ICE GENESIS Final Public Workshop

6-7 December 2023
Toulouse, France

ICE GENESIS

The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 824310.

Ground tests-experimental database WP8

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

The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 824310.

Wind tunnel tests in supercooled liquid icing conditions

ICE GENESIS

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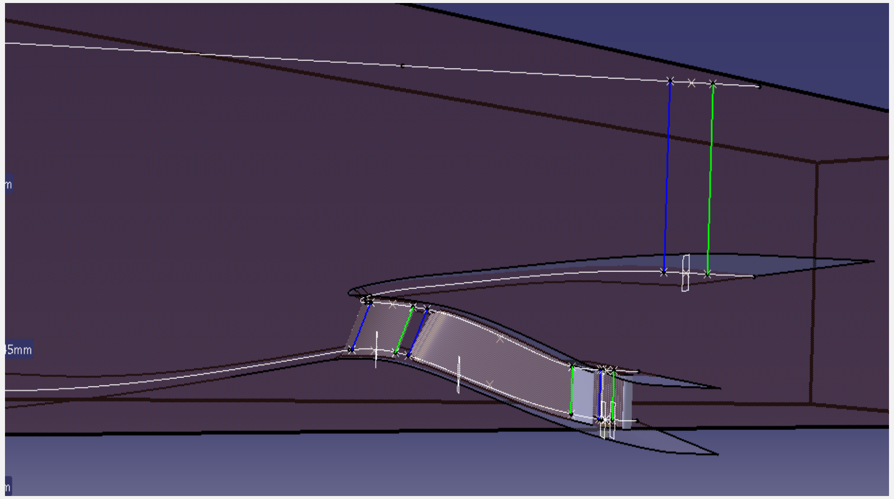
Tests in industrial environment : 7 mockups

