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NRC Ultrasound Ice Accretion Sensor for UAS Icing Detection

NRC Program: Aviation Product Development and Commercialization (APDC)

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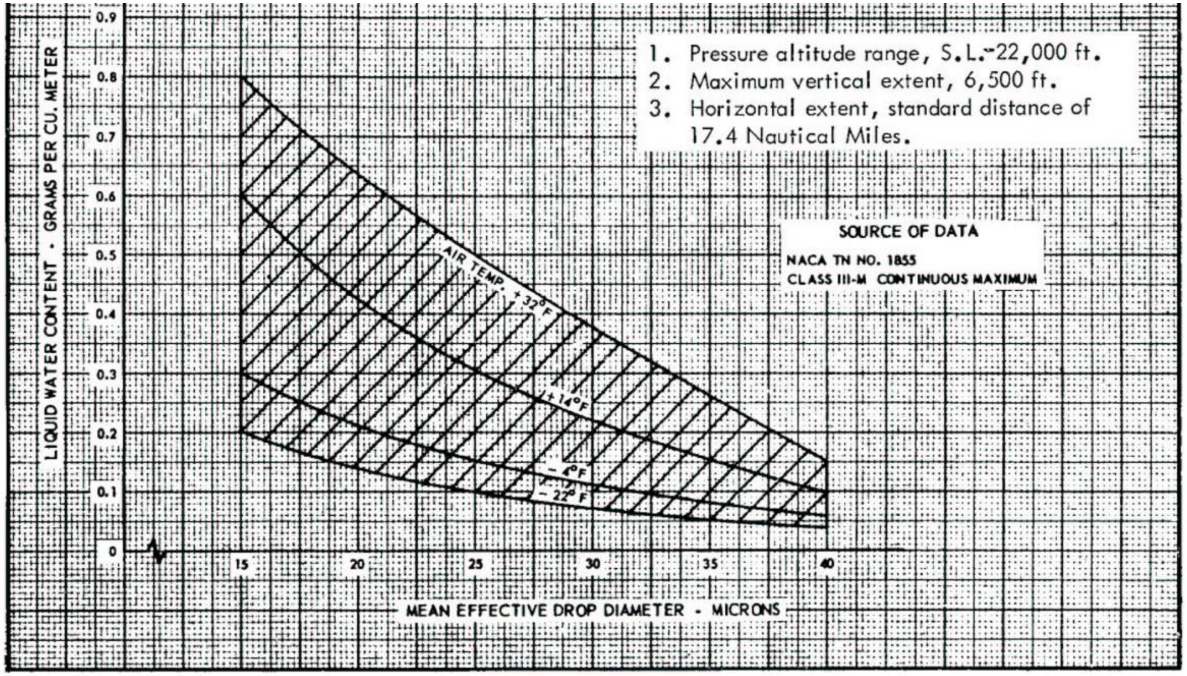
Aviation Icing Overview

- Supercooled water is below freezing but still in liquid form
- When it contacts a surface, it will freeze
- Depending on how much <0ºC, a certain percentage will freeze upon impact and remainder run along the surface and freeze as exposed to cold
- This produces different types of accretion (rime, mixed and glaze/clear)
- Federal Aviation Regulation (FAR) Part 25, Appendix C characterizes supercooled water droplet (SWD) conditions icing



Continuous Maximum Appendix C icing condition: LWC vs MED vs SAT

Aviation Icing Overview

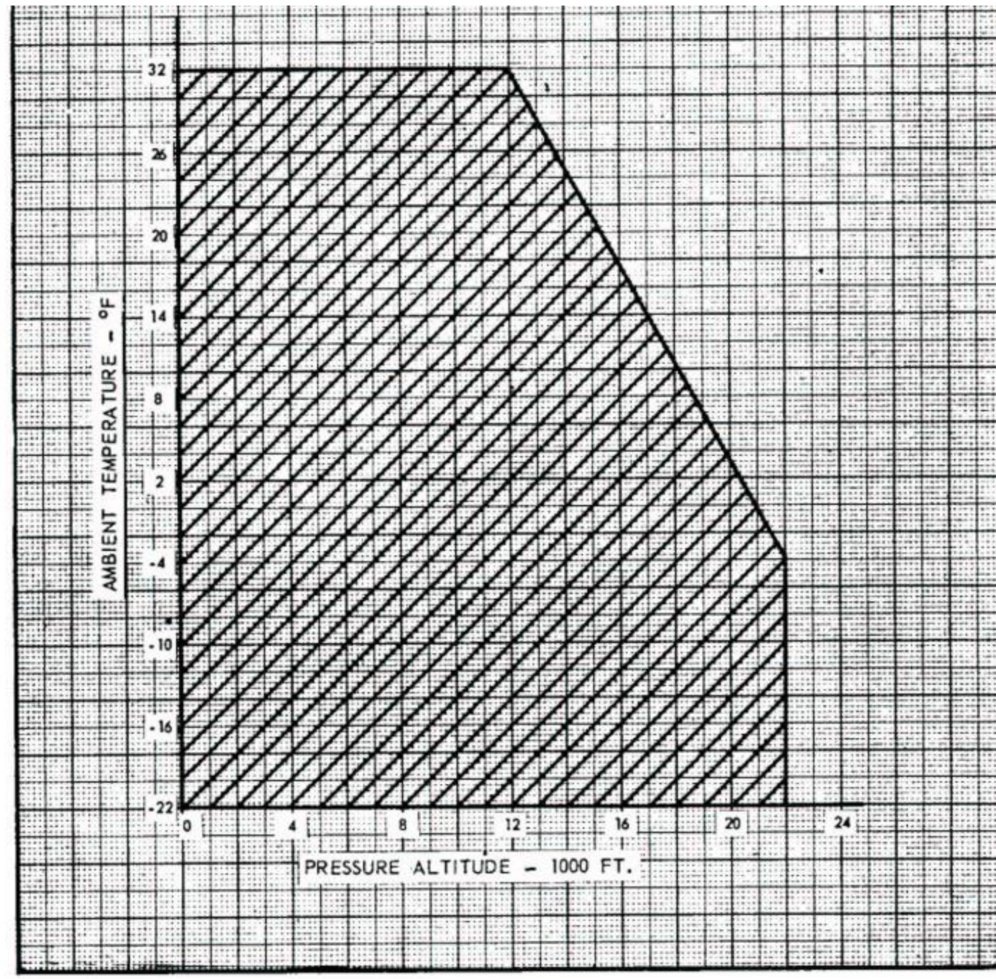
FAR Part 25, Appendix C Specifies:

