UV Cure 'Shark Skin bio-mimicking' Antimicrobial surfaces for Autonomous Vehicles?

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Agenda

- ❑ Autonomous Vehicle (AVs) Revolution?
- ❑ History & Development of UV-A Cure Automotive Paints
- ❑ Background on Aircraft ‘Shark Skin” (Riblet) UV Curable Aerospace Coatings
- ❑ So what is the connection between Shark Skin Antimicrobial and AV?
- ❑ Current Shark Skin (Riblet) Antimicrobial Surfaces in the market
- ❑ So where do we go next?
- ❑ Conclusions

Expected release Dates of Autonomous Vehicles (AV)

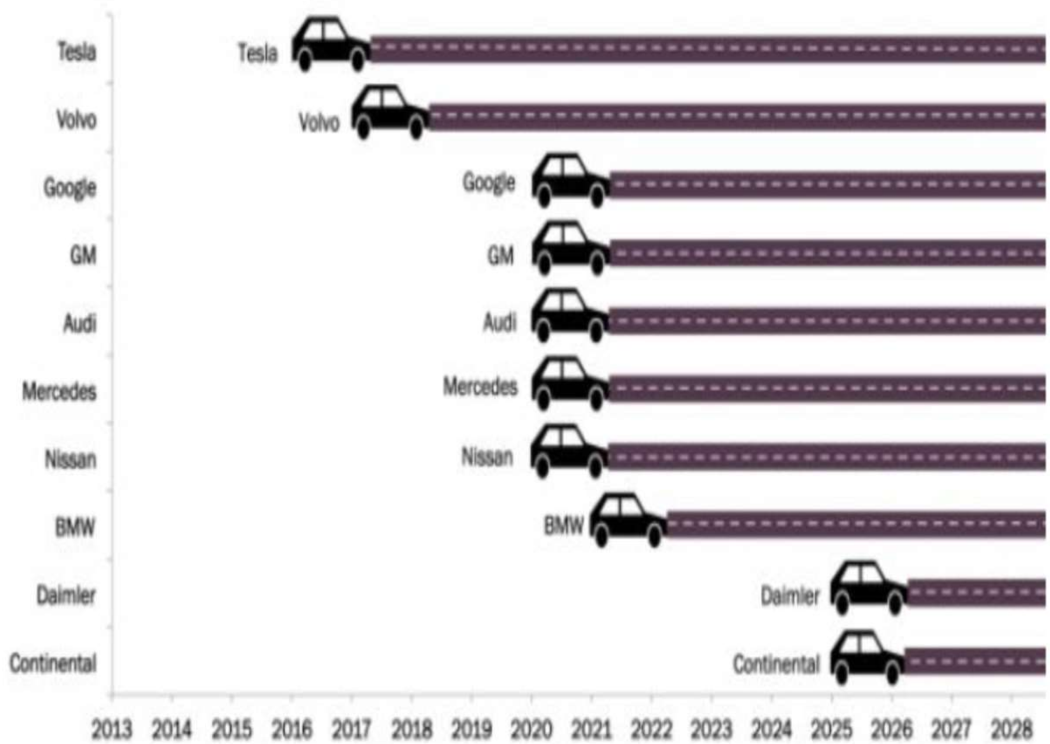


Figure 5: Expected release of Autonomous cars

AI based Autonomous Car, Bin Sulaiman, R., Institute of Arts,
Science & Technology, Dept. of Computing, Glyndwr University, Wrexham, UK (2018)

Autonomous Vehicles; Follow the Money

- Country: **USA** | Funding: **$3.6B**
  Argo AI is a self-driving technology platform company.
- Country: **USA** | Funding: **$3.4B**
  Cruise Automation is a self-driving car company that develops an autopilot system for existing cars.
- Country: **USA** | Funding: **$3B**
  Waymo is Google's self-driving technology startup with a mission to make it safe and easy for people and things to move around.
- Country: **USA** | Funding: **$1.5B**
  NURO is a technology company that aims to accelerate the benefits of robotics for everyday life.
- Country: **USA** | Funding: **$1.3B**
  Pony.ai is a developer of AI-based robot designed for autonomous driving.

https://ai-startups.org/top/self_driving_cars/

Stages of Autonomous Vehicles Introduction

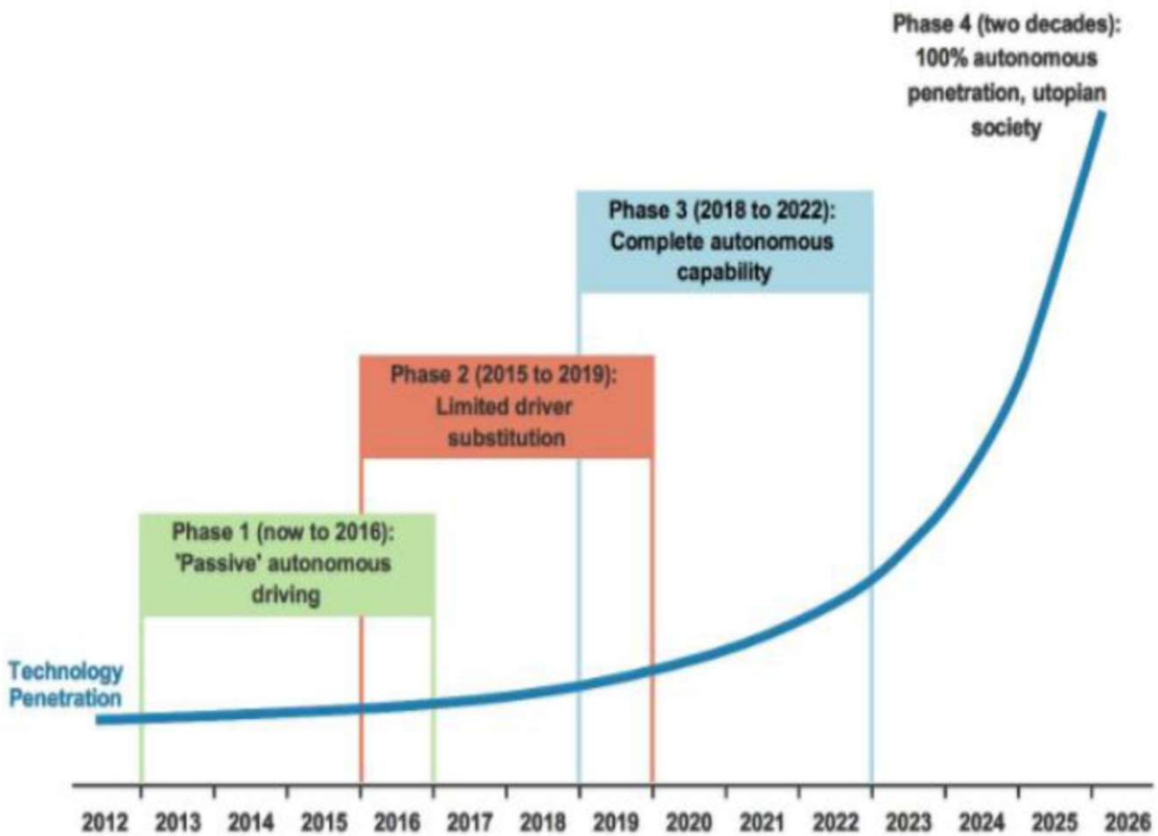


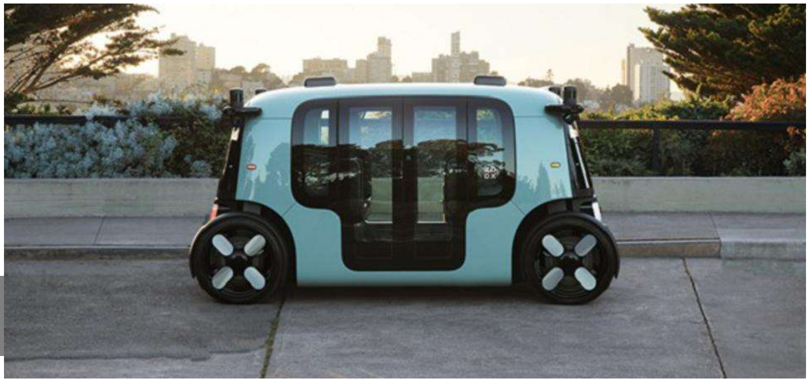
Figure 6: Stages of Autonomous car

Autonomous Vehicle (AVs)Revolution?

