

# ICE GENESIS Final Public Workshop

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Toulouse, France



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# Ground tests-experimental database WP8



DASSAV,  
CIRA,  
AIIS  
SAE,  
Cranfield University,  
LDO,  
SONACA ,  
CNRC

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# Wind tunnel tests in supercooled liquid icing conditions



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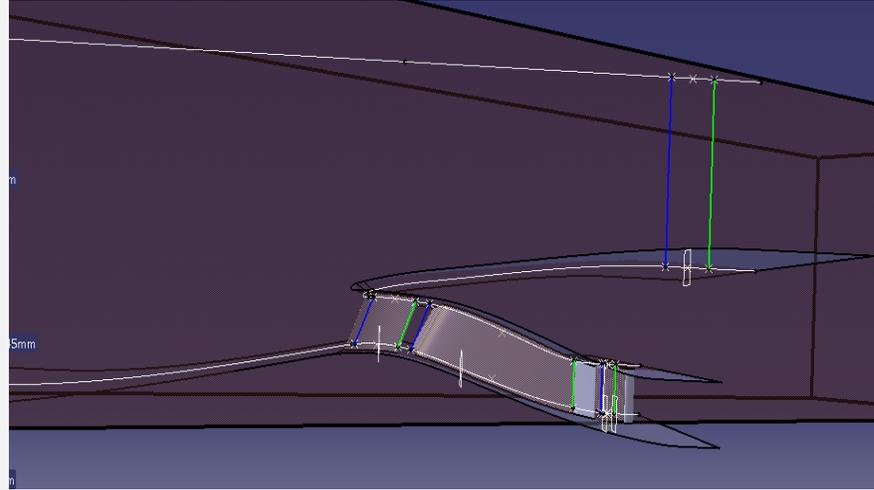
# Tests in industrial environment : 7 mockups