- Drop size
- Liquid water content, i.e. concentration for given cloud type
- Temperature
- Horizontal and vertical extent, i.e. concentration vs. exposure time
- Altitude range

Looks old?

It is.

Dates back to 1964.



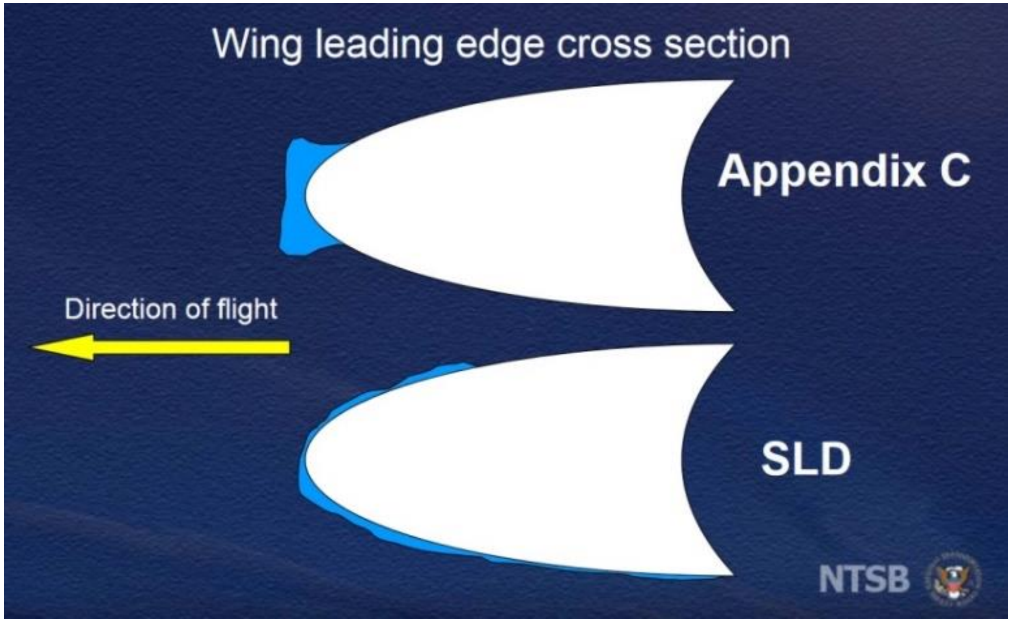
Continuous Maximum Appendix C icing conditions: SAT vs. Alt.

Aviation Icing Overview

Supercooled large drops (SLD) represents a different type of icing condition

- Drops much larger than Appendix C resulting in more run back
  - Drizzle: $D_{max} \approx 400\ \mu m$
  - Rain: $D_{max} \approx 2{,}000\ \mu m$
  - App. C: $D_{max} \approx 125\ \mu m$
- New SLD regulations introduced to FAR Part 25 (Appendix O): January 2015

In summary, icing can result in loss of performance, safety margin and damage from sheds



Comparison of Appendix C and O supercooled water ice accretion characteristics

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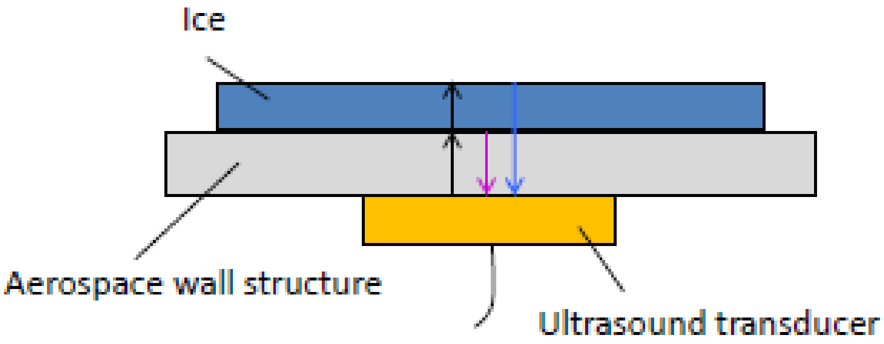
Ultrasound Ice Accretion Sensor (UIAS)