- Waymo (former Google Div.) is the front-runner in the self-driving race.
  - It has been ferrying paid passengers around Phoenix for the past year (2019)
  - These AVs often are running without a “safety driver”
  - Waymo One (robotaxi service) topped 100,000 trips in 2019
  - Waymo One has fully driverless vehicles drove over 70,000 miles on US roads

- Zoox (Amazon-owned) has an autonomous robotaxi introduced in December 2019
  - Fully driverless (no steering wheel) that can go 75 mph
  - The AV is built for ride hailing
  - Passengers face each other
- An endless loop Uber/Tesla/Waymo AVs?
  - Car ownership is a thing of the past?

[Why 2021 Will Be The Year Self-Driving Cars Go Mainstream (forbes.com)]



History & Development of UV-A Cure Automotive Paints

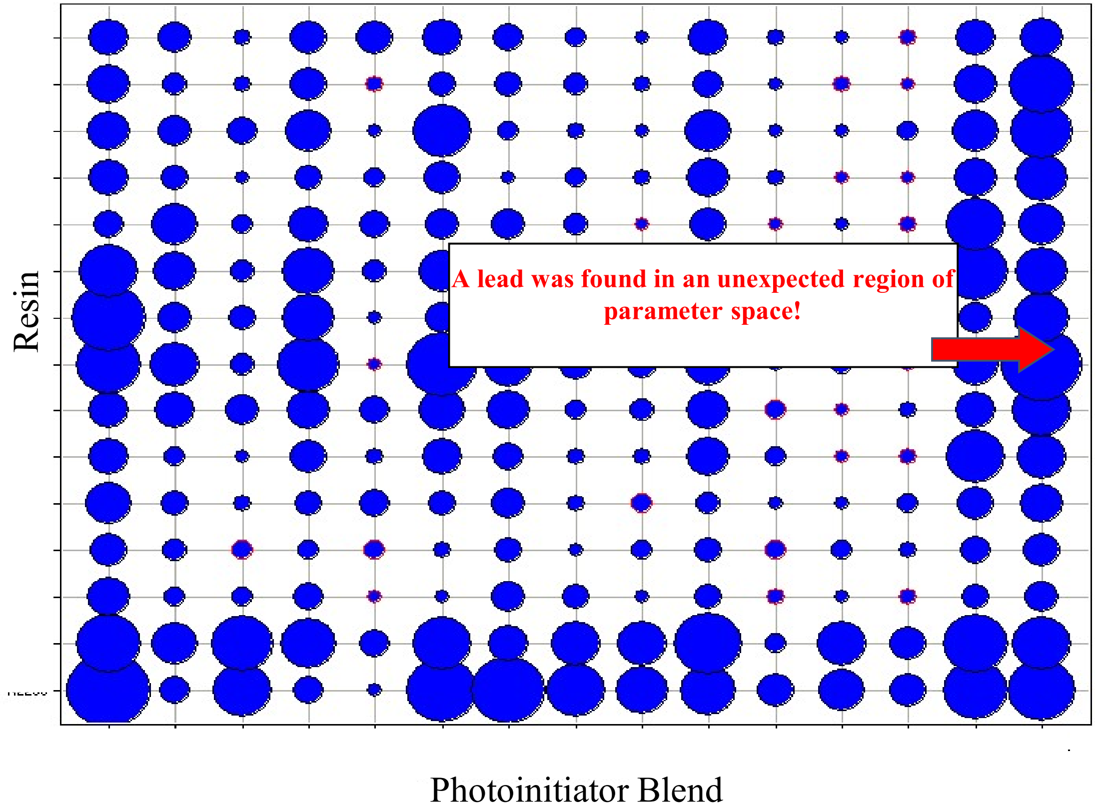
- UV-A lights used to repair stone chips in windshields
- In 2000 a new technique was developed and introduced that would speed up the use of a automotive primer.
- In 2005 Clear Coats were introduced
- This new product brought the use of a UV-A light to cure the primer to american automotive refinish shops
- Current systems being used in NAFTA & Europe

Dvorchak, M. J., Bayer Polymers, LLC, Diffuse UV Cure (UV-A) in the Automotive Coatings Industry: Fact or Fiction?, Focus Conference May 1, 2003

History & Development of UV-A Cure Automotive Paints

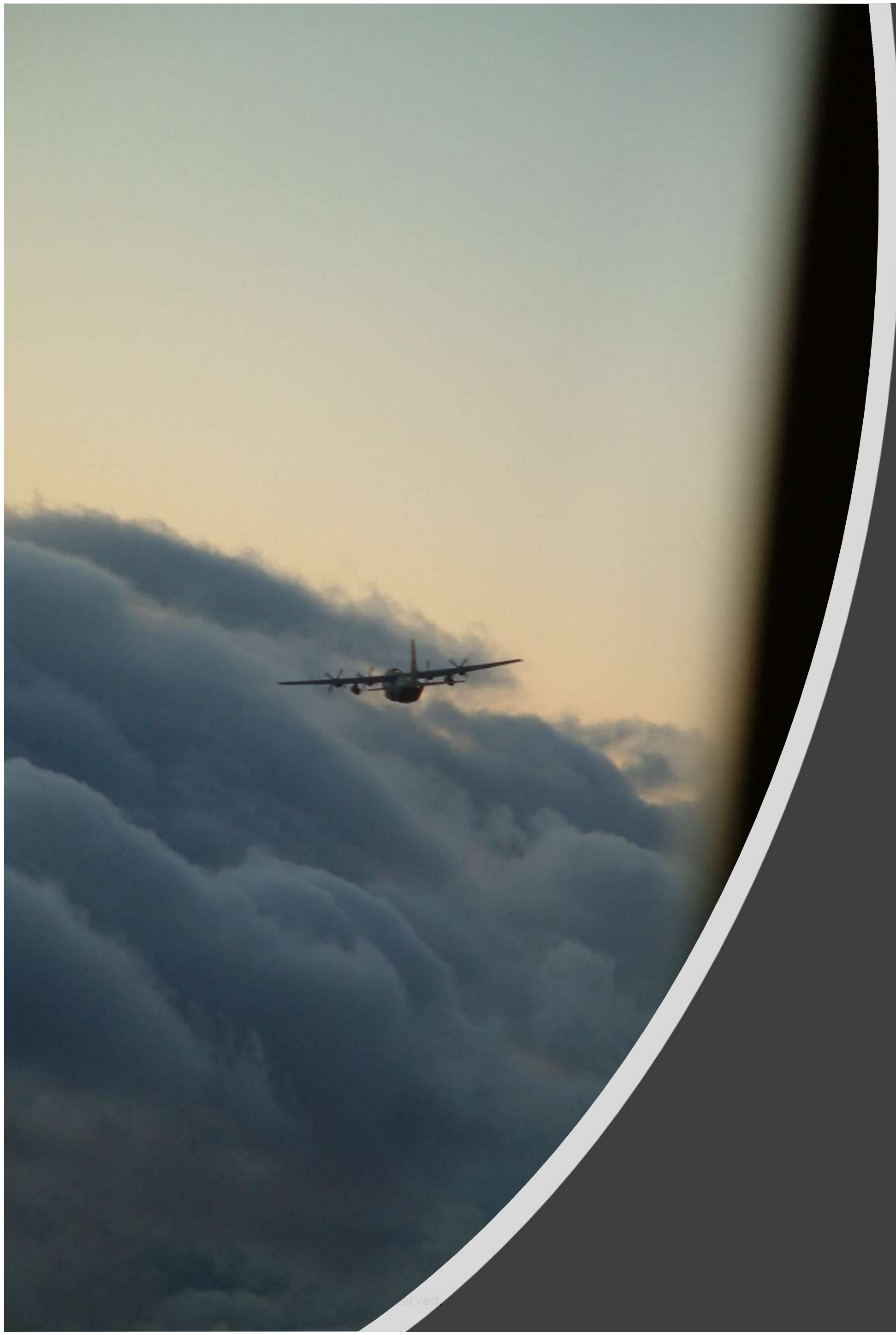
How did researchers overcome the oxygen inhibition issues with UVA Cure ?