DASSAV@CIRA



App. O

SAFRAN AIRCRAFT ENGINES@Cranfield



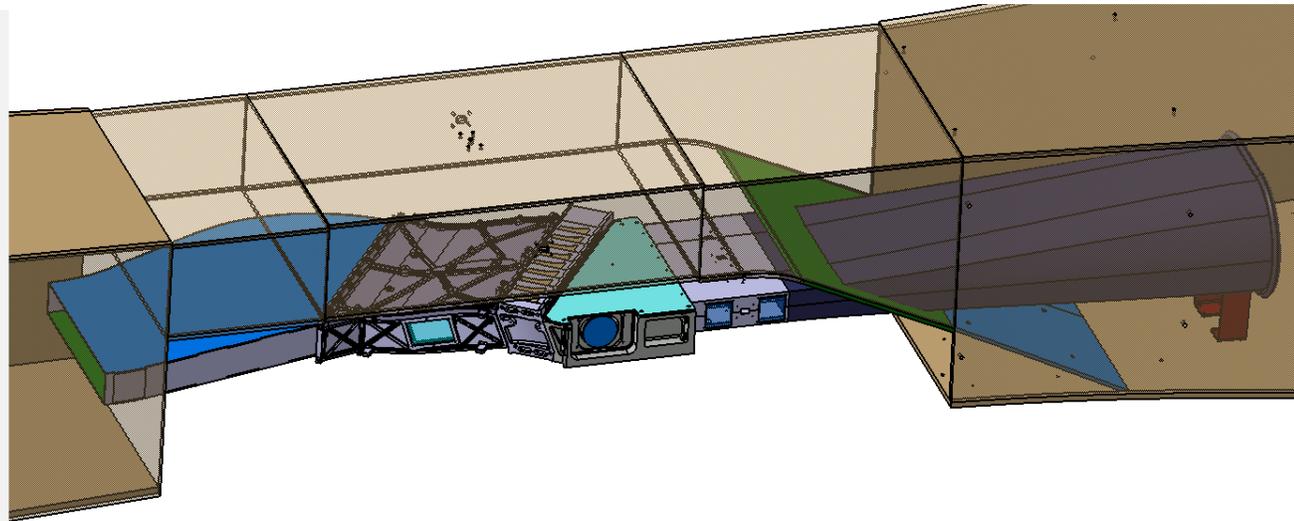
App. C



CNRC fan rotor

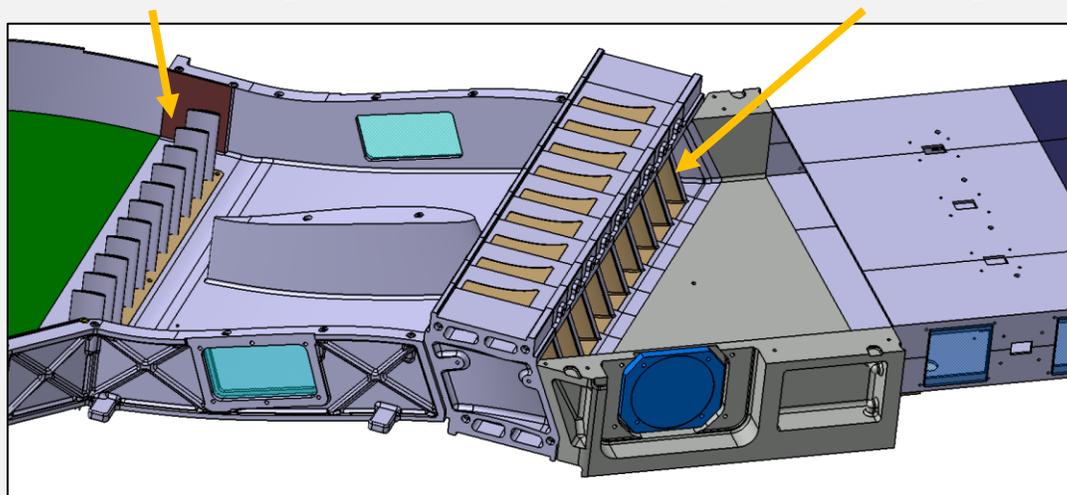
App. C

# Cascade rig : mock-up presentation



Downstream stator grid

Upstream stator grid



# Cascade rig : test matrix



## Anti-icing tests

- 31 different tests are realized
- Parameter range :
  - Air speed in the main stream : from 40 m/s to 80 m/s
  - Air temperature: from -20°C to -5°C
  - LWC: from 0.4 g/m<sup>3</sup> to 1.0 g/m<sup>3</sup>
  - IGV Pitch from 0° to 35° (with the main air flow direction)
- Test sequence
  - Stabilization of aerodynamic in dry condition
  - Activation of the heaters
  - Activation of the cloud
  - Heaters power decrease step by step until shut down
  - cloud stops, air speed decrease to 40m/s then activation of the heaters at full power



## Accretion ice tests & 3D scan

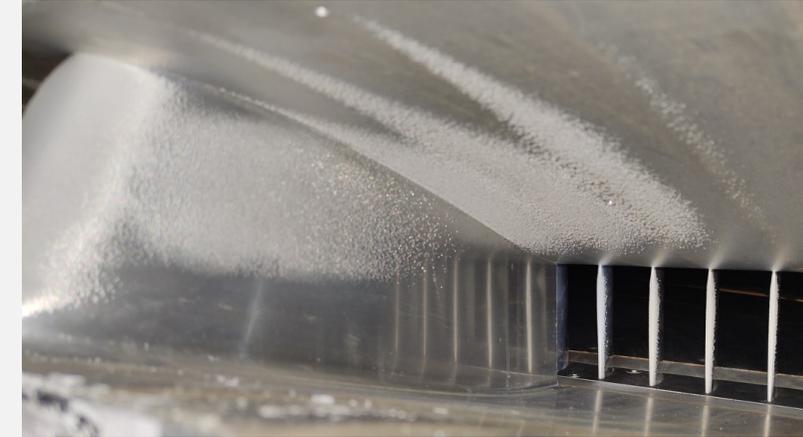
- 17 different tests are realized
- Parameter range :
  - Air speed in the main stream : from 40 m/s to 80 m/s
  - Air temperature: from -20°C to -5°C
  - LWC: from 0.4 g/m<sup>3</sup> to 1.0 g/m<sup>3</sup>
  - IGV Pitch at 0°
- Test sequence:
  - Stabilization of aerodynamic in dry condition
  - Activation of the cloud during the specified time
  - Stop of the cloud
  - Extraction of upstream grid to scan the 3 center blades.
- For few test cases, density of ice accreted on the leading edge is estimated.
  - After 3D scan, the ice is removed for weighing. Then the blade is scanned a second time (without ice on LE).
  - The volume of the weighed ice will be get by the difference of the two 3D scans.

# Cascade rig : ice accretion

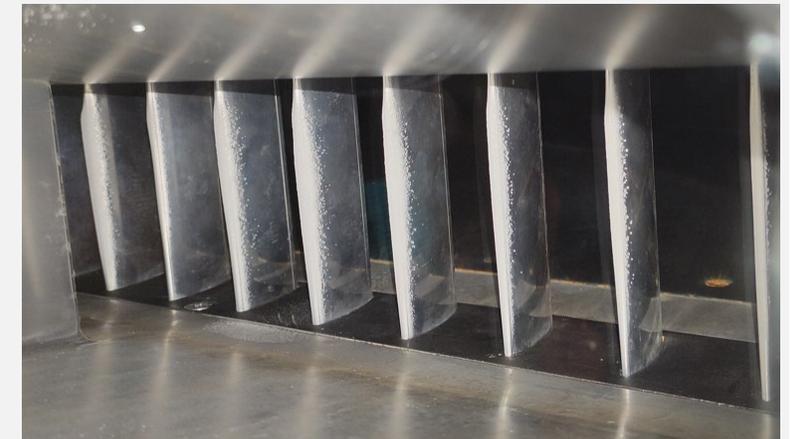
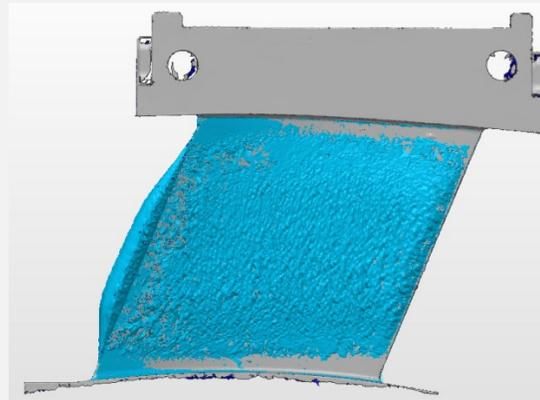
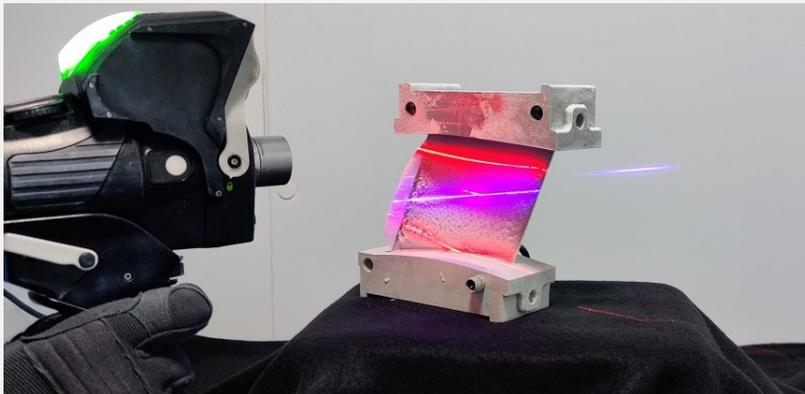
Upstream Grid