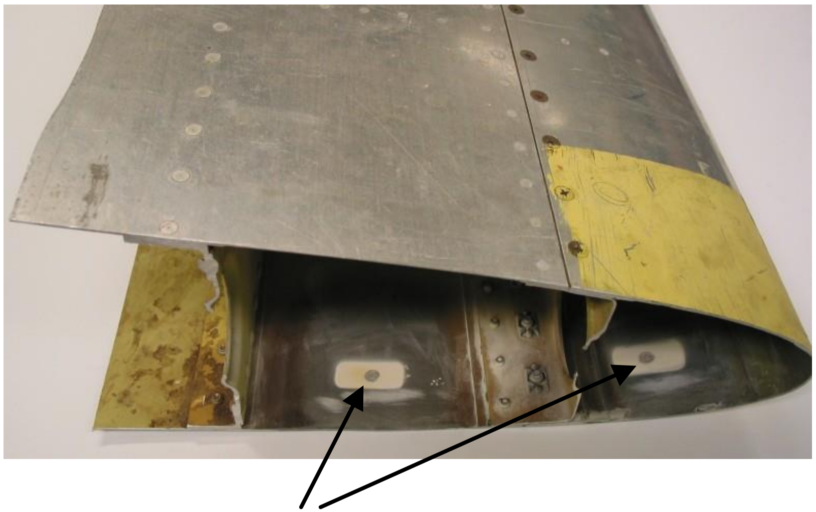
- Many commercial aircraft use sensors to detect icing conditions
- For UAS applications, they are typically bulky, increase drag and have large power draws…

- Ultrasound waves can be used to detect ice on a surface
- Non-intrusive, as the sensor is installed on the surface opposite to the accretion
- Small, light weight and low power (<1 cm dia., few grams and few watts)
- Can quantify ice accretion coverage, i.e. severity



Example of NRC ultrasound sensor

Ultrasound Ice Accretion Sensor (UIAS)



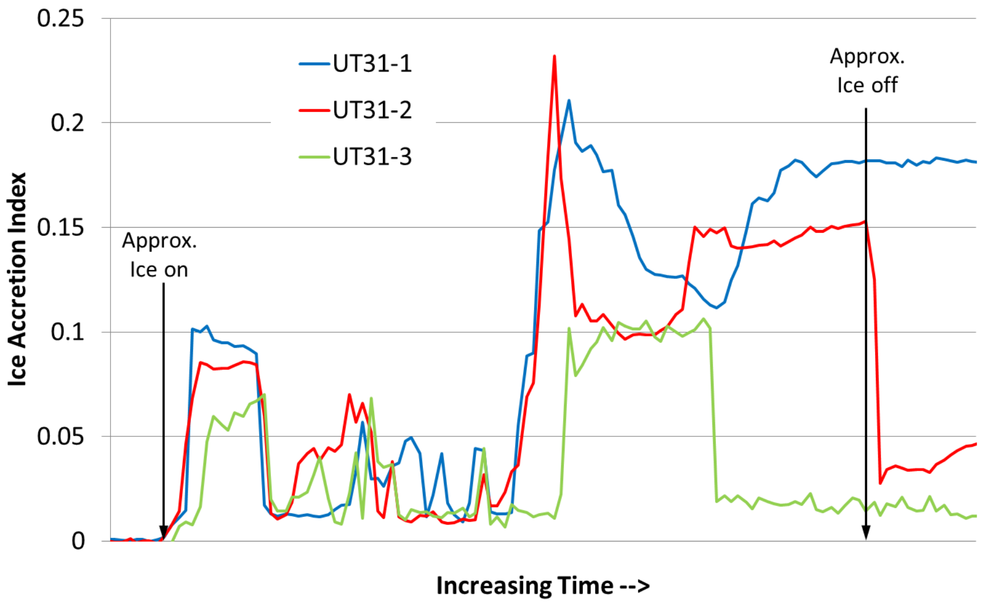
Integrated UT

Ice accretion detection test conducted on aircraft horizontal stabilizer for proof of principle:

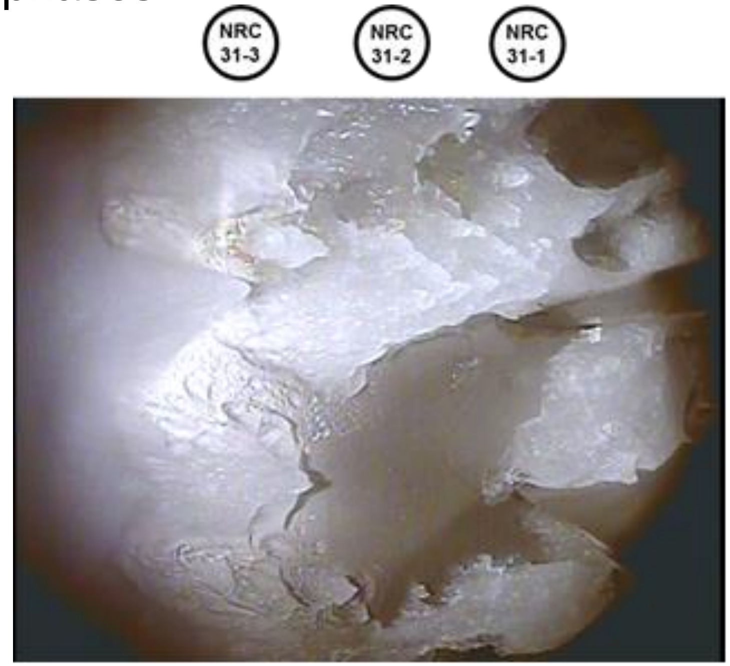
- Accretion detection for thickness << 1 mm
- Resolution in the order of 100 microns
- Thickness measurement possible when thickness >1 mm (smooth, parallel ice)