DASSAV@CIRA

App. O

SAFRAN AIRCRAFT ENGINES@Cranfield

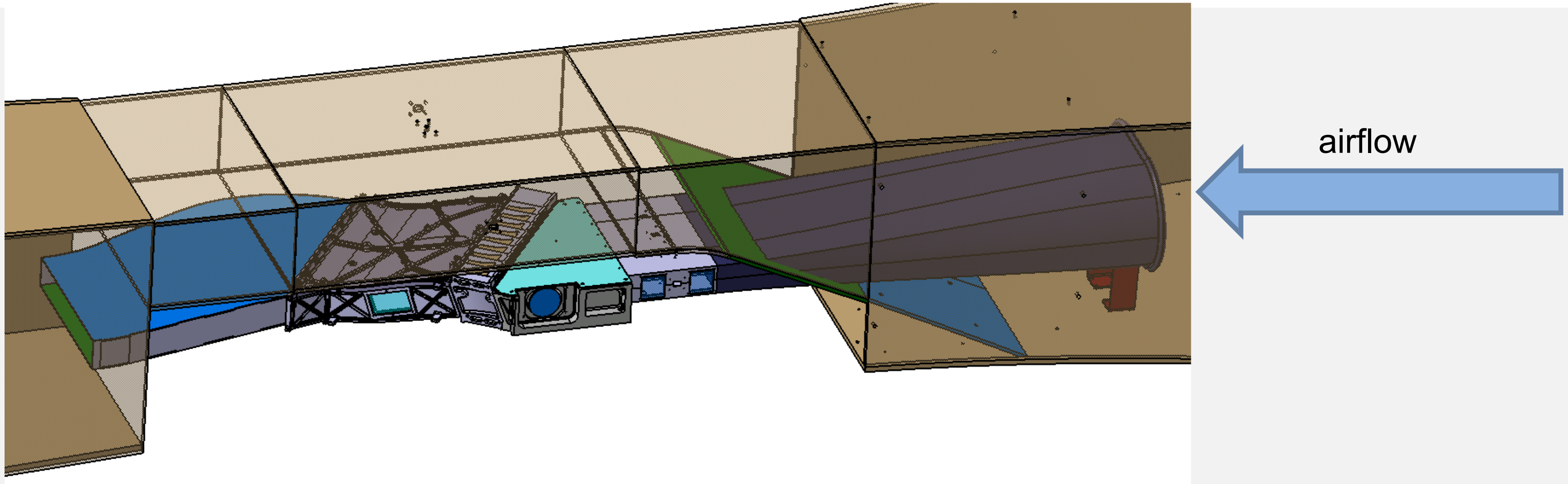


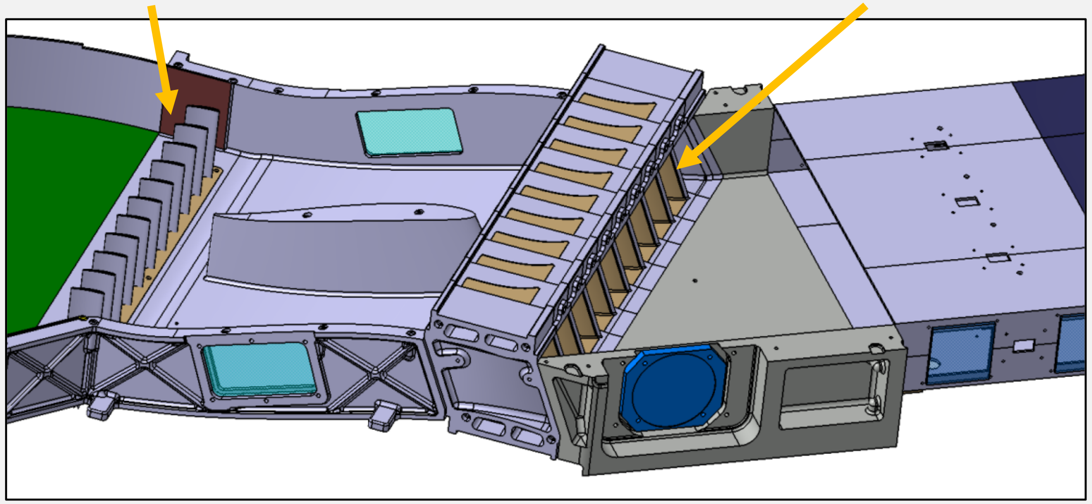
App. C

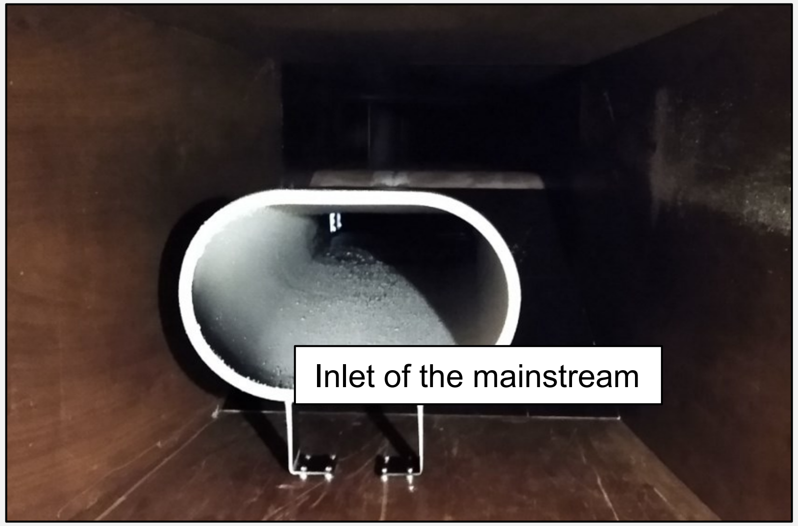
CNRC fan rotor

App. C

Cascade rig : mock-up presentation







Cascade rig : test matrix

Anti-icing tests

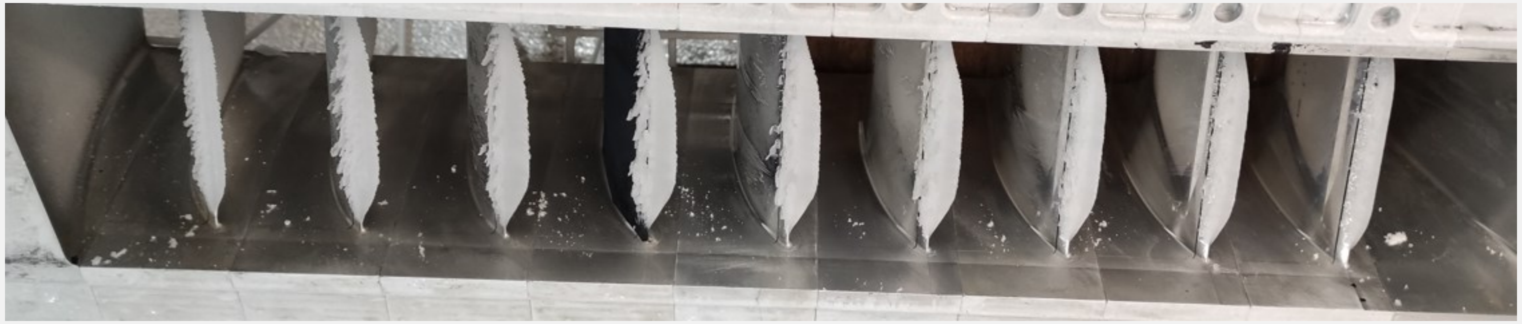
- 31 different tests are realized
- Parameter range :
  - Air speed in the main stream : from 40 m/s to 80 m/s
  - Air temperature: from -20°C to -5°C
  - LWC: from 0.4 g/m3 to 1.0 g/m3
  - IGV Pitch from 0° to 35° (with the main air flow direction)
- Test sequence
  - Stabilization of aerodynamic in 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

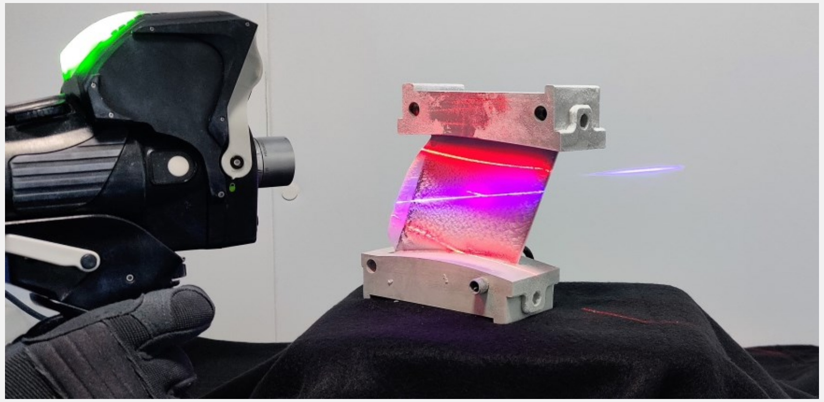
- 17 different tests are realized
- Parameter range :
  - Air speed in the main stream : from 40 m/s to 80 m/s
  - Air temperature: from -20°C to -5°C
  - LWC: from 0.4 g/m3 to 1.0 g/m3
  - IGV Pitch at 0°
- Test sequence:
  - Stabilization of aerodynamic in dry condition
  - Activation of the cloud 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.