Downstream Grid



3D scan operation performed by AIIS

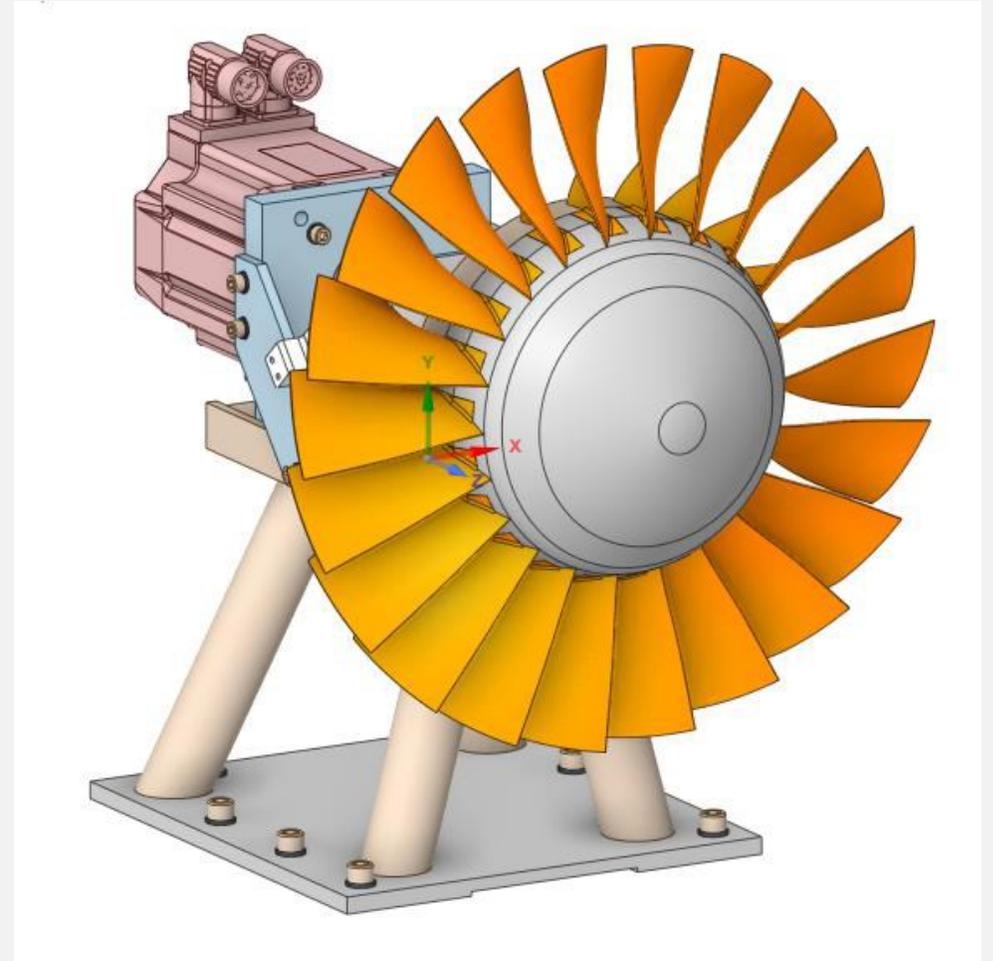


# Cascade rig

- 🧬 This test campaign leads to :
  - Build an experimental database for ice accretion on 3D engine parts with cold and heated walls with a high fidelity device (scans)
  - Study ice accretion occurrence in a primary vein representative of new engine architectures
- 🧬 These data are available in the ICE-GENESIS database (restricted to the Consortium)

# CNRC : fan rotor test rig

- 🧬 CNRC Design and Fabrication Services' concept
- 🧬 22 blades individually manufactured and assembled in specifically designed hub
- 🧬 Maximum 4000 RPM

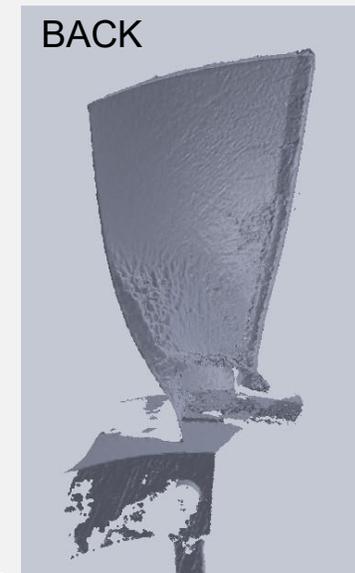
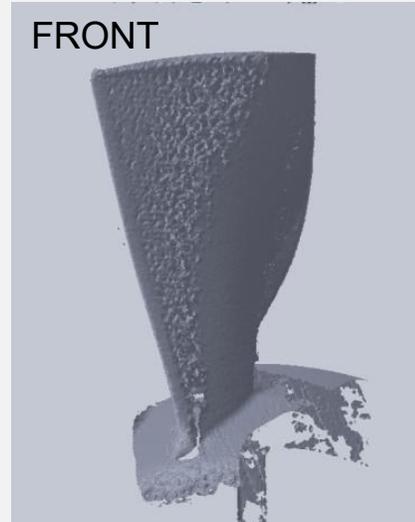


# CNRC : test matrix

TAT	MVD	LWC	Rotation speed	Air Speed	Altitude	Time Accretion
°C	µm	g/m3	rpm	m/s	ft	s
-3	20	0.3	1500	20	0	240
-10	20	0.3	1500	20	0	240
-10	20	0.3	1500	20	0	360
-10	20	0.3	2000	20	0	360
-10	20	0.3	2500	20	0	360
-10	20	0.3	1000	20	0	360
-10	20	0.3	500	20	0	360
-3	20	0.3	1500	20	0	360
-25	20	0.8	1500	20	0	240
-3	20	0.8	1500	20	0	240
-3	20	0.8	1500	20	0	240
-3	20	0.8	1500	20	0	480
-3	20	0.3	2500	35	0	240
-3	20	0.3	1500	20	12000	360