Full Scale Engine Icing Test

- Ability to detect ice crystal accretion in ALF502 aircraft engine flow path
- Accrete-shed cycles observed and match UIAS signals
- Differences in axial accretion seen (Sensor 1 vs 2 vs 3)
- Rapid response rate for both accretion and shed phases



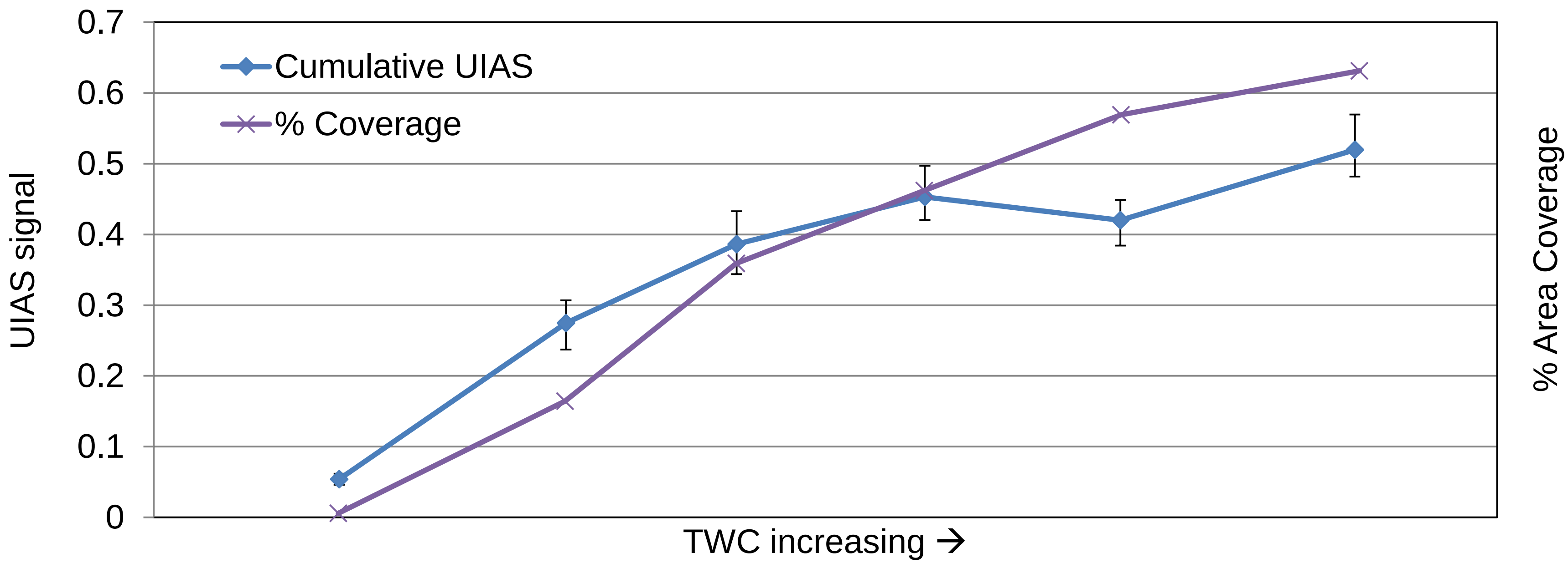
UIAS icing index for full roll back on ALF502 altitude accretion point (Escort reading 93)



Location of UIAS's and irregular ice accretion seen for full roll back (Escort reading 93)

Signal Versus Accretion Coverage

- UIAS can also be used to detect and quantify ice accretion severity
- % ice coverage and cumulative UIAS signal can be compared at a specific time after ice on
- % ice coverage increases with TWC as expected
- UIAS signal also increases with TWC and in good agreement with % coverage