Scale: bigger marker, better surface cure



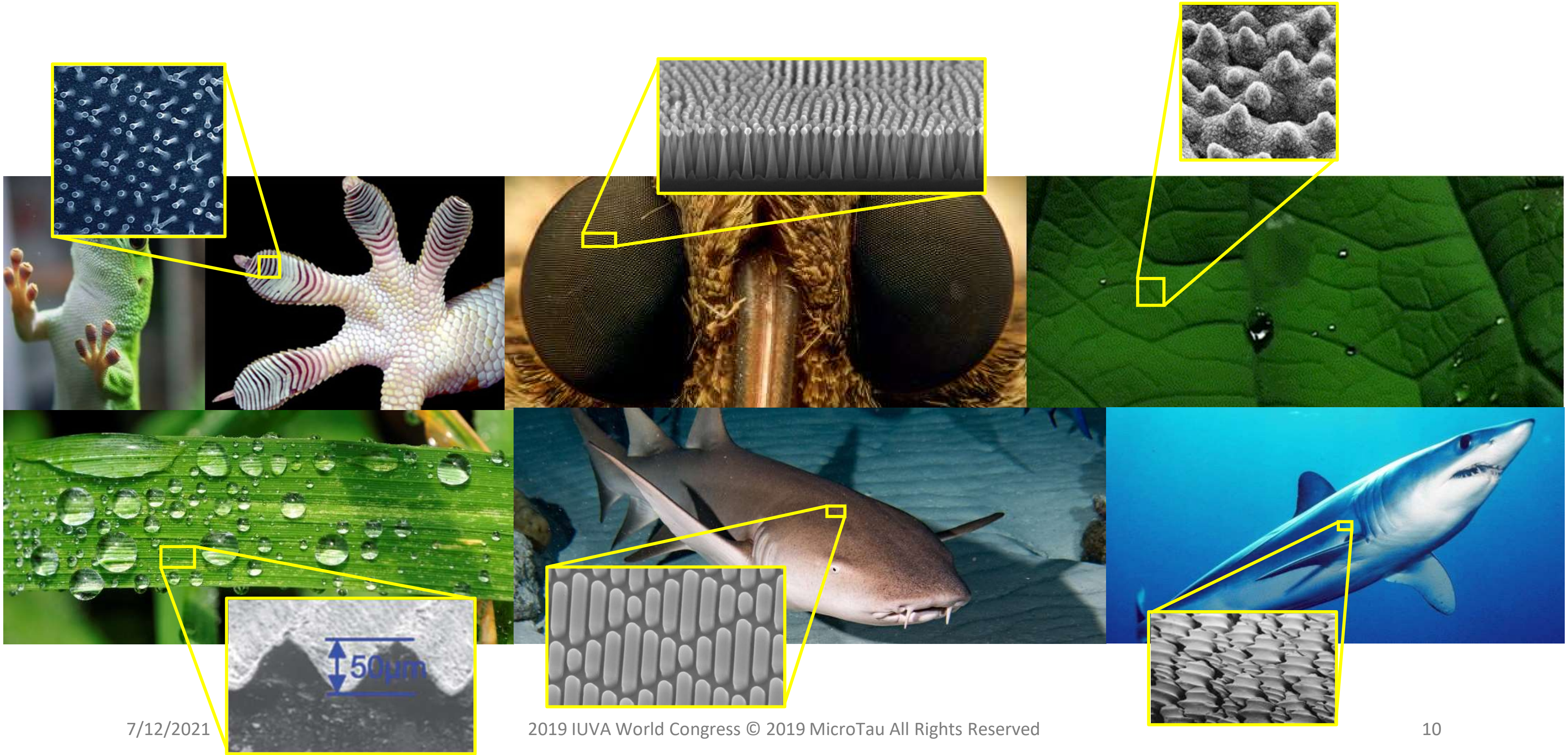
Determine average response as a function of resin, RD, PI, [PI], lamp distance, irradiation time

Dvorchak, M. J., Bayer Polymers, LLC, Diffuse UV Cure (UV-A) in the Automotive Coatings Industry: Fact or Fiction?, Focus Conference May 1, 2003



Background on Shark Skin (riblets)

Functional Microstructures



History of Shark Skin (Riblet) UV Curable Aerospace Coatings?

- ❑ Current USAF technical orders require min. 72-hr ‘dry-to-fly’ time for polyurethane topcoat
- ❑ Painting operations in depot and field units typically cause a ‘bottleneck’ in the work flow
  - ❑ Any one operational base may have up to *dozens* of aircraft and *hundreds* of pieces of support equipment – all need maintenance
  - ❑ Depots collectively paint hundreds of aircraft per year – all require lengthy dry-to-fly time
- ❑ Typical USAF coatings contain 340 – 420 g/L VOC

O’Neil, J., US 8,227,050 Jul. 24, 2012

History of Shark Skin (Riblet) UV Curable Aerospace Coatings

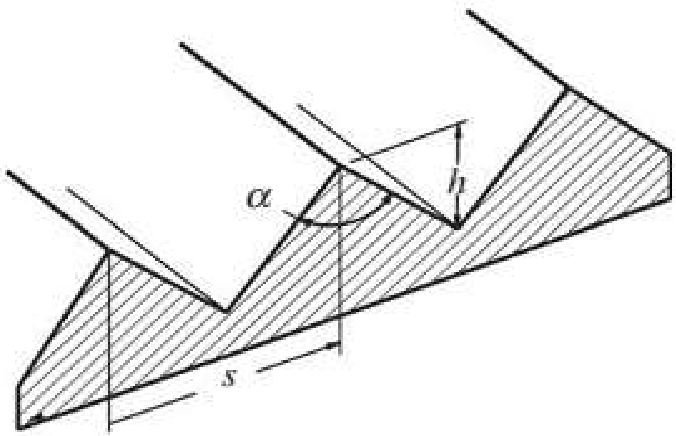
Air Force Research Lab's Engineered Surfaces, Materials and Coatings (ESMC) Program

- USAF C-17, C-5 and C-130 consumed 618 million gal. fuel in 2014
- Ohio Aerospace Institute (OAI) as prime contractor to Lockheed Martin
- OAI did an InnoCentive request and received 95 submissions for the potential to obtain $10,000 to conduct research
- Out of the 95 submissions 9 were selected and reduced to 3 for the Phase 1 monies in April 2016.
- Results of this program awarded Micro Tau Phase 2 monies in early 2017

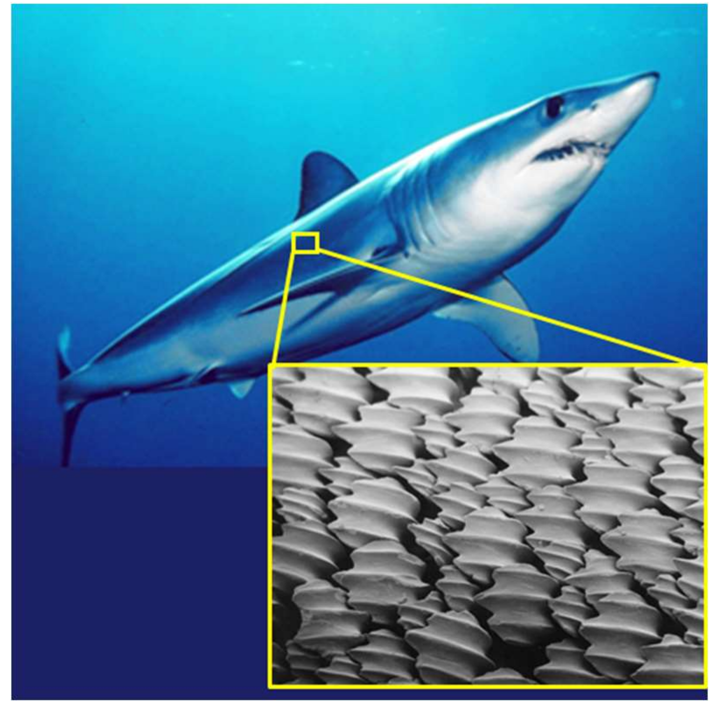
Warwick, G, U.S. Air Force Tackles Fuel-Burn Reduction On Legacy Aircraft, Aviation Week & Space Technology Jan 26, 2017