# CNRC : ice pictures and scans

🧬 TAT = -25°C, MVD = 20 μm, LWC = 0.8 g/m<sup>3</sup>, RPM = 1500, TAS = 20 m/s

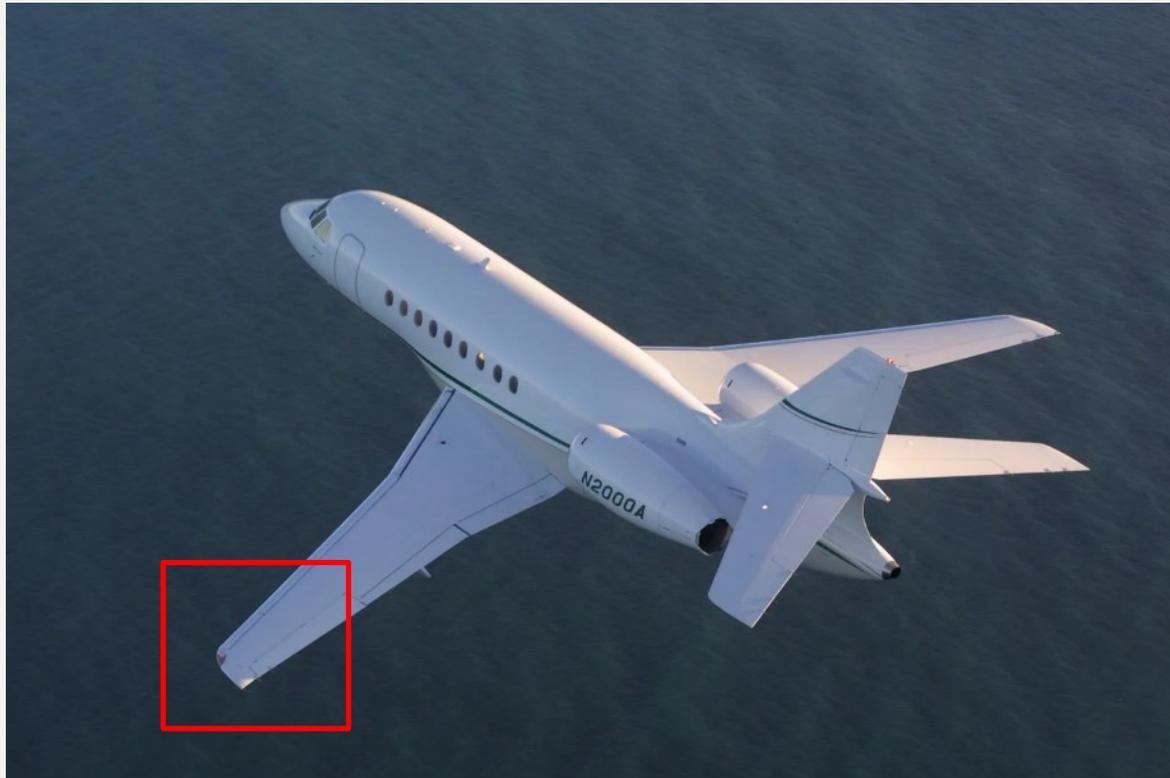


# CNRC : fan rotor test rig

-  Data not uploaded yet in the ICE-GENESIS database
-  Could be used for 3D numerical tools validation

# 3D Wing

- 🧬 Dassault Generic 3D Wing
- 🧬 High lift device (slat) retracted or extended
- 🧬 Tested at CIRA facility July, 2022



# 3D Wing : configurations

HLD :            Flap    0°  
                  Slat    retracted  
                  AOA    4.5°



CTL:            Flap    0°  
                  Slat    ext  
                  AOA    8.5°

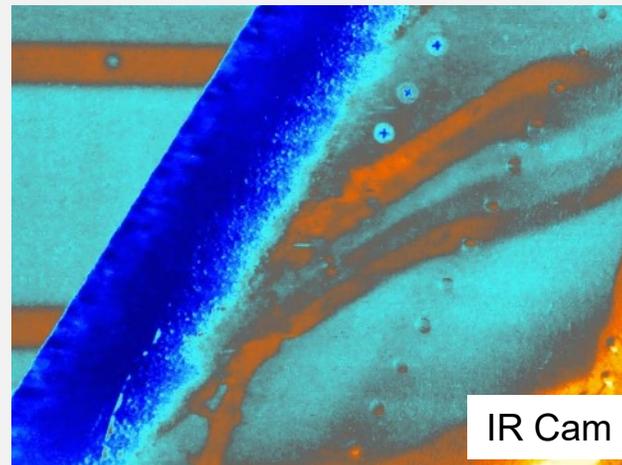
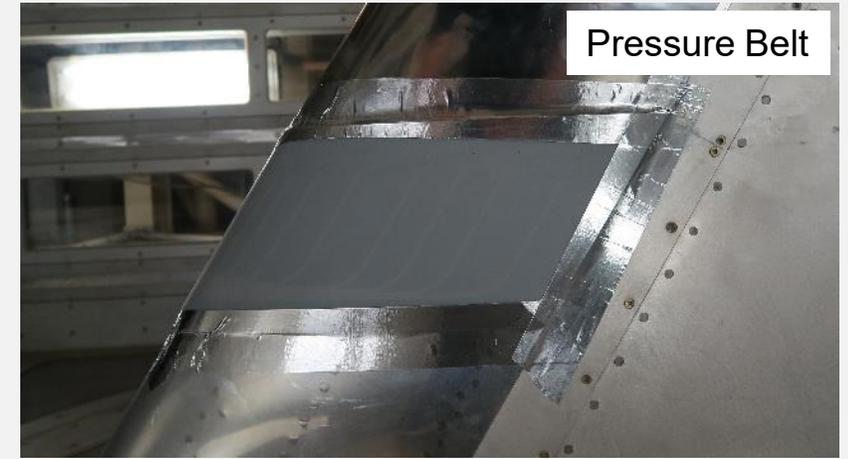