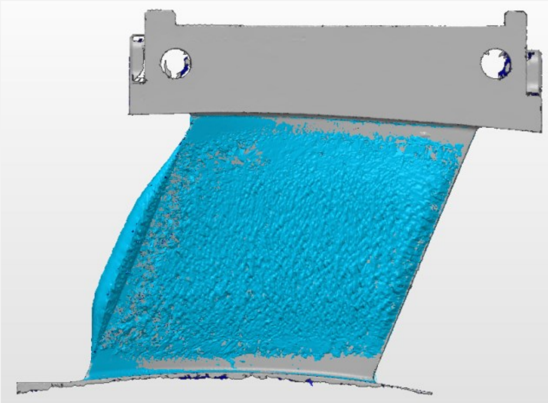
Cascade rig : ice accretion

Upstream Grid

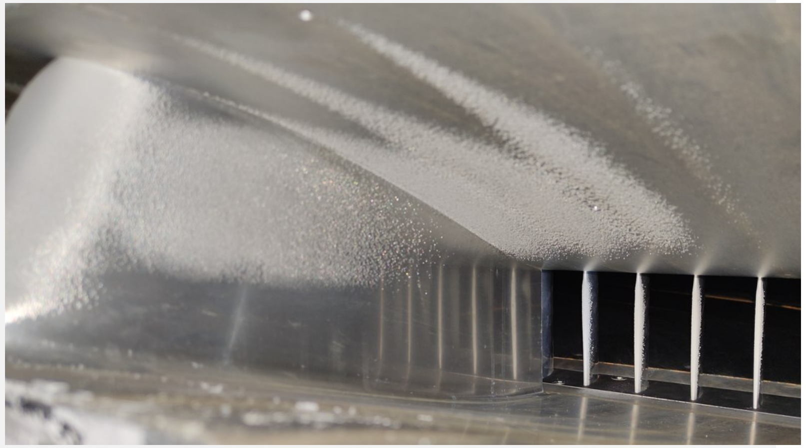


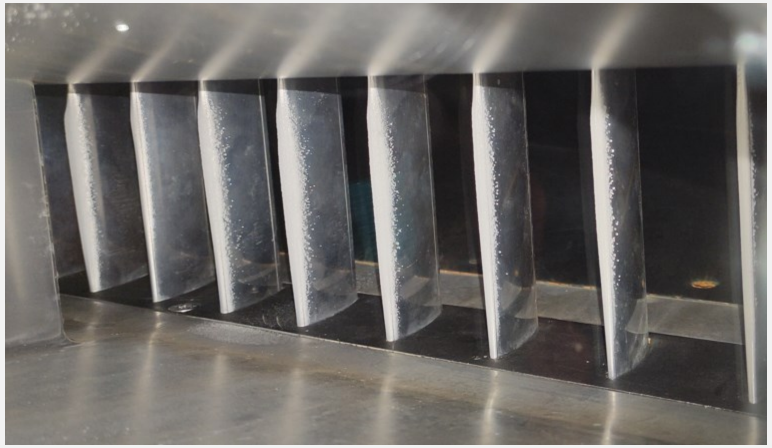
3D scan operation performed by AIIS





Downstream Grid





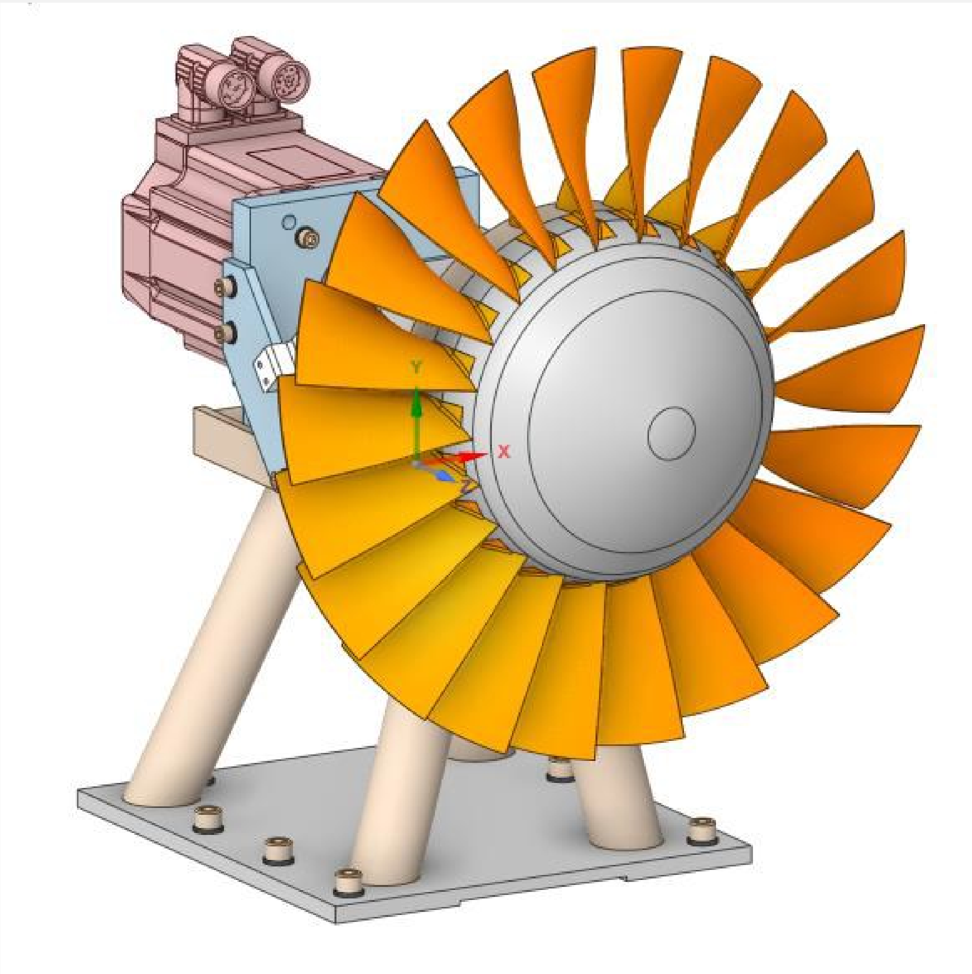
Cascade rig

- 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

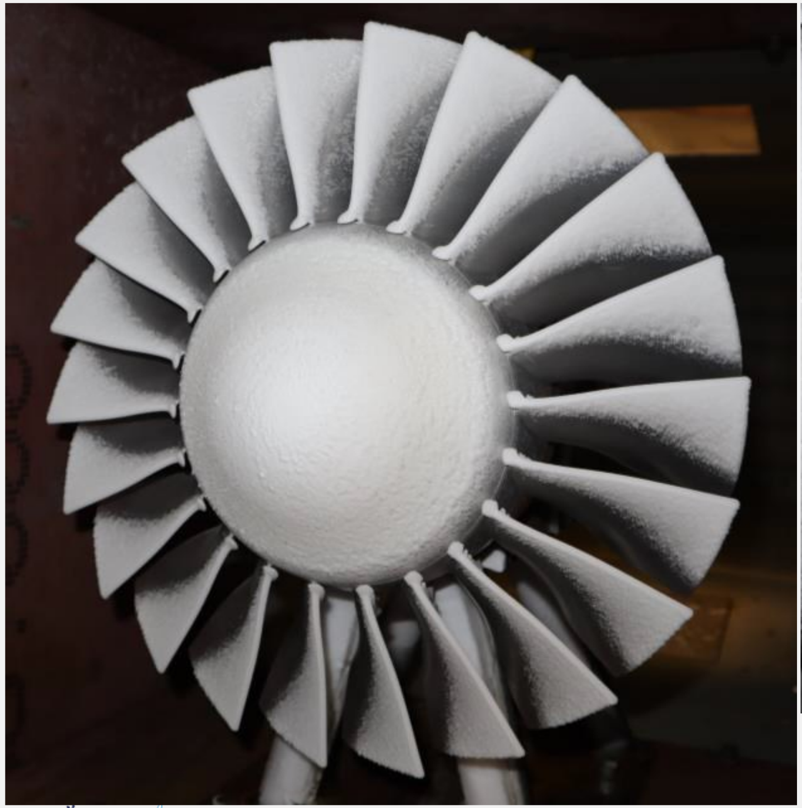


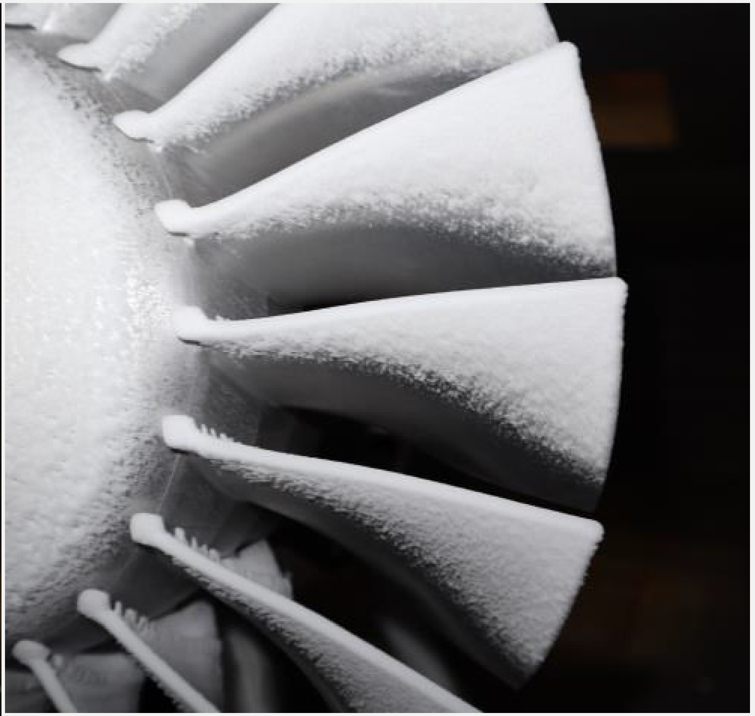