Problem

- **Riblets**



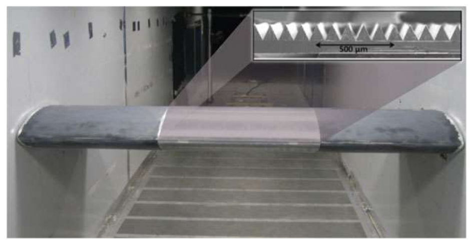
  – 5-10% reduction skin friction drag
  – 40+ years of evidence



- **Yet to be implemented due to economic viability**
  – Application time and cost
  – Durability and maintenance
  → *Total cost out weighs fuel saving benefits*

Previous attempts at Riblets (Shark Skin)

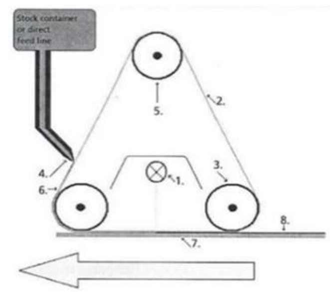
Appliqué films



Yet to prove economically (cost > savings):

- Application time and cost
- Lifespan (durability and maintenance)
- Limited coverage

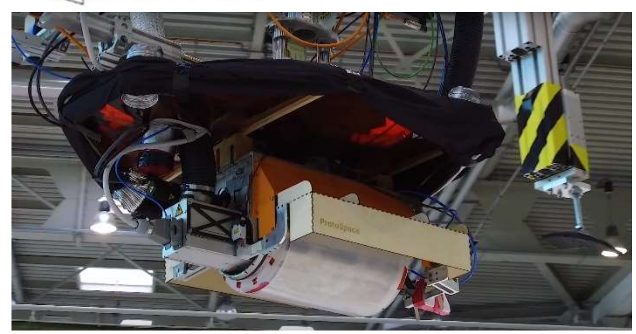
Nanoimprint Lithography



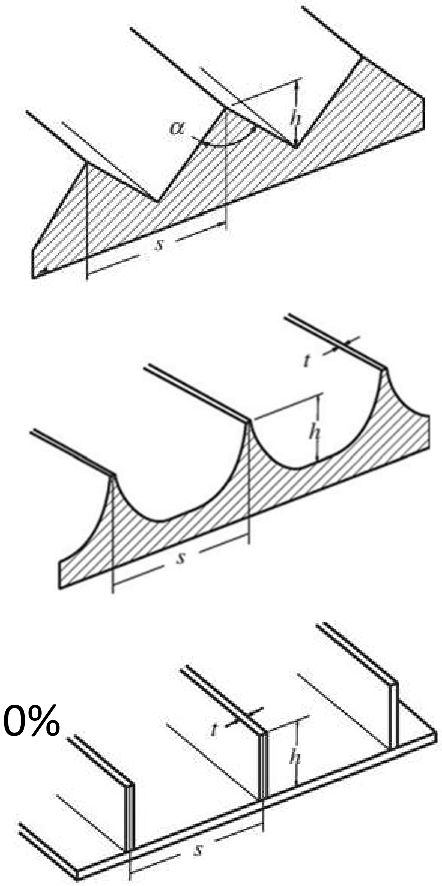
Lufthansa Technik

Fraunhofer IFAM

AIRBUS GROUP



History of Shark Skin (Riblet)
UV Curable Aerospace Coatings

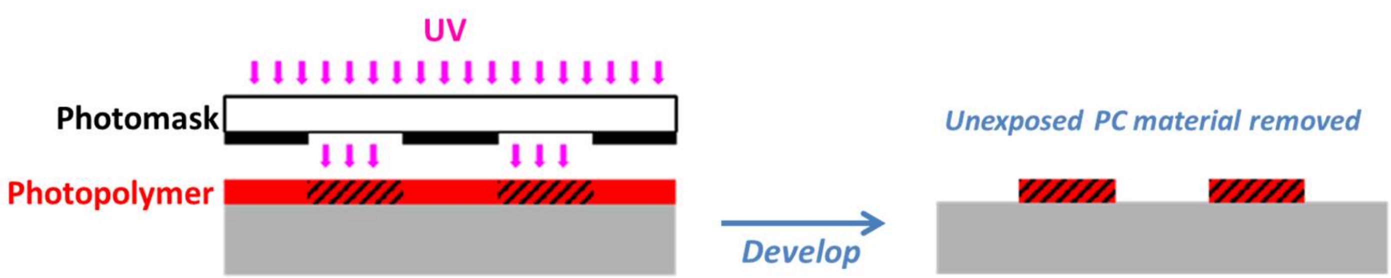


- Spacing & height ~50-150µm
- Turbulent drag reduction of up to 10%

Bilinsky, H., MicroTau Pty Ltd
SciTech January 9, 2017

History of Shark Skin (Riblet)
UV Curable Aerospace Coatings

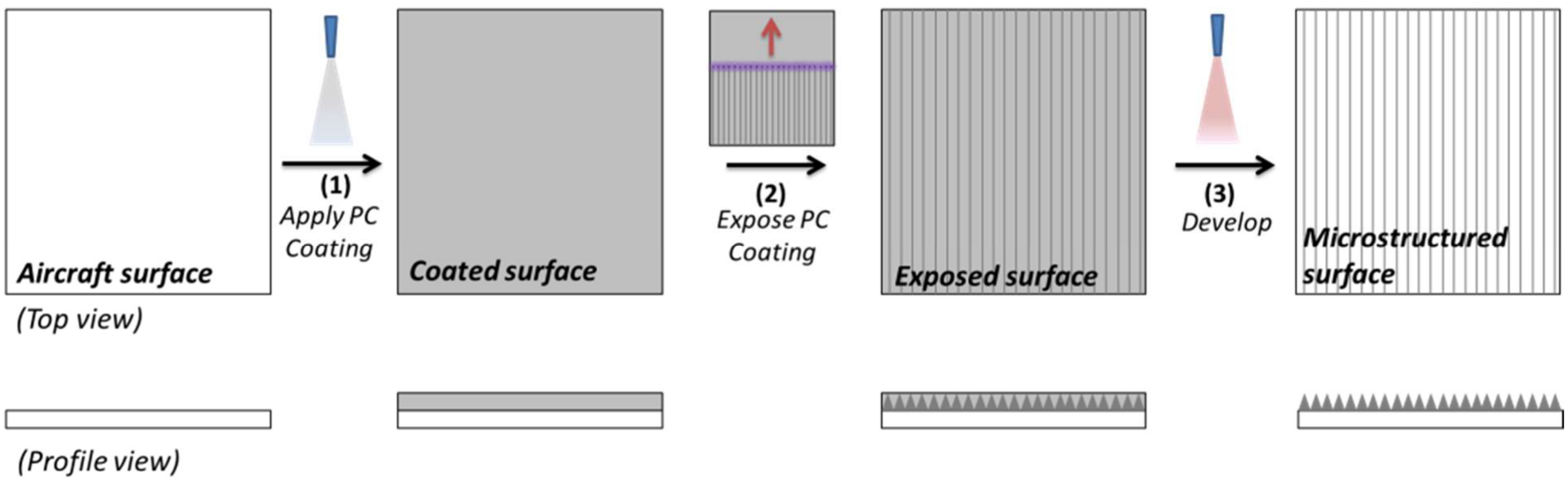
Photolithography (computer chip fabrication)