LDG :            Flap    15°  
                  Slat    ext°  
                  AOA    13°



# 3D Wing : measurements

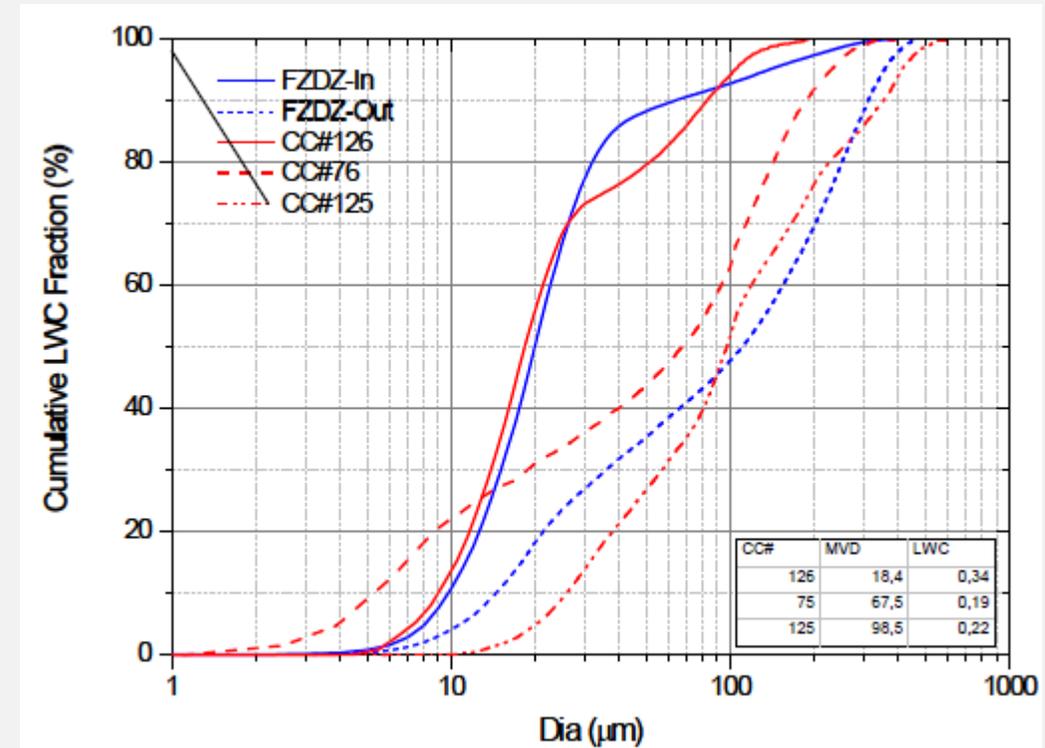
- Pressure taps (aero tests)
- Manual ice tracings at 2 locations
- Laser scans
- Icing blade
- Ice density (mass & volume)
- Skin thermocouples
- Hot air mass flow & temperature
- Videos



# 3D Wing : Test Matrix Overview

- Total amount of 22 runs
- 3 App. O conditions :
  - FZDZ1 : MVD= 18.4  $\mu\text{m}$ ; LWC= 0.34  $\text{g}/\text{m}^3$ ; bimodal
  - FZDZ2\_1 : MVD= 65  $\mu\text{m}$ ; LWC= 0.2  $\text{g}/\text{m}^3$ ; bimodal
  - FZDZ2\_2 : MVD= 98  $\mu\text{m}$  ; LWC= 0.2  $\text{g}/\text{m}^3$ ; monomodal
- 1 App. C condition :
  - DVM= 20  $\mu\text{m}$ ; LWC= 0.34  $\text{g}/\text{m}^3$
- 3 impingement test cases (SLD ice accretion with short duration)
- 10 App.O FZDZ ice shapes (45 min. exposure)
- 2 App. C ice shapes (45 min. exposure)
- 7 ice protection system (bleed air) runs (6 App.O, 1 App.C)
- Particle drop size sensitivities in SLD FZDZ conditions