CNRC : test matrix

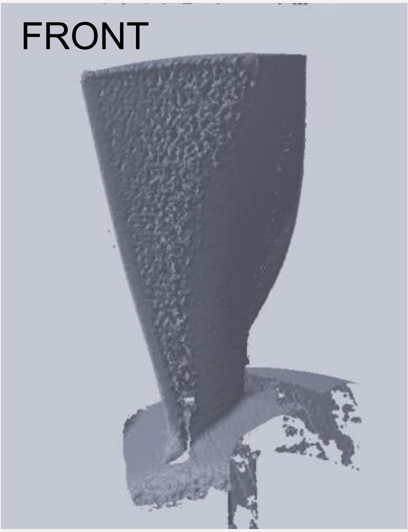
TAT	MVD	LWC	Rotation speed	Air Speed	Altitude	Time Accretion
°C	µm	g/m3	rpm	m/s	ft	s
-3	20	0.3	1500	20	0	240
-10	20	0.3	1500	20	0	240
-10	20	0.3	1500	20	0	360
-10	20	0.3	2000	20	0	360
-10	20	0.3	2500	20	0	360
-10	20	0.3	1000	20	0	360
-10	20	0.3	500	20	0	360
-3	20	0.3	1500	20	0	360
-25	20	0.8	1500	20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