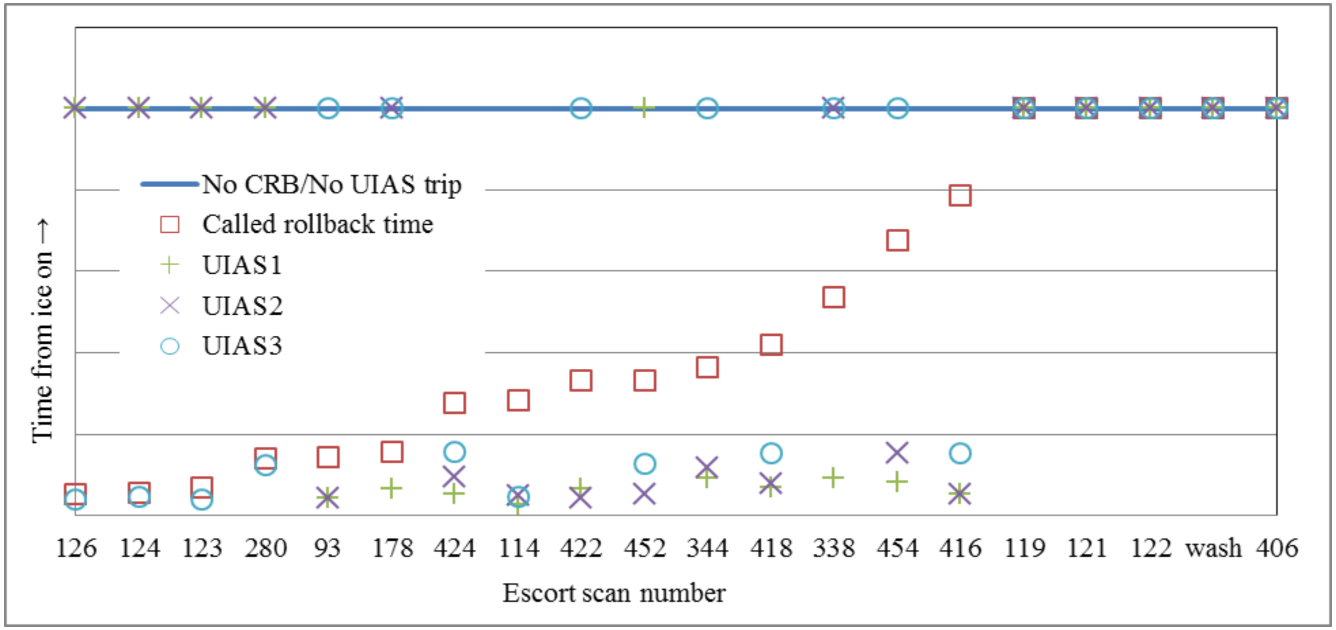


UIAS accretion signal in compressor of ALF502 gas turbine
NASA/Honeywell/ICC altitude ice crystal engine test

Ability to Quantify Icing Severity

- Plotting the UIAS detection times versus called rollback (CRB*) times for a range of test points shows level of agreement and relative detection times
- In all cases, the UIAS detection time was shorter than the CRB time
- When there was no CRB, there is no UIAS detection
- Triggering of different UIASs agrees with spatial variability of accretion

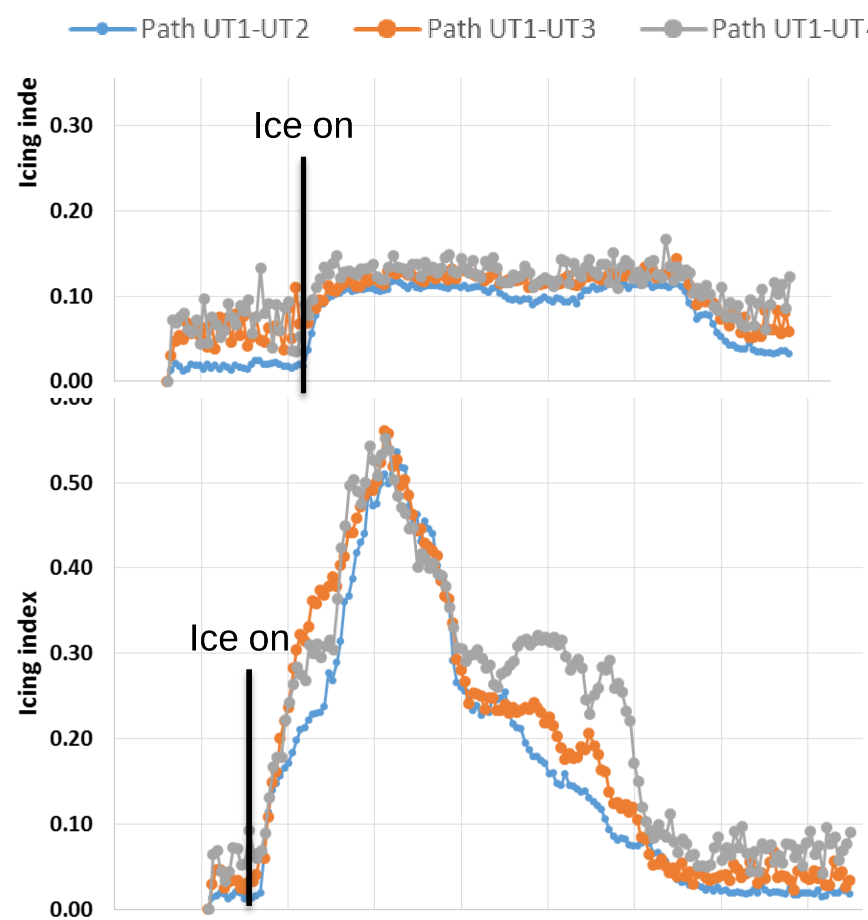
* CRB is early accretion detection using test cell measured engine operating parameters



UIAS ice accretion detection and CRB times for various test points in order of increasing CRB time (decreasing severity)

Large Area Detection (Between Sensors)

- A new capability is being developed to measure conditions between sensors
- Effective in detecting accretion over different sensor-to-sensor paths
- The detection area of UT1-4 is about ~10x's that of a single sensor and can provide even earlier detection
- Covers potential blind spots
- Decrease sensor count for same detection area
- Accretion detection at individual sensors can still be achieved in this scenario



UIAS accretion signal between sensors vs time
Top: running wet, Bottom: ICI accretion