Bilinsky, H., MicroTau Pty Ltd
SciTech January 9, 2017

History of Shark Skin (Riblet)
UV Curable Aerospace Coatings

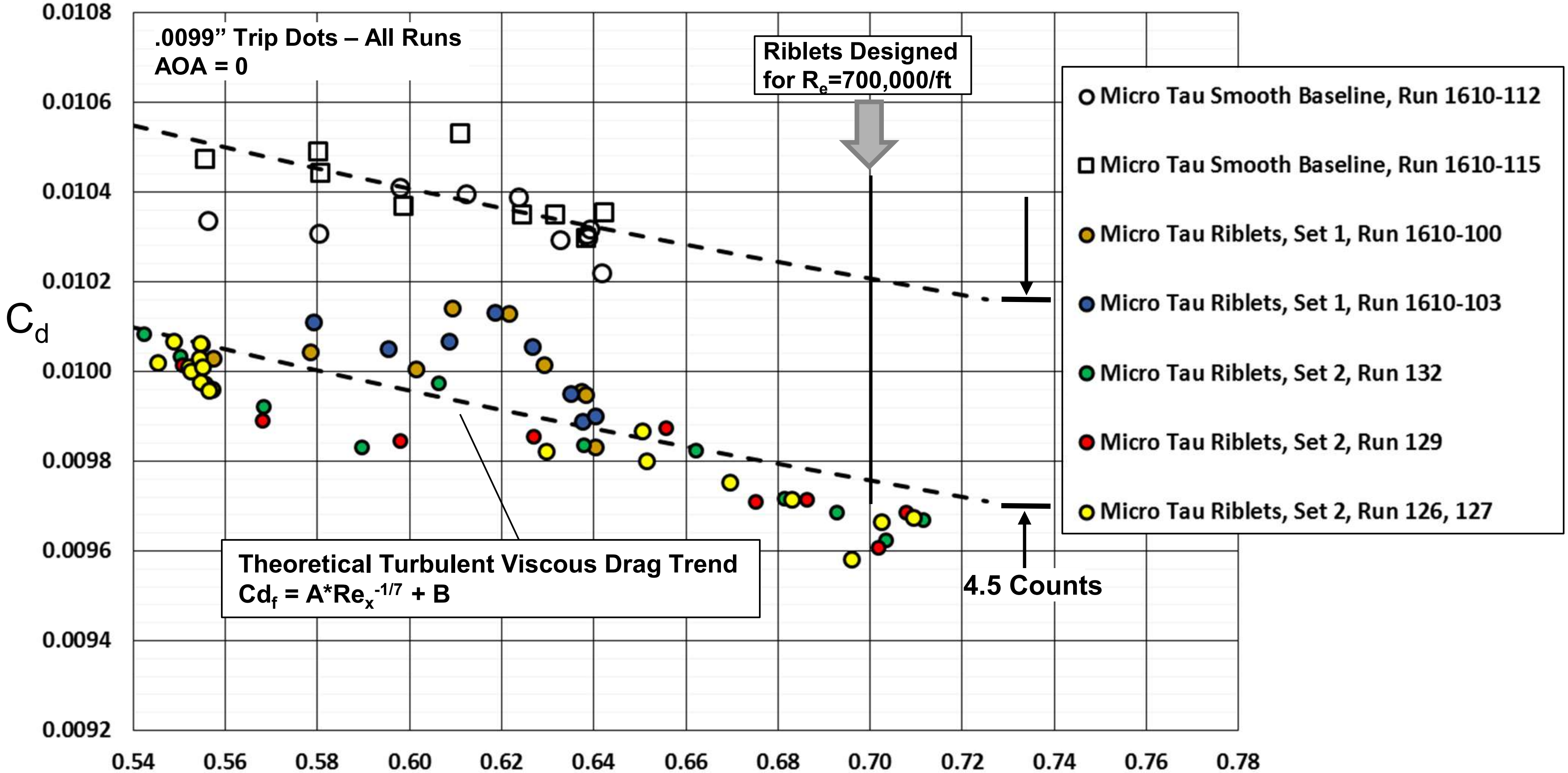
3 Step Riblet Microfabrication



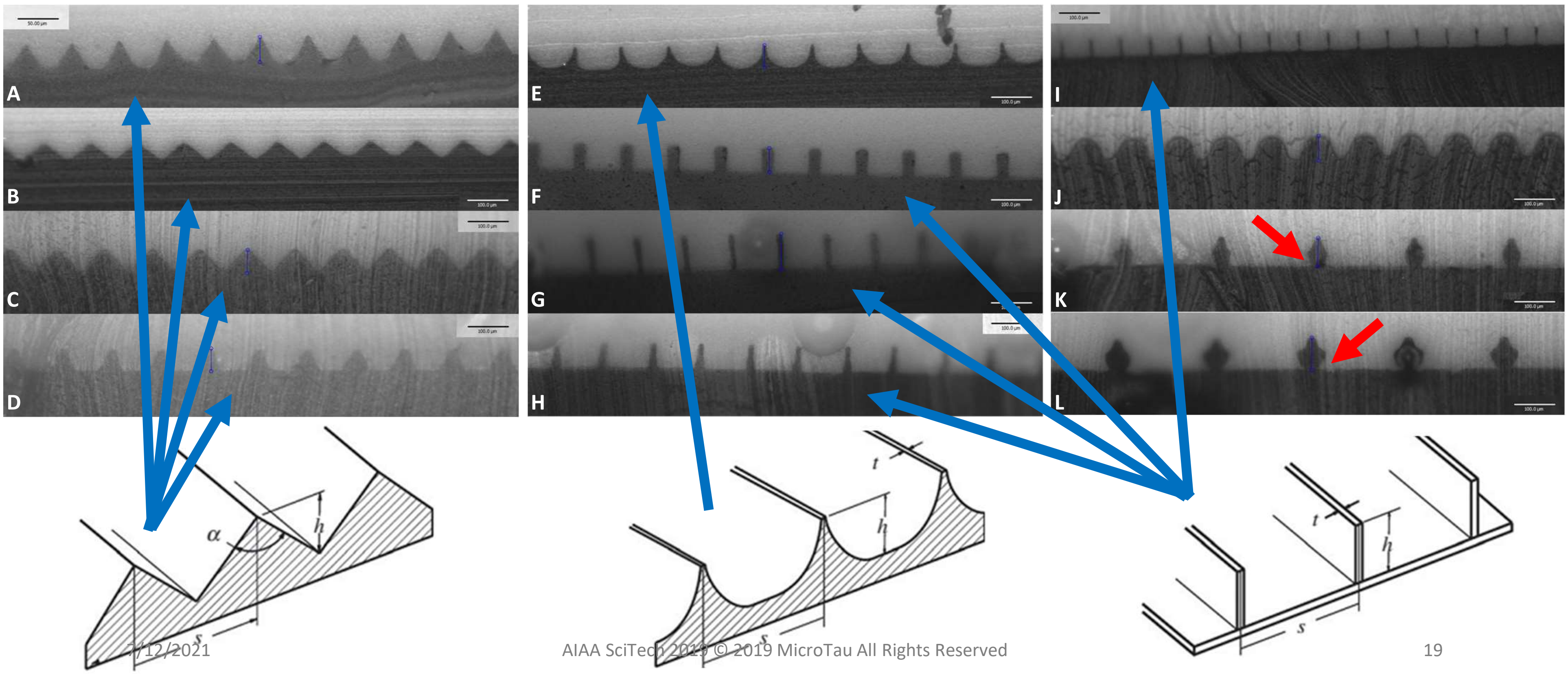
Bilinsky, H., MicroTau Pty Ltd
SciTech January 9, 2017