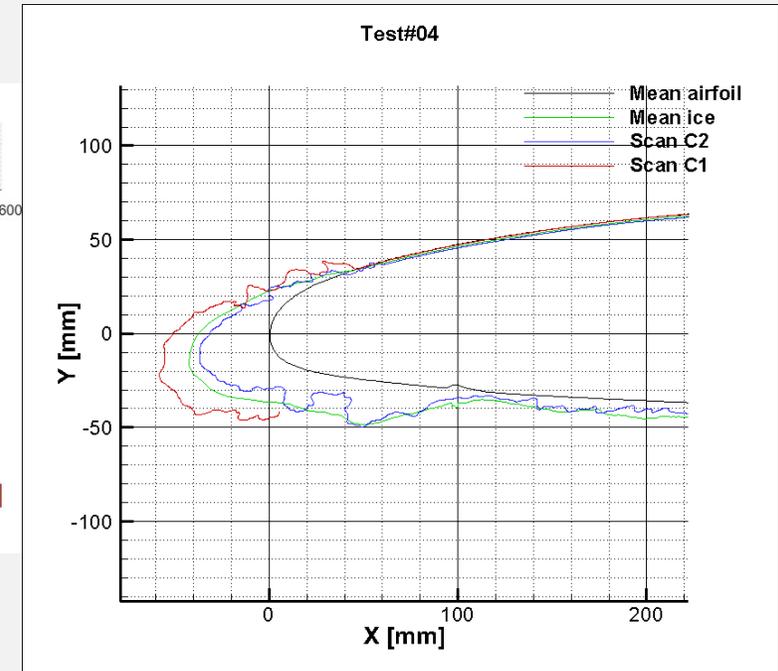
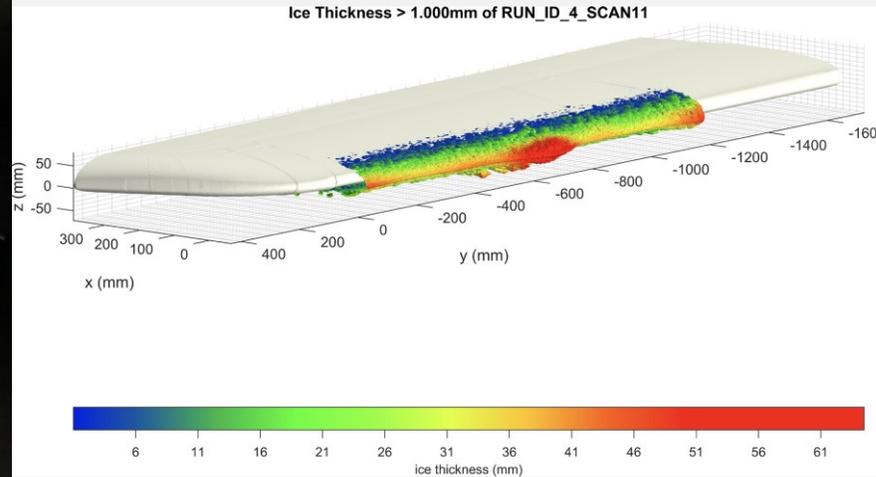
Mach : 0.28 – 0.34 – 0.36  
SAT : -12°C /-16°C  
Alt : 15kft – 17kft



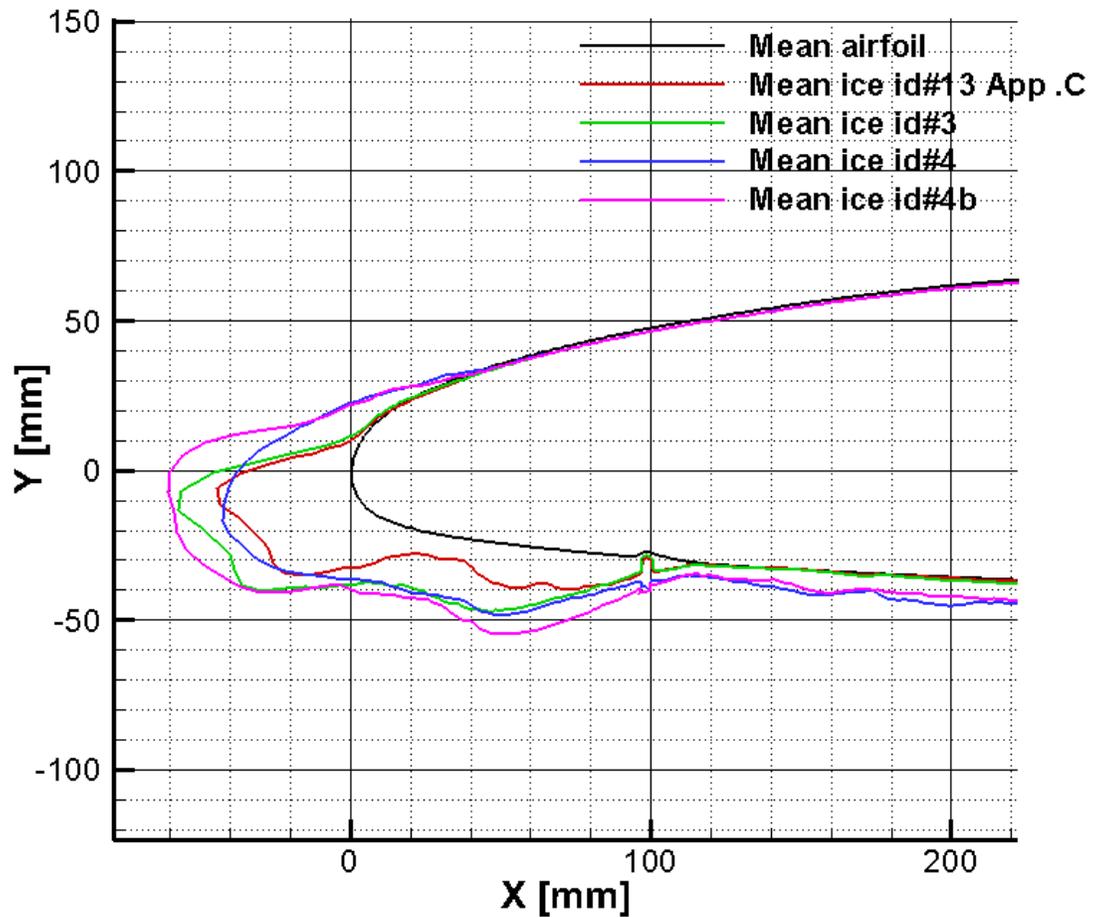
# 3D wing : HLD ice shapes (id#4)



Test #4									
SAT [degC]	V [m/s]	Mach [-]	Altitude [m]	AoA [deg]	$\delta_{flap}$ [deg]	MVD [ $\mu\text{m}$ ]	LWC [ $\text{g}/\text{m}^3$ ]	Exp. Time [min]	PSD
-16,24	116,02	0,361	4572	4,43	0,00	65,0	0,197	44,97	bimodal