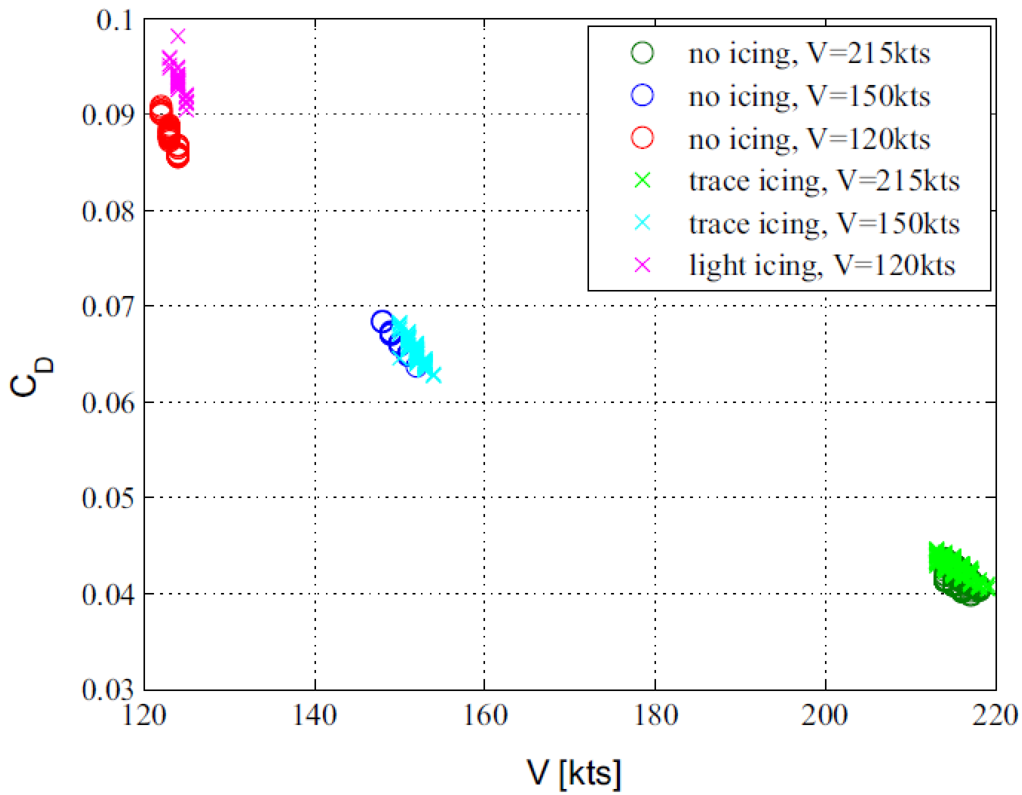
Supercooled Water Droplets (SWD): UIAS

- Ultrasound ice accretion sensor (UIAS) applications have been focused on ice crystal icing (ICI) accretion
- NRC has started to test and develop it for supercooled water droplet (SWD) icing conditions (e.g. Appendix C & O)
- Some ICI test conditions result in clear (or glaze) accretion
- This example shows UIAS accretion detection occurs at a very early stage of visible accretion
- There are just a few locations of minor accretion and only partial coverage of the UIAS
- However, is this an adequate level of detection?
- We can roughly correlate visible accretion to performance loss

UIAS accretion detection versus visual accretion on internal surface of an aircraft engine vane segment in supercooled icing (Red circle: UIAS dia. ≈ 5 mm)

Supercooled Water Droplets (SWD): Effect on Drag

- Supercooled liquid water accretion can affect external flight surfaces, wings, rotors…
- One of the key performance indicators that can be used to detect accretion is increase in drag
- Armani et al found light icing produced a small change in drag (~10%)
- This is small when compared to the scatter for both iced and clean airfoils
- Therefore, for this analysis, we assume ~20% change in drag to potentially be detectable