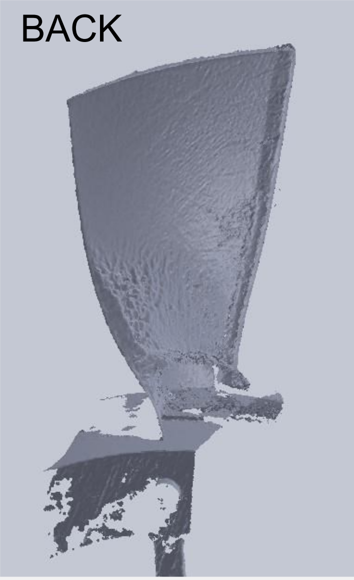
CNRC : ice pictures and scans

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







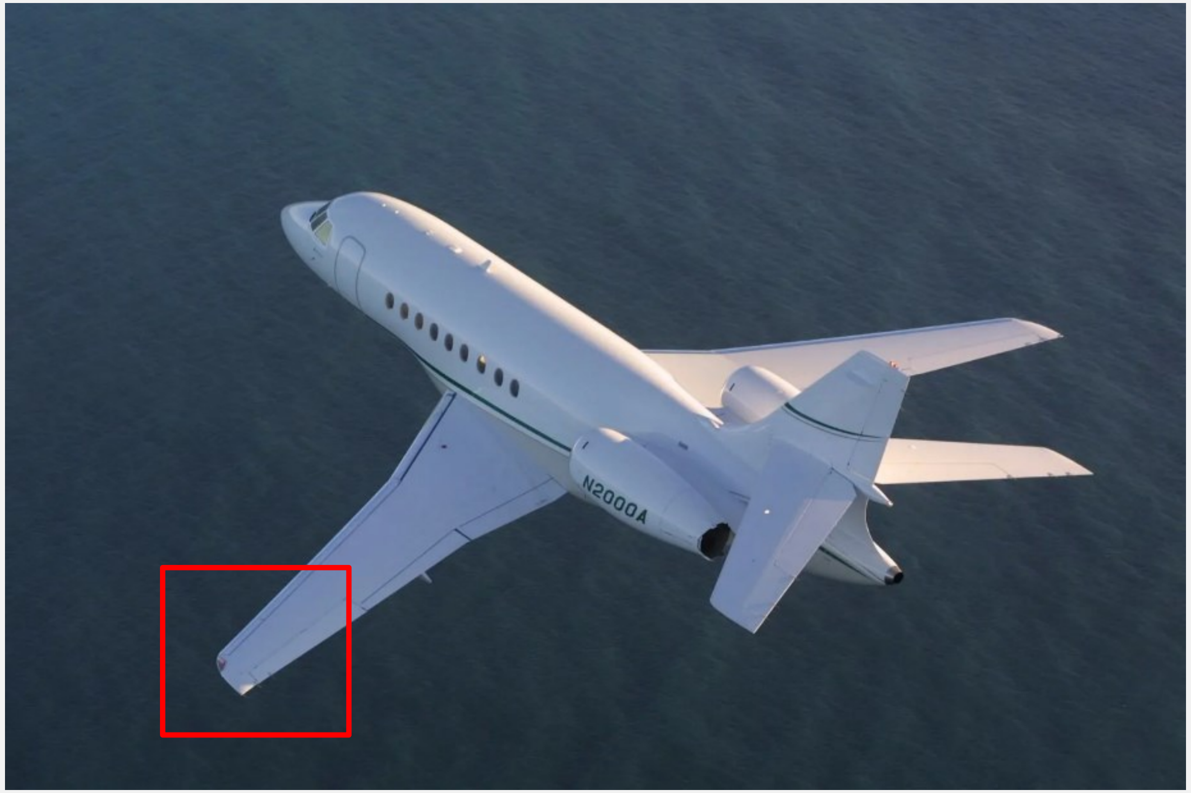


CNRC : fan rotor test rig

- 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

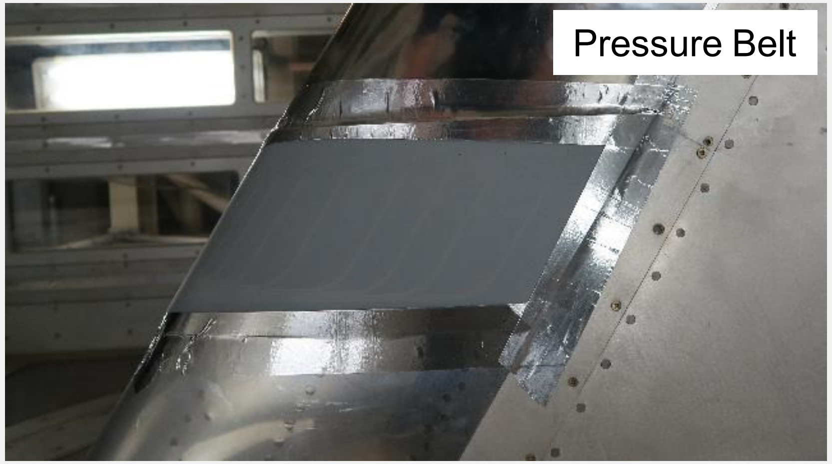


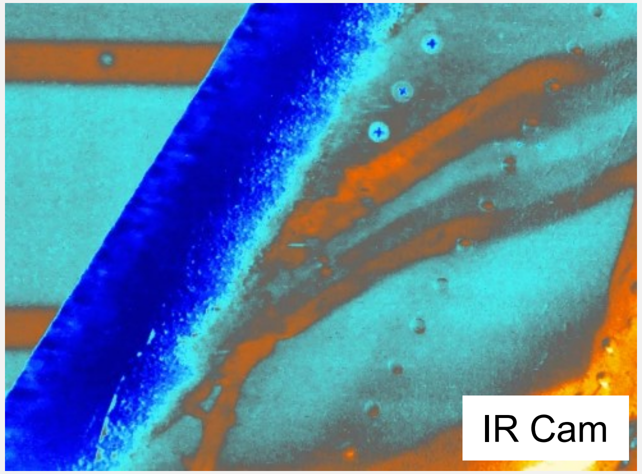
3D Wing : configurations

HLD :			CTL:			LDG :		
	Flap	0°		Flap	0°		Flap	15°
	Slat	retracted		Slat	ext		Slat	ext°
	AOA	4.5°		AOA	8.5°		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