Phase I

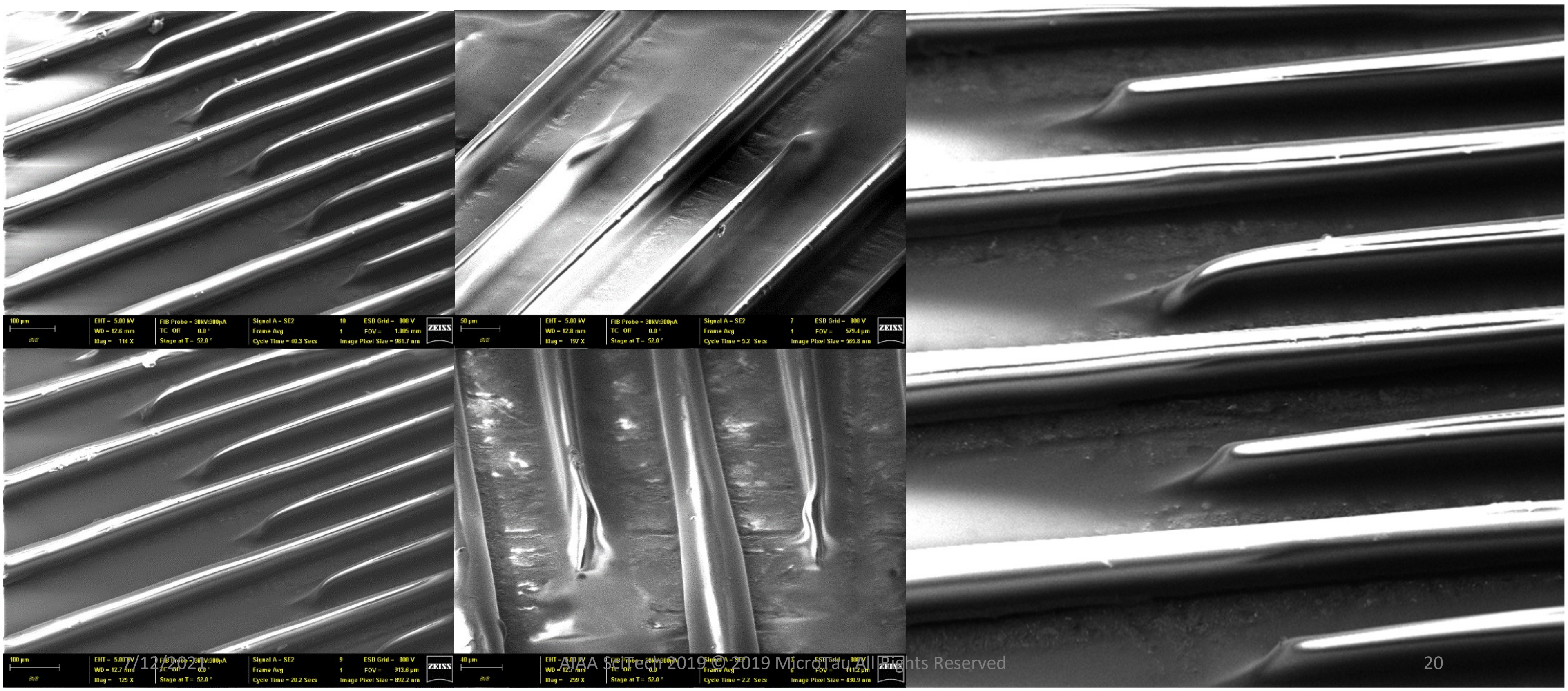
- **Wind Tunnel Results**



Riblet (Shark Skin) New Profiles

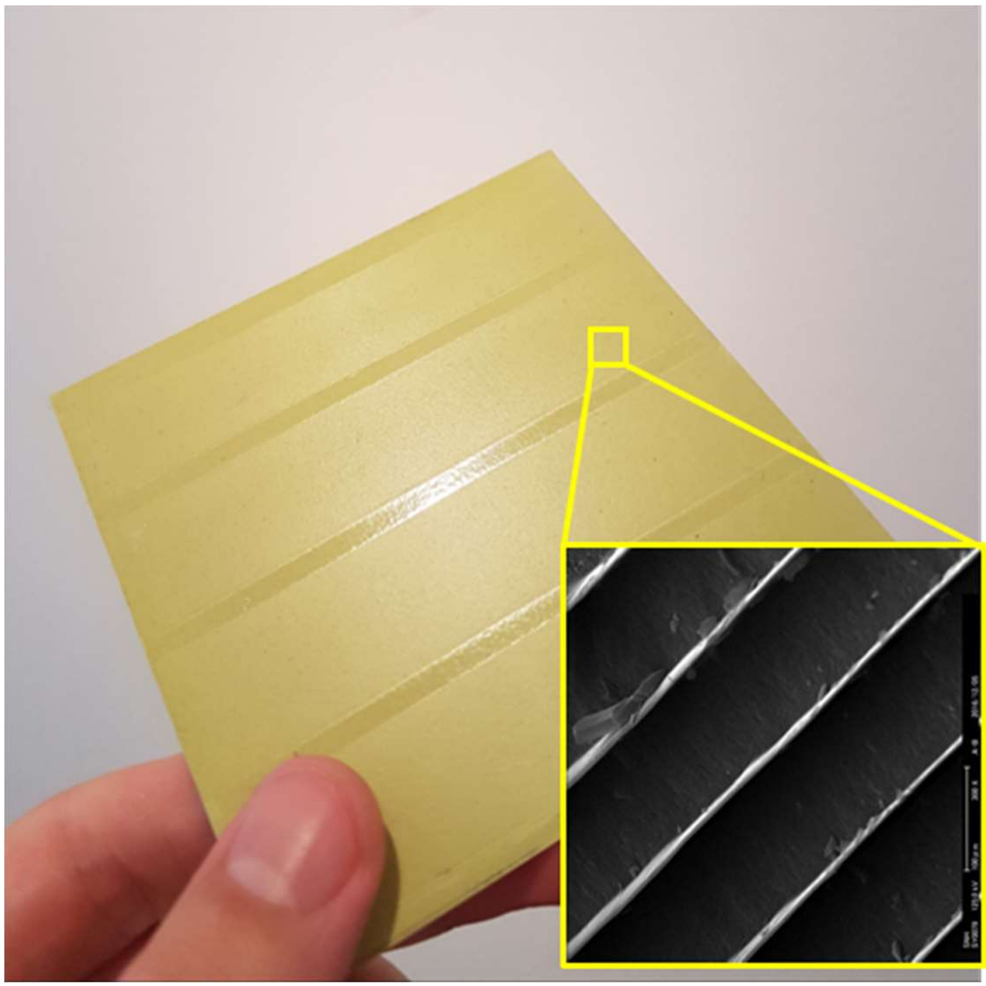


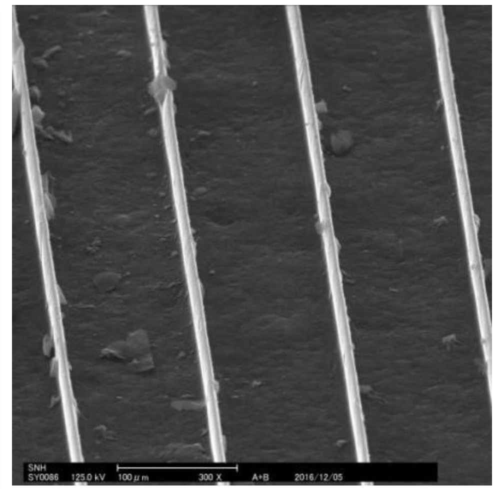
Shark Skin; 3D Riblet Designs

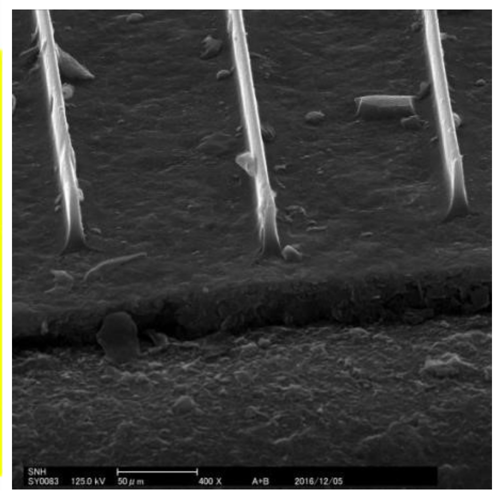


What the riblets (Shark Skin) look like to the naked eye

- **DCM-fabricated riblets**



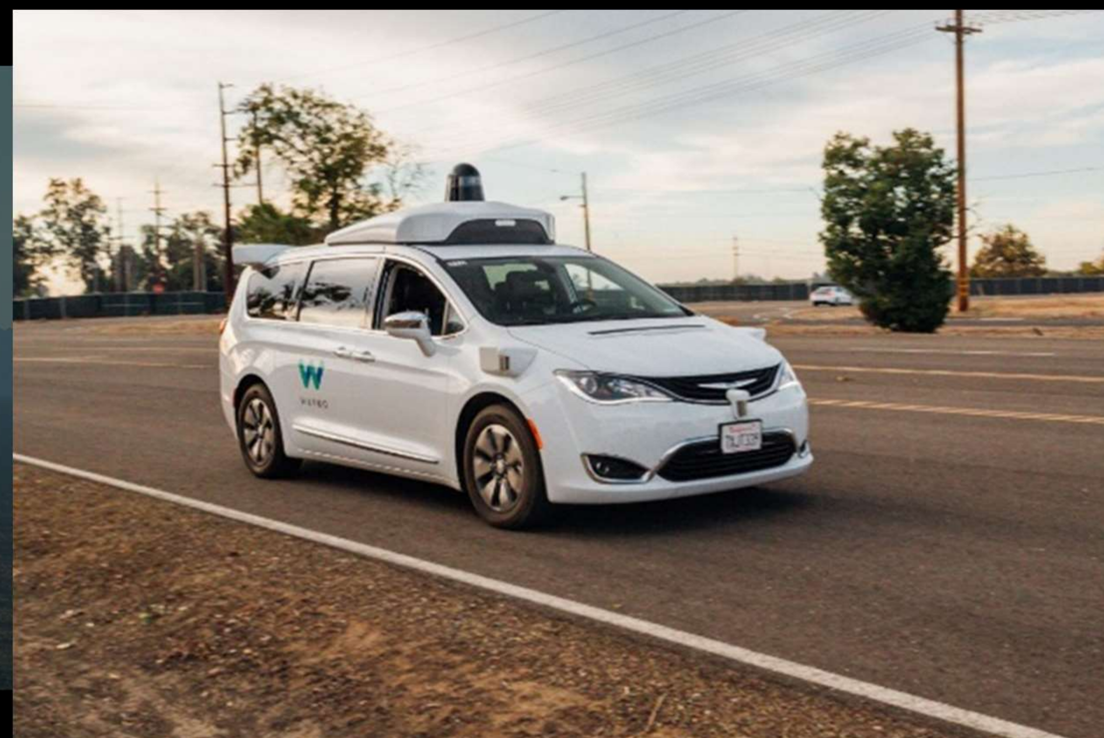




Benefits of this style of Riblet (Shark Skin) Production

- **Contactless, continuous and fast application**
  - *Reduce cost and time of application*
  - *Greater surface coverage and thus drag reduction*
- **Fabricated from military aircraft coating**
  - *Improve durability*
- **Live manipulation of riblet heights/geometry**
  - *Optimize riblets for fuel savings over PDM*
  - *Possible self-cleaning properties for maintenance*

So what is the connection between ‘Shark Skin’ Antimicrobial and Autonomous Vehicles?



So what is the connection between Shark Skin Antimicrobial and AV ?

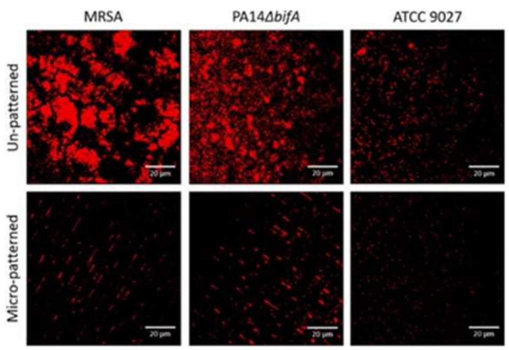
- AV will have the capability to pick up and deliver passengers at an extremely high rates
- The 'touch surfaces' within the AV have the potential to hold Microorganisms that can be easily transferred to the next passenger
- Auto manufacturers expect to have the first mass produced level 5 AV in operation by 2021
- When that AV Taxi shows up will you have the 'Hotel Room Experience?'

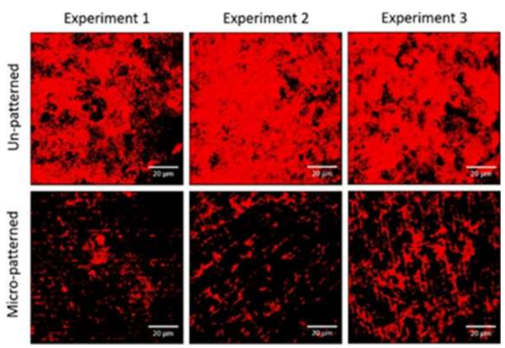
Current Riblet (Shark Skin) Antimicrobial Surfaces in the Market

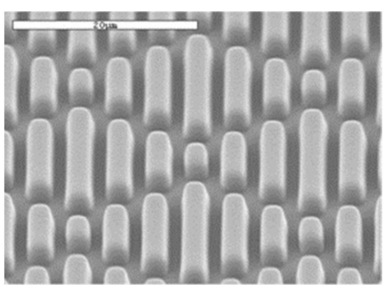
- Sharklett Technologies, Inc. is currently marketing Shark Skin technology
- Hospital high-touch environment surfaces with the Shark Skin technology can create a bacterial inhibition area
- Hospital-acquired infections account for more than $30 billion in excess healthcare costs

Surface Micropattern Resists Bacterial Contamination Transferred by Healthcare Practitioners, Mann EE, Mettetal MR, May RM, Drinker MC, Stevenson BC, Baiamonte VL, Marso JM, Dannemiller EA, Parker AE, Reddy ST and Sande MK, Journal of Microbiology & Experimentation 2014, Vol 1 Issue 5