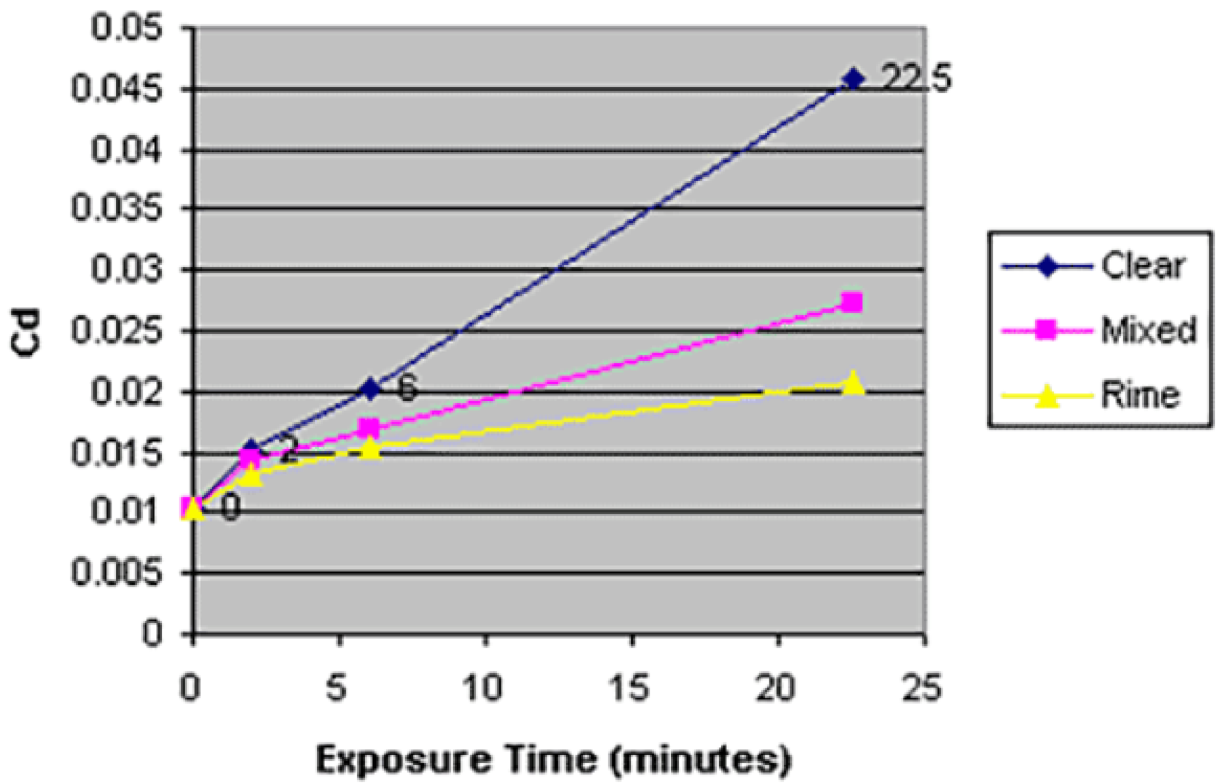


Icing effect on drag for Jetstream 31

Ref: Armani et al, “Decision-making for unmanned aerial vehicle operation in icing conditions, 2016”

Supercooled Water Droplets (SWD): Effect on Drag

- NASA tests have correlated drag to accretion for various wing and flight conditions
- A typical icing condition shows ~20% increase in drag after ~2 minutes icing for a general aviation wing with laminar flow
- In addition to change in drag, visualization of the accreted ice is also documented

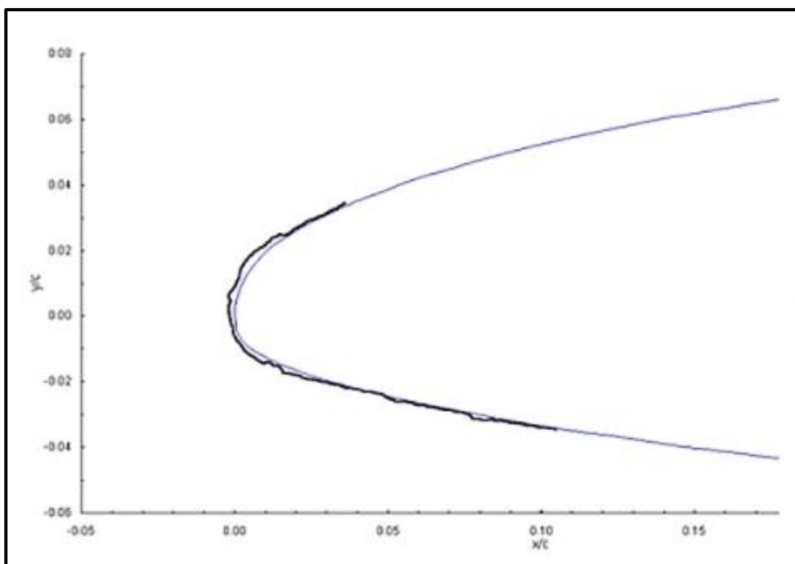


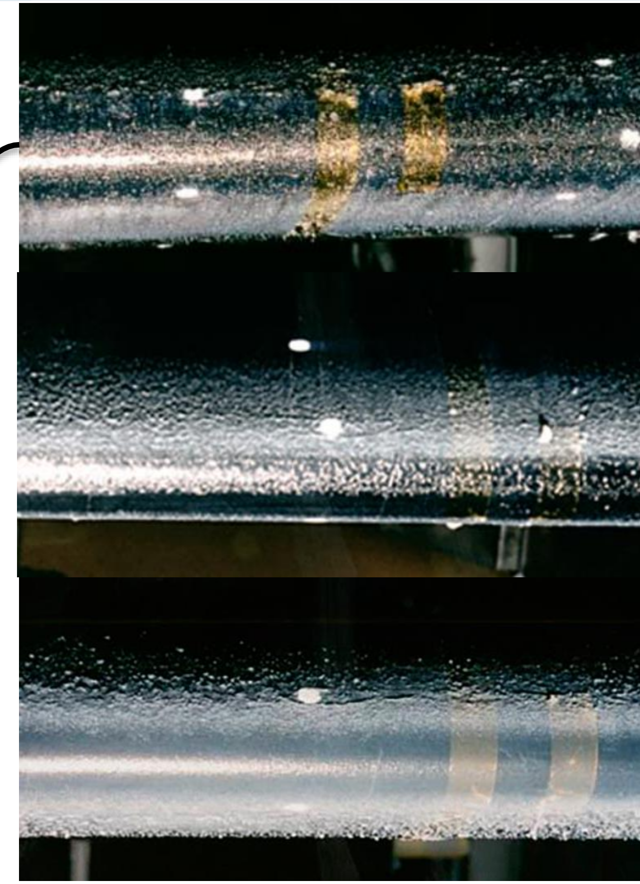
Drag vs. time for SWD ice accretion on a general aviation wing with natural laminar flow
IAS=130 kts, AOA=0.3 deg, LWC=0.54 g/m^3, MVD=20 microns, SAT= -5°C (Clear), -10°C (Mixed), -15°C (Rime)

Ref: NASA, “A Pilot's Guide to Inflight Icing”