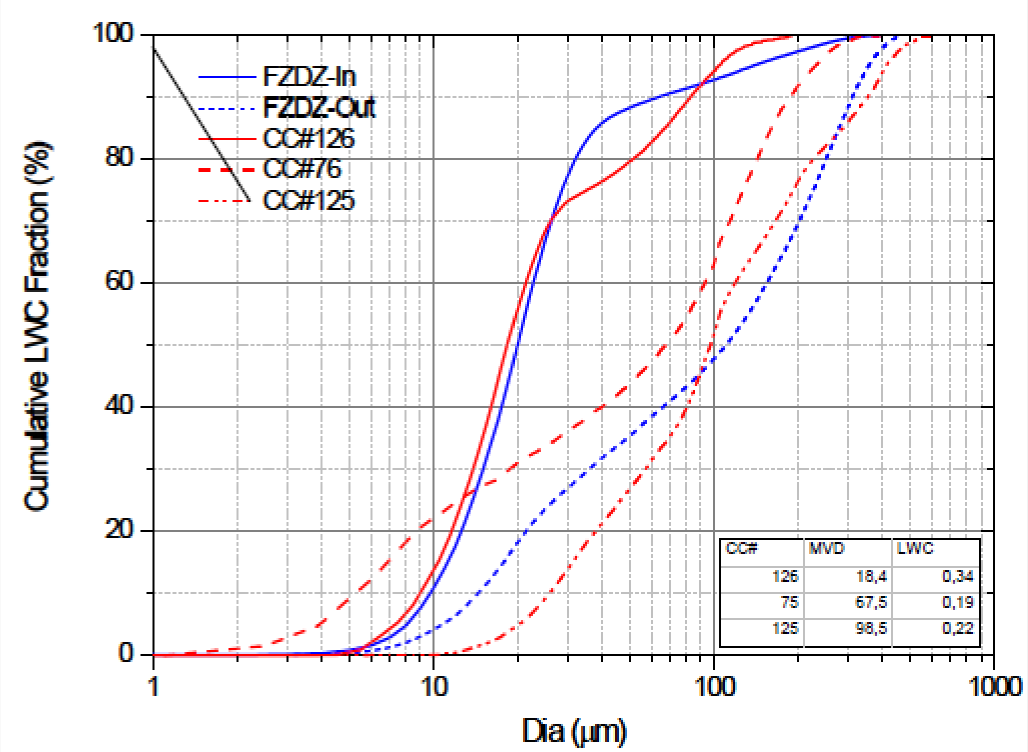




3D Wing : Test Matrix Overview

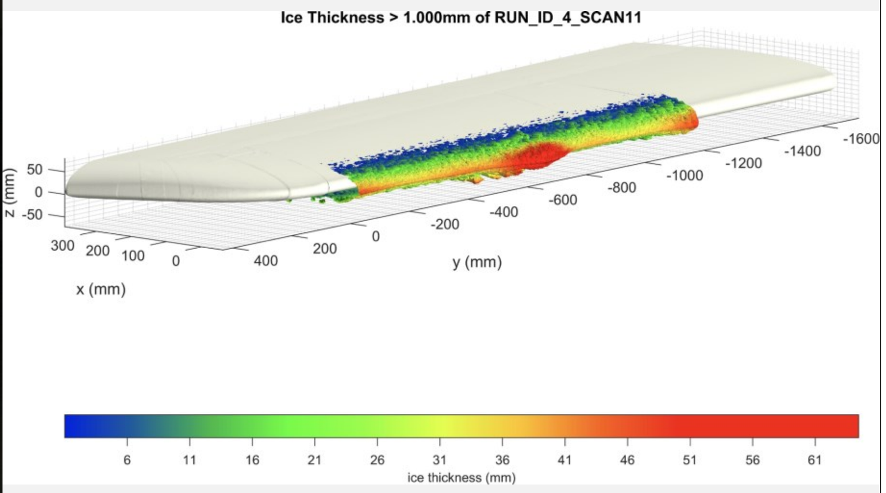
- **Total amount of 22 runs**
- **3 App. O conditions :**
  - **FZDZ1 : MVD= 18.4 µm; LWC= 0.34 g/m^3 ; bimodal**
  - **FZDZ2_1 : MVD= 65 µm; LWC= 0.2 g/m^3; bimodal**
  - **FZDZ2_2 : MVD= 98 µm ; LWC= 0.2 g/m^3; monomodal**
- **1 App. C condition :**
  - **DVM= 20 µm; LWC= 0.34 g/m^3**
- **3 impingement 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**

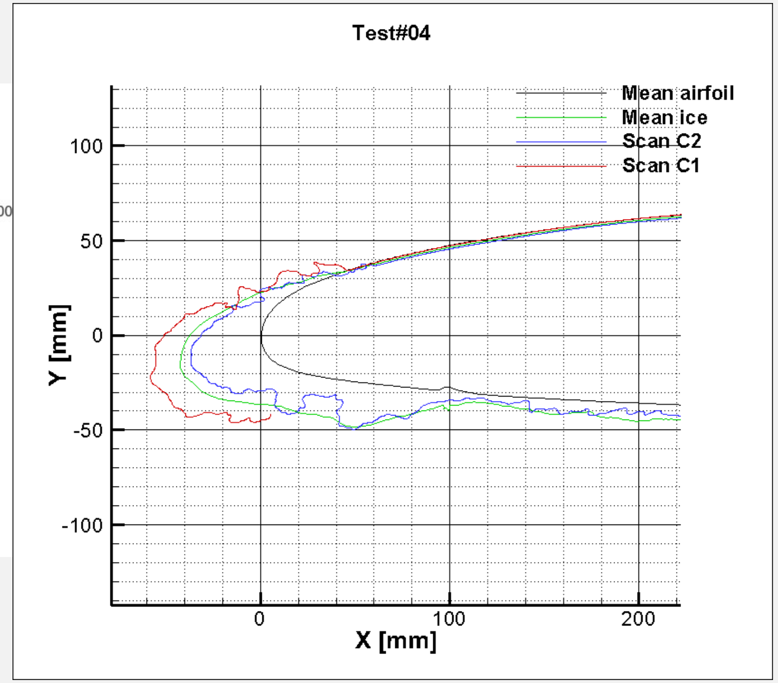
Mach : 0.28 – 0.34 – 0.36
SAT : -12°C /-16°C
Alt : 15kft – 17kft



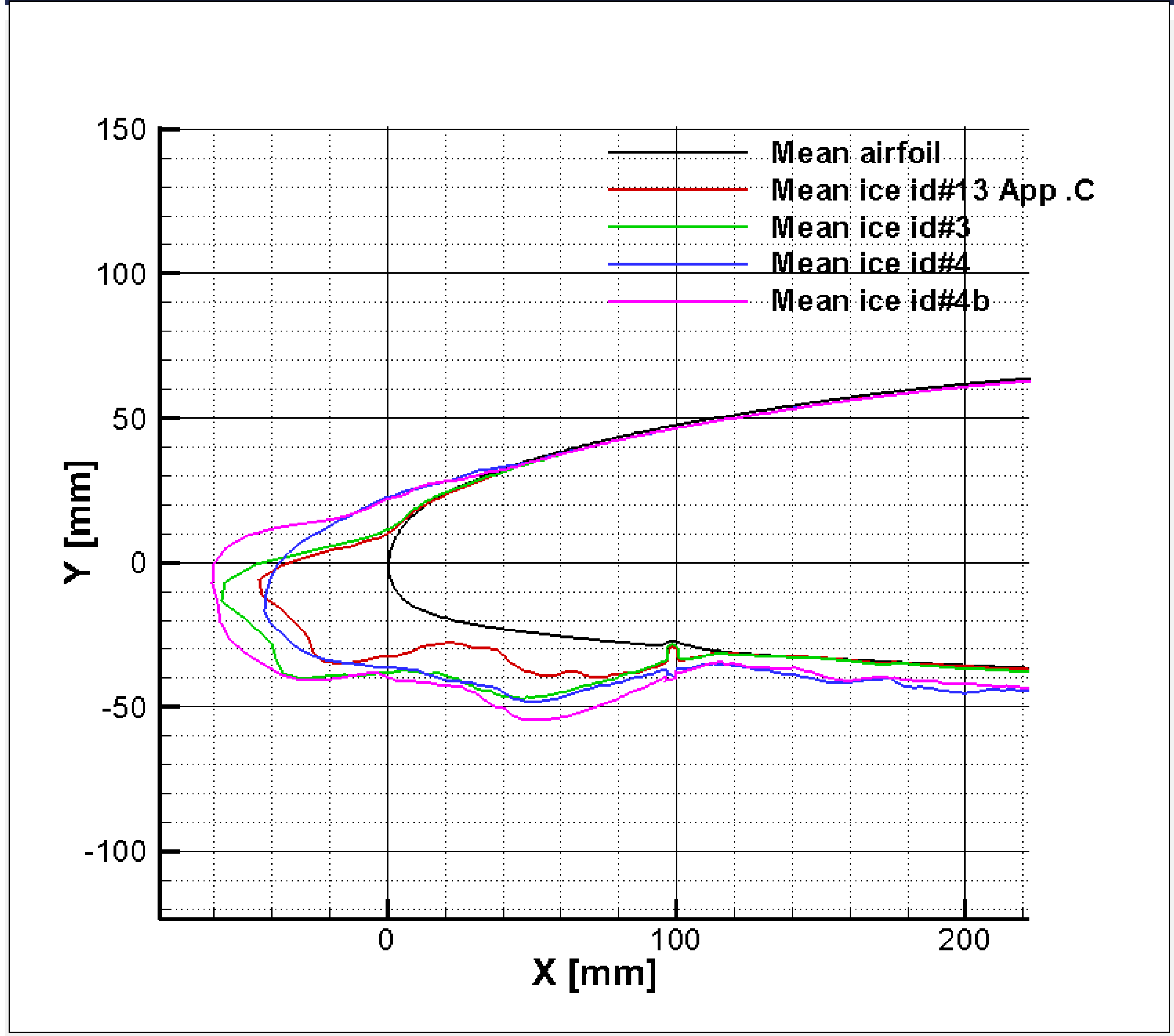
3D wing : HLD ice shapes (id#4)