Current Riblet (Shark Skin) Antimicrobial Surfaces in the Market







- ❑ Clinical testing has shown that Shark Skin technology reduces such pathogens as MRSA and P. aeruginosa
- ❑ Additional testing showed that in a mucin rich environment that P. aeruginosa was reduced by 58% over three separate experiments

Micro-patterned surfaces reduce bacterial colonization and biofilm formation in vitro: Potential for enhancing endotracheal tube designs, May RM, Hoffman MG, Sogo MJ, Parker AE, O'Toole GA, Brennan AB and Reddy ST, Clinical and Translational Medicine 2014 3:8

Shark Skin Riblets

- Shark Skin is self-cleaning, anti-biofouling, hydrophobic, drag reducing and aerodynamic.
- Anti-biofouling and self-cleaning properties is attributed to the micro-structured riblets found on its dermal denticles
- These micro-structures distinguish sharks from other aquatic species, such as whales, which are covered by barnacles.

Bio-mimicking nano and micro-structured surface fabrication for antibacterial properties in medical implants, Jaggessar, A., Shahali, H.,Mathew, A., and Yarlagadda,P., Journal of Nanobiotechnology, (2017) 15:64

Shark Skin Riblets Structures on Spiny Dogfish & Copper Sharks

- Spiny Dogfish (mud) shark structure
  - Triangular riblets
  - Width of 100 to 300 microns
  - Peak radius of 15 microns
  - Height 200 to 500 nm
  - Center to center spacing of 100 to 300 microns
- Copper Shark
  - Length 200 to 300 microns
  - Height 20 to 30 microns
  - Width of 50 to 80 microns
- Silicone patterned shark skin micro-structures
  - Reduced drag resistance on submarines and ships by 15%
  - Reduced algae cell attachment on submarines and ships by 67%

Bio-mimicking nano and micro-structured surface fabrication for antibacterial properties in medical implants, Jaggessar, A., Shahali, H.,Mathew, A., and Yarlagadda,P., Journal of Nanobiotechnology, (2017) 15:64