# 3D wing : HLD ice shapes comparison

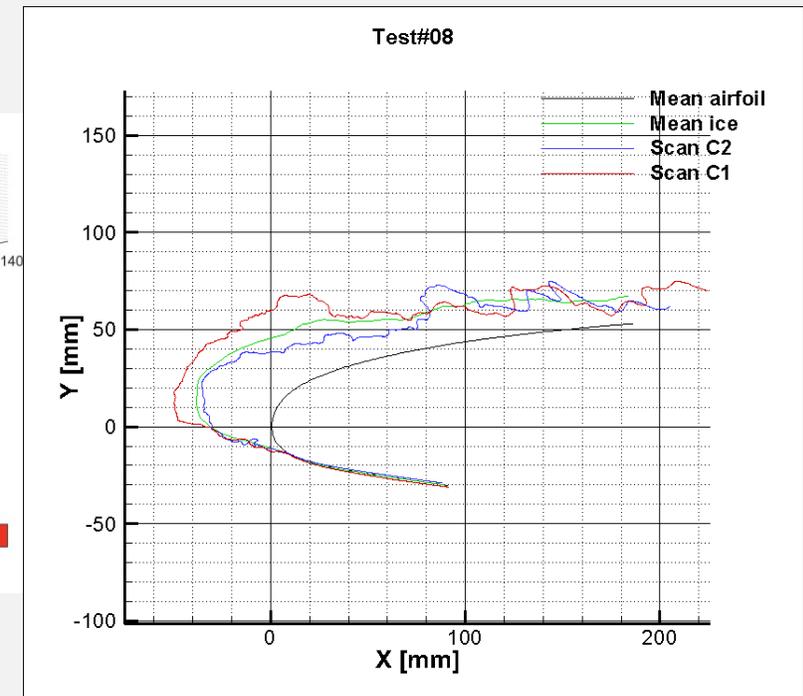
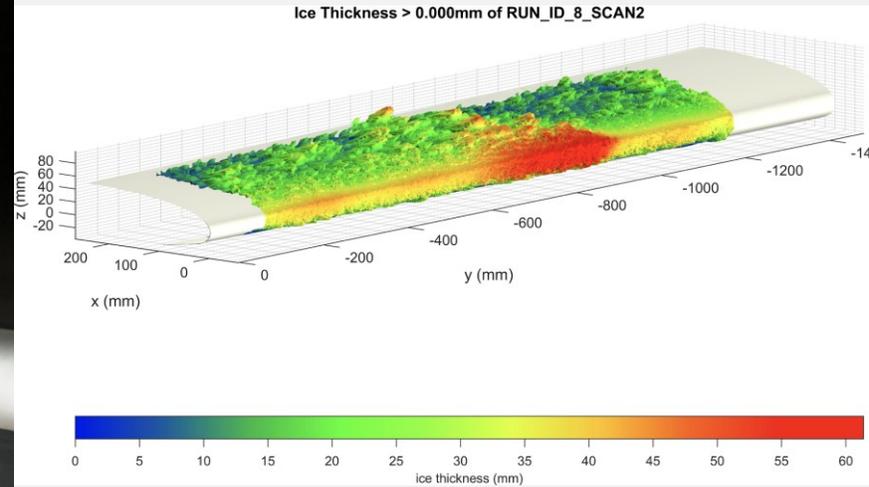


- 🧬 Slight differences between SLD Particle Size Distribution (impingement limits)
- 🧬 Usual coherence between manual tracings and cuts into the scan geometries
- 🧬 Cloud uniformity degradation noticed when the drop size increases
- 🧬 Regarding the ice mass, assuming a “standard” bulk ice density, SLD ice shapes should be heavier than App.C ones, but is this assumption still valid ?

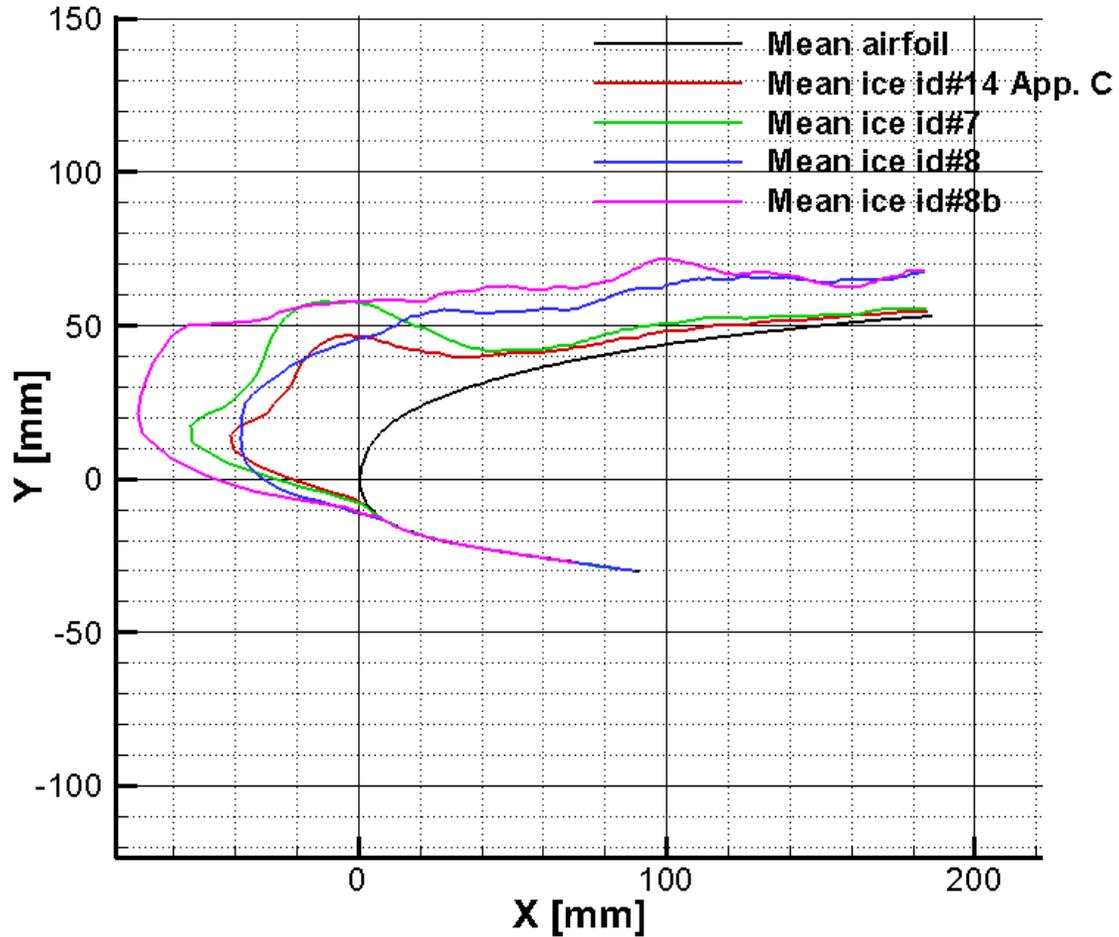
# 3D wing : CTL ice shapes (id#8)