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



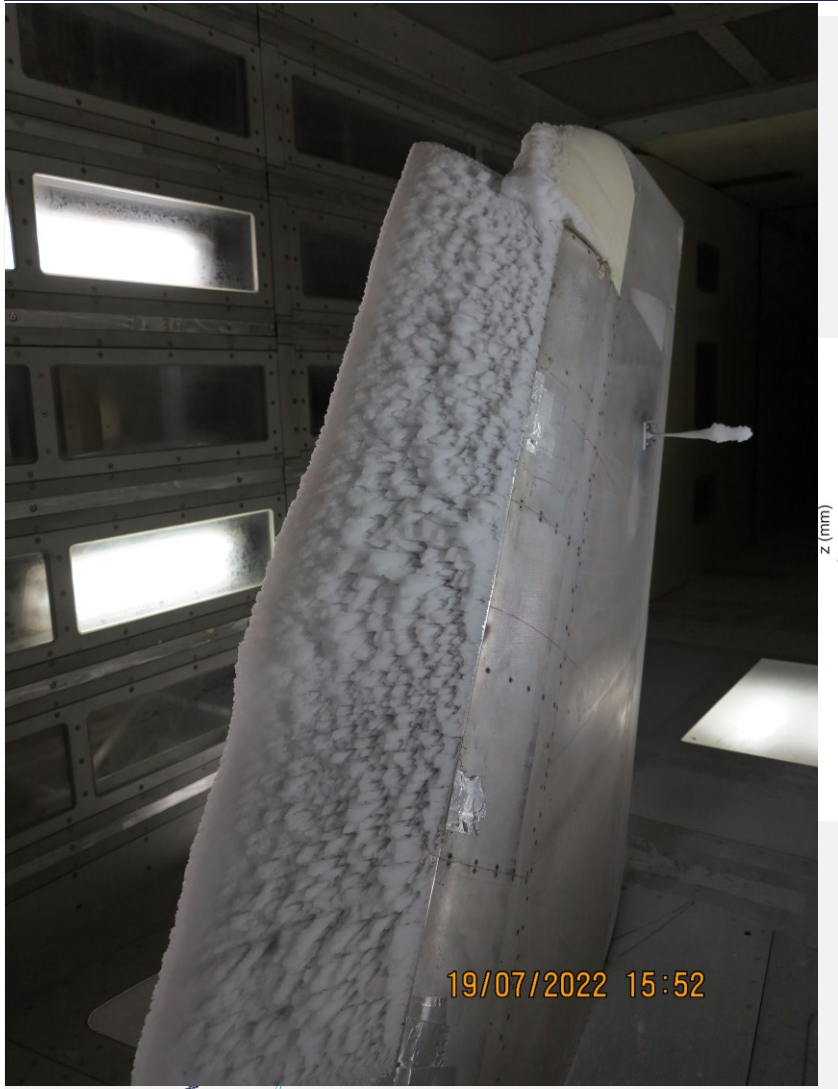


3D wing : HLD ice shapes comparison

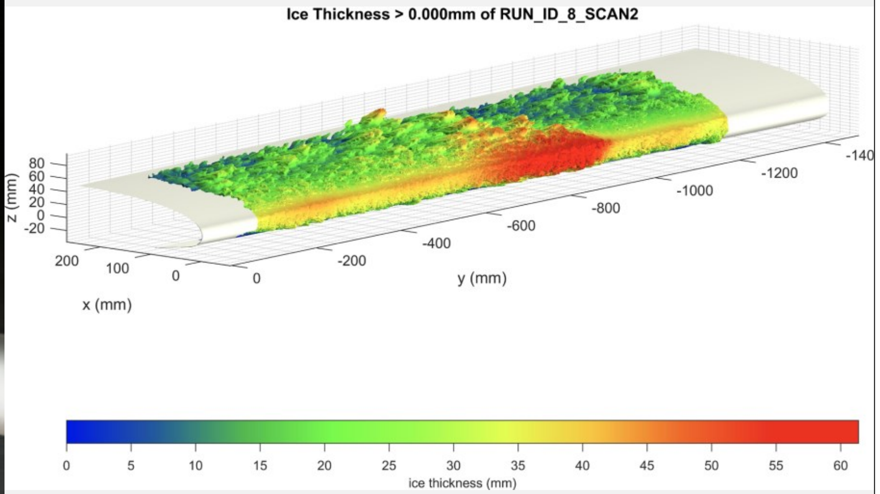


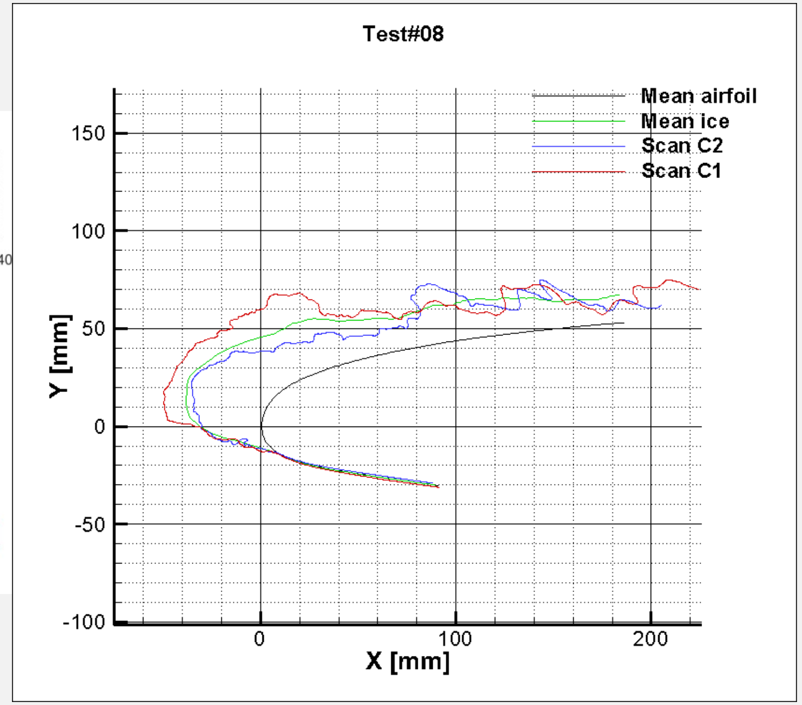
- Slight differences between SLD Particle Size Distribution (impingement limits)
- Usual coherence between manual tracings and cuts into the scan geometries
- Cloud uniformity degradation noticed when the drop size increases
- Regarding the ice mass, assuming a “standard” bulk ice density, SLD ice shapes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

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

