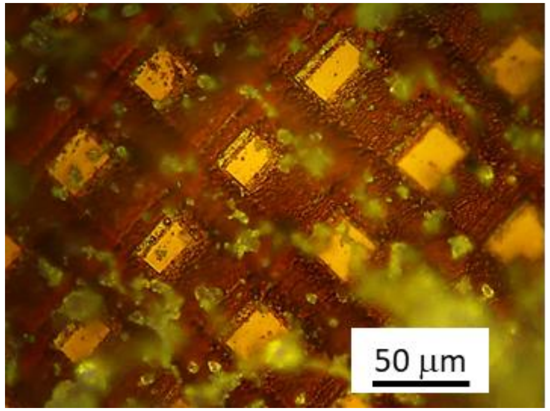
Dust Management-
Must Tolerate

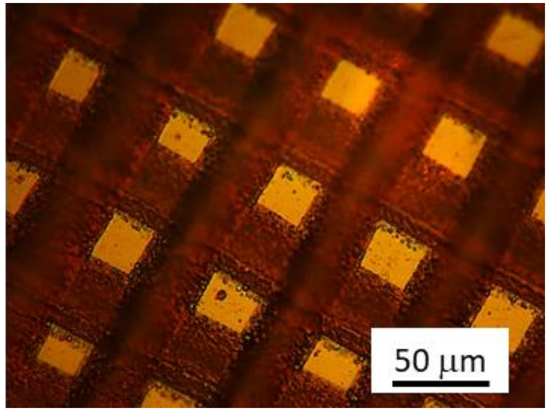


❖Engaging aspects of lunar dust from mitigation to management

Scalable topography

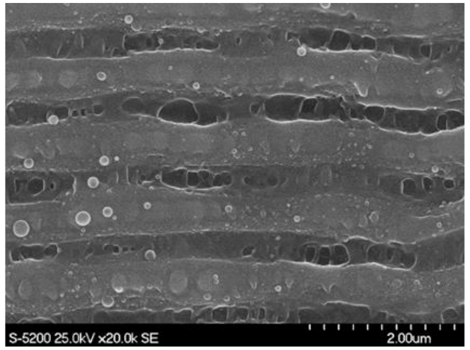
Laboratory scale



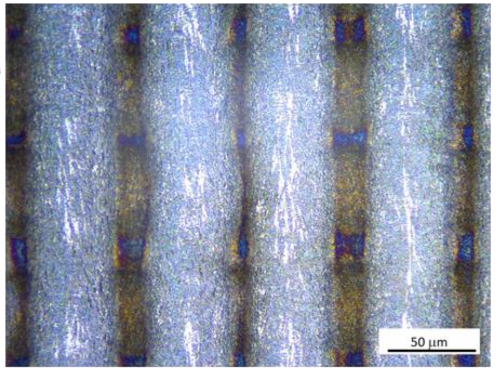


Operational scale

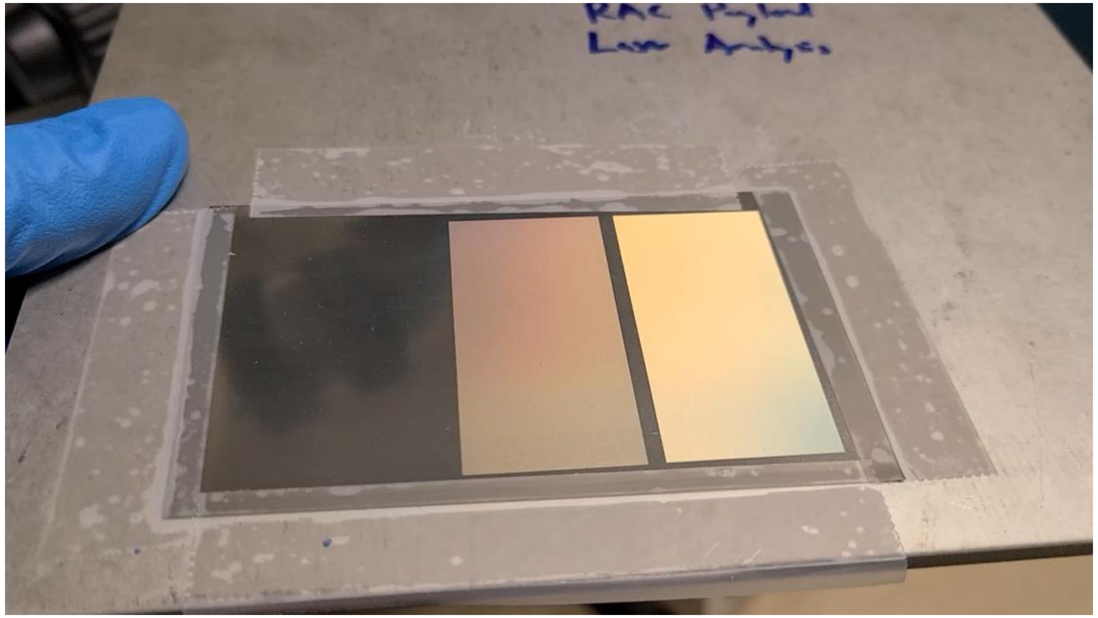
Hierarchical topography



Nanometer-scaled Laser-Induced Period Surface Structure (LIPSS)

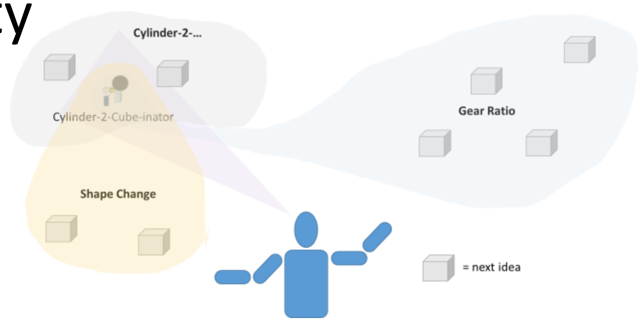


Micrometer-scaled Direct-write Laser Patterning

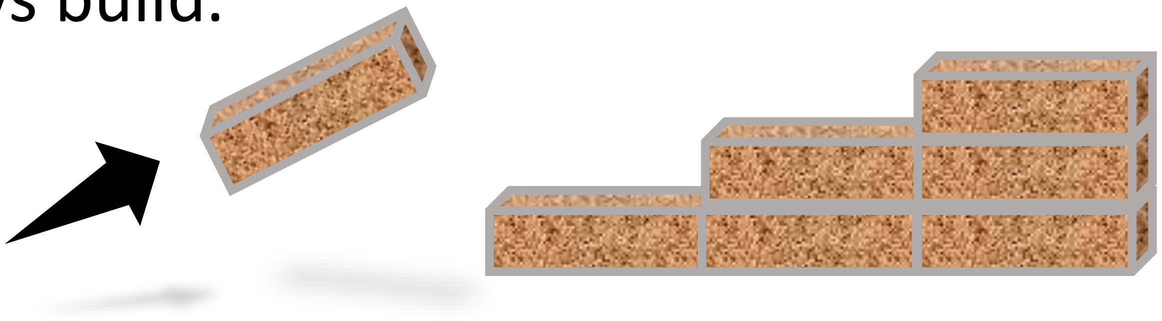


Conclusions

- As your research progresses and results start to develop …
  - Expand your perspective to look for the next opportunity
  - Apply the lessons you have learned



- There is no such thing as starting from ground level after your first research activity, it can always build.



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