Supercooled Water Droplets (SWD): Visible Accretion

- Images show the accretion to be very visible, contiguous and covering the LE (5% to 10% chord) for the three SWD icing conditions
- The thickness was also measured where the smallest accretion, is approximately 0.35% x/c
- Assuming a 12” chord for an UAS, ice thickness = 0.042” (~1 mm)





Ice accretion after 2 minutes
Top=-5°C (Clear), Mid=-10°C (Mixed), Bottom= -15°C (Rime)

Ref: NASA, “A Pilot's Guide to Inflight Icing”

Visual Accretion Comparison: Drag vs. UIAS Accretion Detection

- The visible ice coverage from the +20% drag case can be compared to the coverage at the UIAS detection point
- The UIAS detection has a much lower coverage showing promise for early detection in SWD conditions
- Early detection is key, e.g. implement anti-icing systems quickly, maximize time for detect and exit

Accretion on a wing resulting in ~20% drag increase

Ref: NASA, "A Pilot's Guide to Inflight Icing"

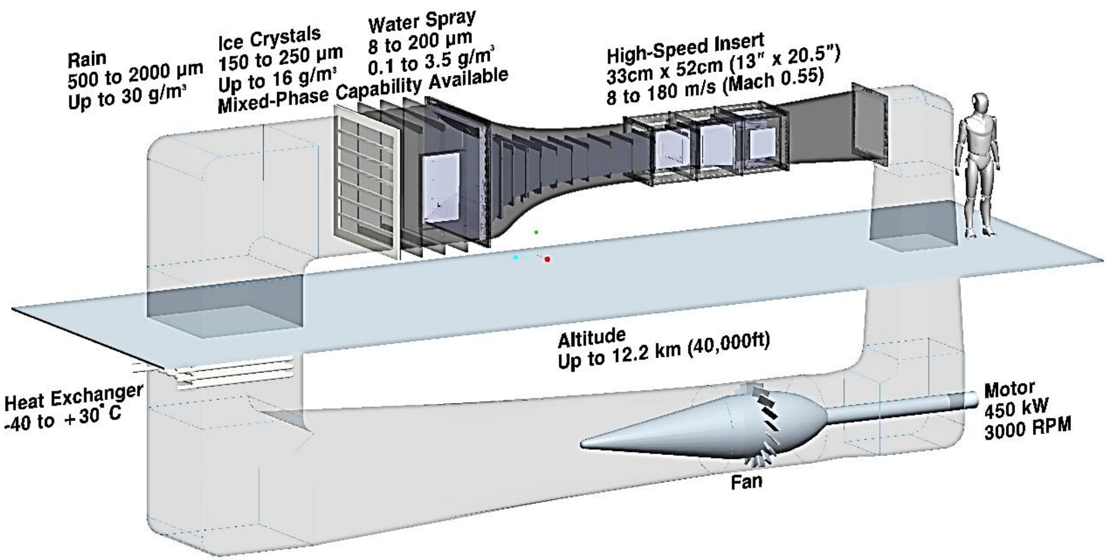
Accretion at UIAS detection on vane segment surface, non optimized for SWD
(Red circle: UIAS ~5 mm dia.)

Comparison of visual clear/glaze type SWD ice accretion

Potential UAS Test

- As part of our new Aviation Product Development and Commercialization (APDC) program, plans are underway to carry out UIAS tests in SWD conditions: tunnel and flight
- NRC has a wide range of test facilities and capabilities
- Always looking for partners interested in collaborative testing, e.g. test articles (incl. rotors), participation in testing, materials/geometries of interest…
- NRC does not commercialize…
- We partner for technology transfer for industry to commercialize

NRC Convair 580 icing flight test aircraft



NRC Altitude Icing Wind Tunnel (AIWT)

Estimate for a Commercial Version

- UIAS's built to date are R&D systems
- However, it is possible to estimate a commercial version based on the existing architecture:
  - Data acquisition and control (DAC) unit including signal processing and analog output (e.g. icing severity)

- DAC is about the size and weight of 4 USB flash drives (2W x 2H)
- This system can accommodate up to 8 UIAS's (no extra power)
- Developing a built in test equipment (BITE) health check algorithm

→ UIAS represents a potential technology for icing detection on unmanned air systems

Power	Dimensions			Weight
	L	W	H	
W	mm	mm	mm	g
3 to 5	75	40	20	45

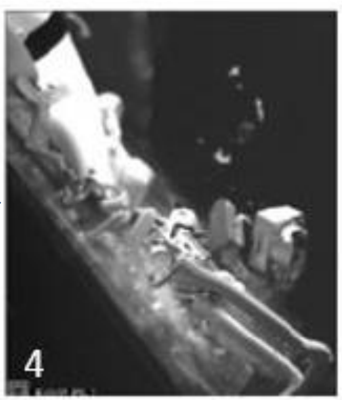
Estimated specifications for a commercial version of an ultrasound ice accretion sensor (UIAS)

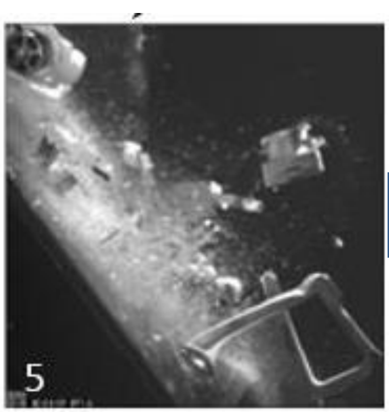
Drone vs. Windscreen @ 250 knots

We do more than icing..

Launch

Impact





Result

Thank you

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