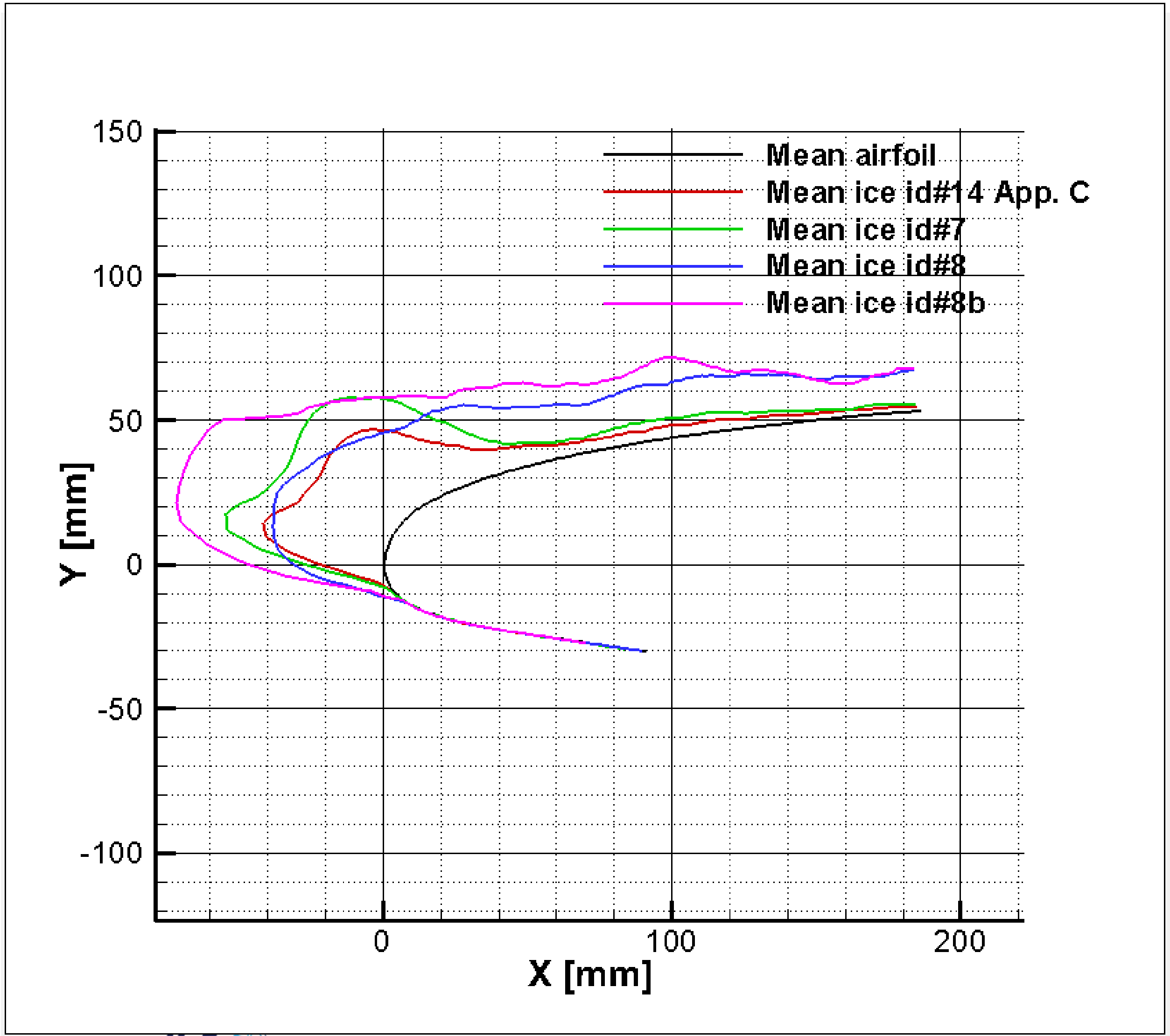


Test #8									
SAT [degC]	V [m/s]	Mach [-]	Altitude [m]	AoA [deg]	δ_{flap} [deg]	MVD [μm]	LWC [g/m^3]	Exp. Time [min]	PSD
-15,05	110,71	0,344	4572	8,45	0,00	65,0	0,209	45,00	bimodal





3D wing : CTL ice shapes comparison



- Significant differences : impingement limits, max thickness
- Cloud uniformity degradation with drop size growth
- Non uniformity ⇒ 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 ≥ 900 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^3	1.53 g/m^3
MVD spectrum	15 µm	225 µm
Icing duration	1 min	2:45 h