Test #8									
SAT [degC]	V [m/s]	Mach [-]	Altitude [m]	AoA [deg]	$\delta_{flap}$ [deg]	MVD [ $\mu$ m]	LWC [g/m <sup>3</sup> ]	Exp. Time [min]	PSD
-15,05	110,71	0,344	4572	8,45	0,00	65,0	0,209	45,00	bimodal



# 3D wing : CTL ice shapes comparison



- ❄️ Significant differences : impingement limits, max thickness
- ❄️ Cloud uniformity degradation with drop size growth
- ❄️ Non uniformity  $\Rightarrow$  exaggerated differences between mean ice shapes ?
- ❄️ Potential large differences in ice mass between SLD and App.C ice shapes

# 3D wing : conclusions

- ❧ Large series of tests performed on an aircraft representative configuration with High Lift device and tunnel conditions close to inflight encounters
- ❧ Ice shapes data for different SLD FZDZ clouds and long time duration (45 min.)
- ❧ High fidelity set of data with the use of a laser scan device
- ❧ Preliminary results for an Ice Protection system comparing App. C performance vs. App. O FZDZ
- ❧ Ranking the most critical ice shapes in FZDZ with different PSD and MVD is not easy, even when compared to App .C
- ❧ Bulk ice density always  $\geq 900 \text{ kg/m}^3$ , whatever the icing cloud is; “apparent” ice density was not assessed
- ❧ With IPS activated, no significant runback was observed in SLD FZDZ once the design is efficient in App.C (CM-IM)
- ❧ Some of these test cases were used in WP11 for 3D numerical tools validation.

# 3D wing : conclusions



Some remaining gaps have been identified :

- Cold temperature investigations : ice shapes and ice protection
- Cloud uniformity still needs to be improved : bimodal PSD, large droplet size
- Droplet temperature uncertainties and impact also needs to be better identified

# Icing database for supercooled conditions



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# Icing database

Top-level goal of ICE GENESIS: <https://icing-database.eu>

- Generation of an **online searchable and extendable database** covering classical icing conditions (Appendix C) and SLD icing conditions (Appendix O)

What is in the database?

- 390 individual icing runs, 17 different test objects
- ICE GENESIS data & legacy data from previous projects and sources (e.g., NASA SLD database)
- Some data are public, others restricted to the Consortium

	minimum	maximum
Velocity spectrum	40 m/s (78 kt)	205 m/s (400 kt)
SAT spectrum	-25 °C	-2.5 °C
LWC spectrum	0.12 g/m <sup>3</sup>	1.53 g/m <sup>3</sup>
MVD spectrum	15 µm	225 µm
Icing duration	1 min	2:45 h

The screenshot displays the 'Icing Cases' section of the ICE GENESIS database. It features a search bar at the top with the text 'All Icing Cases' and a 'Search' button. Below the search bar, there is a 'Categories' section with the following text: 'The following list shows grouped data of icing cases. One icing case may be present in multiple groups.' The list includes several entries, each with a logo and a brief description:

- NATO RTO Ice Accretion Simulation Evaluation Test Data**: Validation data used in the RTO Technical Report 38 (RTO-TR-038) for icing code assessment and comparison in year 2000.
- EXTICE MINDEF-Campaign**: Data from EU project EXTreme ICing Environment (EXTICE, 2008-2012) produced at DGA (Direction generale de l'Armement, Directorate General of Armaments, MINDEF, Paris)
- EXTICE CIRA-Campaign**: Data from EU project EXTreme ICing Environment (EXTICE, 2008-2012) produced at the Italian Aerospace Research Center CIRA in Capua.
- NASA Database Of Supercooled Large Droplet Ice Accretions**: Large SLD icing database of ice accretion on five different 2D and 3D geometries, tested at the NASA Glenn Icing Research Tunnel
- ICE GENESIS TU Braunschweig Campaign**: Icing test campaign at Technical University Braunschweig within EU project ICE GENESIS.
- ICE GENESIS CIRA 3D Wing Test Campaign**: 3D wing test data from EU project ICE GENESIS (2019-2023) produced at the Italian Aerospace Research Center CIRA in Capua
- ICE GENESIS Cranfield University Engine Cascade Test Campaign**: Engine cascade ice accretion test data from EU project ICE GENESIS (2019-2023) produced at the Cranfield University, GB.
- RTA SLD icing cases**: SLD icing cases investigated at the Rail Tec Arsenal (RTA) icing wind tunnel in Vienna, Austria

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