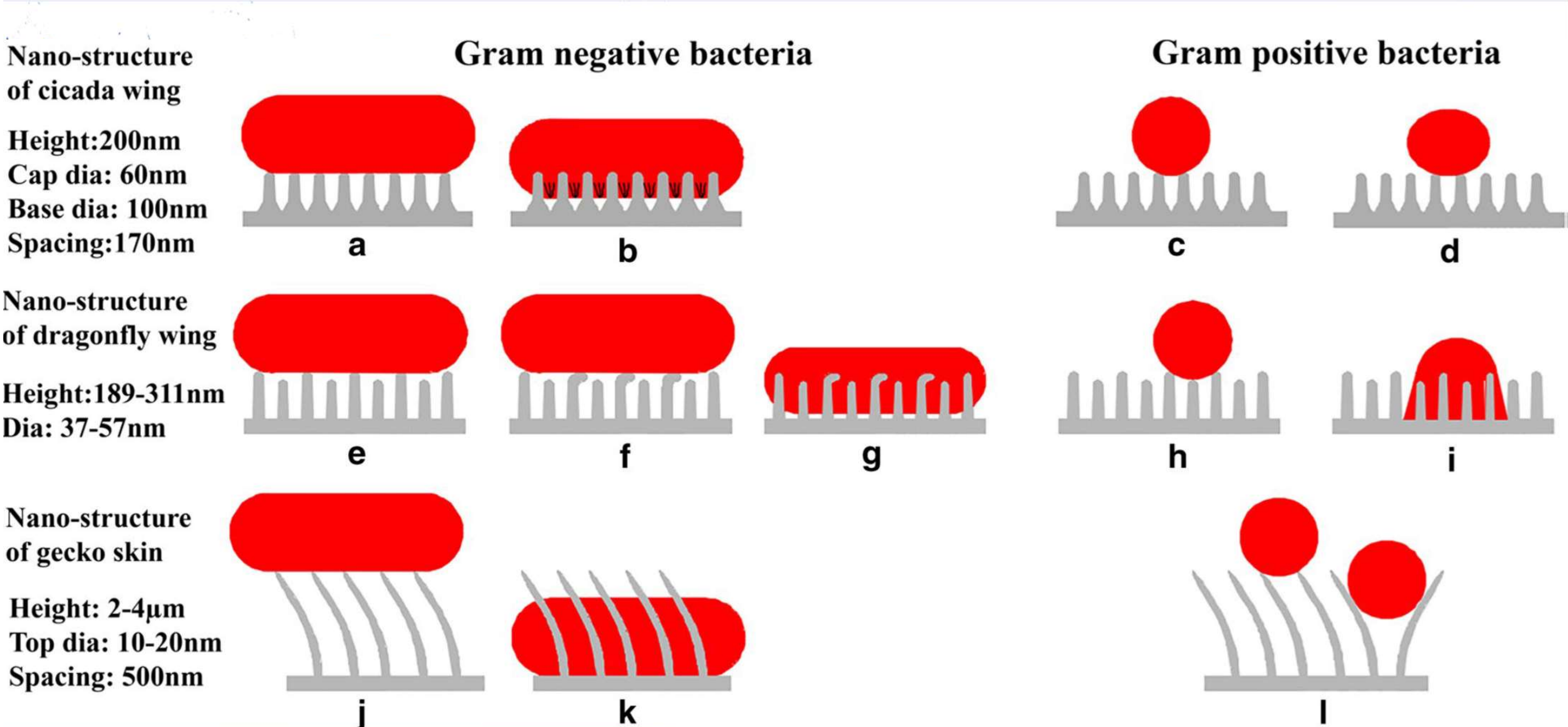


Fig. 4 Schematic showing bacteria-nano-structured surface interaction of: a, b cicada wing and gram-negative bacteria, c, d cicada wing and gram-positive bacteria, e–g dragonfly wing and gram-negative bacteria, h, i dragonfly wing and gram-positive bacteria, j, k gecko skin and gramnegative bacteria and i gecko skin and gram-positive bacteria. Nano-structure dimensions are indicated next to each species, dimensions not to scale

Dr.

Bio-mimicking nano and micro-structured surface fabrication for antibacterial properties in medical implants, Jaggessar, A., Shahali, H.,Mathew, A., and Yarlagadda,P., Journal of Nanobiotechnology, (2017) 15:64

Potential Riblet (Shark Skin) Antimicrobial surfaces in other markets

- Medical implants are great sites for bacterial adhesion, reduction in patient immunity, bacterial infection and can result in revision surgery
- Medical implants need antibacterial coatings
- Performance of Bio-mimicking nano and micro-structured coated surfaces have shown antimicrobial performance
- The mechanism for this antimicrobial performance is that the bacteria cell walls stretch and disfigure when they interact with textured surfaces.
  - Stretching occurs in the regions between structures and if sufficient, cell rupture and death occurs for the bacteria

Bio-mimicking nano and micro-structured surface fabrication for antibacterial properties in medical implants, Jaggessar, A., Shahali, H.,Mathew, A., and Yarlagadda,P., Journal of Nanobiotechnology, (2017) 15:64

Dr. Joshua Jacobs, an orthopedic surgeon, displays a model of a cementless hip replacement in 2014.
M. Spencer Green/AP

How Synthetic Shark-Skin is making Aircraft Carriers more Hydrodynamic

- Aircraft Carriers suffer from a build up of barnacles and algae on the hull of the ship
- Besides reducing drag the Shark Skin coating offers anti-biofouling properties
  - It would prevent the buildup of barnacles and algae on the hull of the ship
- Reduction in the amount of fuel and maintenance costs to remove the barnacles and algae
  - The US Navy spends $50 million per year de-fouling aircraft carriers.

Biomimetic Materials: How synthetic Shark-Skin is making aircraft carriers more Hydrodynamic; Jacobs, A., Mallela S., and Wilson, S., University of Pittsburgh, Swanson School of Engineering, First Year Conference Paper, 08.03.2019

So where do we go next?

- Current 'Shark Skin' products are embossed into the plastic film
  - These structures are limited to the shape and size of the embosser
- Micro Tau's unique UV Cure 'Shark Skin' coating has a vast number of digital structures that it can produce
  - This is due to the photolithography method borrowed from computer chip fabrication
  - These unique 'Shark Skin' structures could be optimized to maximize the reduction microbial activity in the AVs 'Touch surfaces'

Http://www.roadandtrack.com/new-cars/a30235/with-self-driving-cars-its-the-interior-that-matters

Conclusions

- The development of UV A cure automotive coatings is finding use in the aerospace coatings industry
- This technology was then adapted to manufacture Micro Tau's unique UV Cure 'Shark Skin' digital structures that resulted in 5% drag reduction in wind tunnel testing
- The possibility exists that the Micro Tau UV Cure 'Shark Skin' digital micro-structures could inhibit microbial growth for 'Touch Surfaces' in Autonomous Vehicles

Update on the 'Shark Skin (riblet)' Technology

SBIR/AFRL; AF192-046 Passive Coatings for Aircraft Drag Reduction (2019 to 2020)

- OBJECTIVE:
  - Develop an advanced riblet system (ARS) to reduce viscous drag on medium altitude long endurance aircraft (MALE) to increase range/time-on-station (TOS). Riblet application should be fast (m^2/min), compatible with depot processes/timelines, and produce structures resistant to fouling.
- PHASE I:
  - Investigate DCM scale-up (ref 2) by examining use of multiple LEDs and assessing robotic- or gantry-based systems for optical head movement. Assess design variables for 3D riblets (ref 3) numerically (CFD) and develop experimental validation plan. Examine coating chemistries and refine aircraft-compatible application processes to improve the durability of superhydrophobic coatings (ref 4). Design an ultra-precision balance with milli-Newton resolution

SBIR/AFRL; AF192-046 Passive Coatings for Aircraft Drag Reduction (2019-2020)

- PHASE II:
  - Design and fabricate a scaled-up prototype DCM system capable of applying 3D riblets to a major portion of an aircraft (wing or fuselage section) at speeds on the order of m^2/min; mature 3D riblet designs with continued CFD simulations; use the DCM method to produce and wind tunnel test the ARS, using the ultra-precision drag balance designed in Phase I; create the superhydrophobic coatings with the chemistries and application techniques identified in Phase I. Validate the durability of the coatings using ASTM tests and determine thickness to adjust riblet dimensions to compensate.
- PHASE III:
  - Develop and commercialize a full-scale DCM system capable of applying an ARS to military and commercial aircraft. The ARS will be comprised of optimized 3D riblets and Superhydrophobic coatings with effects lasting an entire PDM cycle (nominally 5 years). Commercialize the ultra-precision skin friction balance.
- Results
- SBIR/AFRL Project funds cut by 1/3 of the normal budget and then run/terminated

Patent Applications on Riblets (Shark Skin)

- US 2018/0307138 A1 Microstructure Patterns
  - MicroTau IP Pty Ltd, Bellevue Hill, New South Wales (AU)
  - Henry Bilinsky
  - Publication Date; Oct. 25, 2018
- US 2021/0017415 One Component UV Curable Compositions and Methods for Making Same
  - Dvorchak Enterprises LLC, Monroeville, PA (US)
  - Michael J. Dvorchak et al
  - Publication Date; Jan. 21, 2021

MIcroTau receives grant from NSW for UAVs

From 2022, Lufthansa Cargo will equip all Boeing 777 F freighters with AeroSHARK

For the entire fleet of ten aircraft, this translates to annual savings of around 3,700 tons of kerosene and just under 11,700 tons of CO_2 emissions, which is the equivalent of 48 individual freight flights from Frankfurt to Shanghai.

Acknowledgements

This work is supported by the Operational Energy Capability Improvement Fund (OECIF) from the Office of the Assistant Secretary of Defense for Operational Energy Plans and Programs, ASD(OEPP) and by the Air Force Research Laboratory. We would also like to acknowledge the Ohio Aerospace Institute, through which this work was funded.

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