ICE GENESIS Final Public Workshop

App C&O numerical capability in industrial environment

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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.

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1. Overview
2. Scope
3. Test cases & Simulation Results
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Microsoft PowerPoint - Gnd Icing Winter Ops Conf.ppt [Compatibility Mode] (ukfsc.co.uk)

Understanding Icing | Pilot Getaways

WP 11 : Numerical tools validation in industrial environment

- Main objectives :
  - Transfer the updated tools from the academic partners to the industrial partners,

    OR

    Update the in house tools of industrial partners.

  - Performed simulations to validate the ability of each industrial partners to
    - Perform simulation in SLD conditions (FZDZ & FZRA)
    - Perform 3D simulations in liquid conditions
    - Perform simulation in snow conditions (presentation at 3.30 pm)

  - Define best practices, identify limitations and the gaps to use the tools as a Mean of Compliance (MoC) for the certification.

- Industrial partners:
  - Airbus Operations SAS, Airbus Helicopters, ATR, Bombardier, Dassault, GE, Leonardo, Rolls Royce, Safran AE, Sonaca
- Academic partners:
  - CIRA, ONERA, Politecnico di Milano, Polytechnique Montréal, Tokyo University of Science foundation.

App C numerical capability

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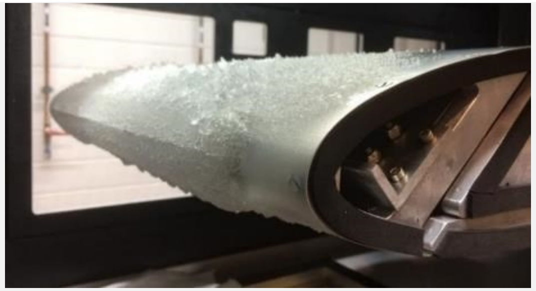
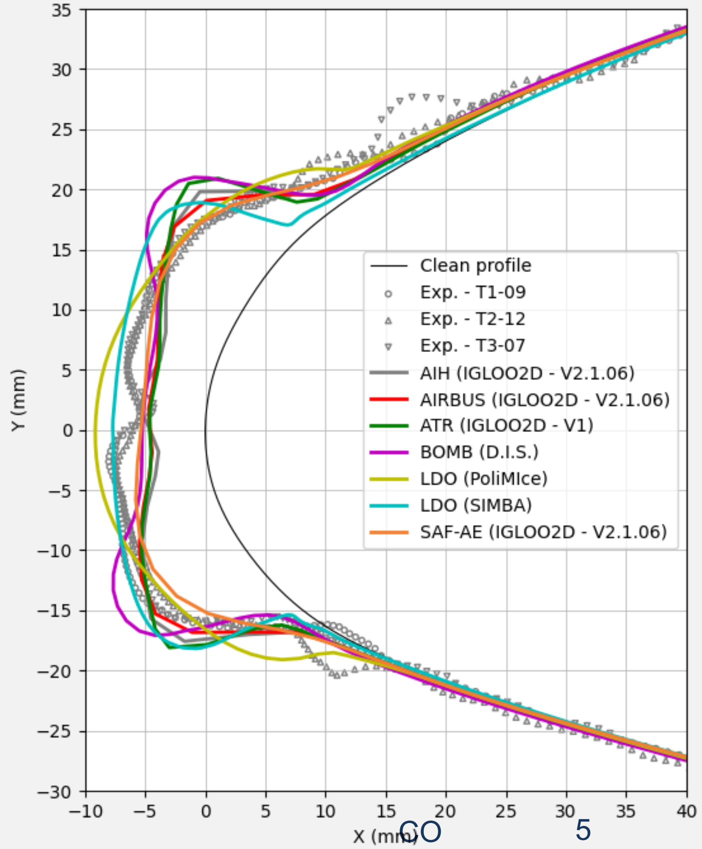
Common Cases

- Test Conditions

SAT [°C]	Altitude [m]	Airspeed [m/s]	Mach [-]	AoA [°]	MVD [µm]	LWC [g/m^3]	ExposureTime [min]
-8.0	0	40	0.12	0	19	0.88	9

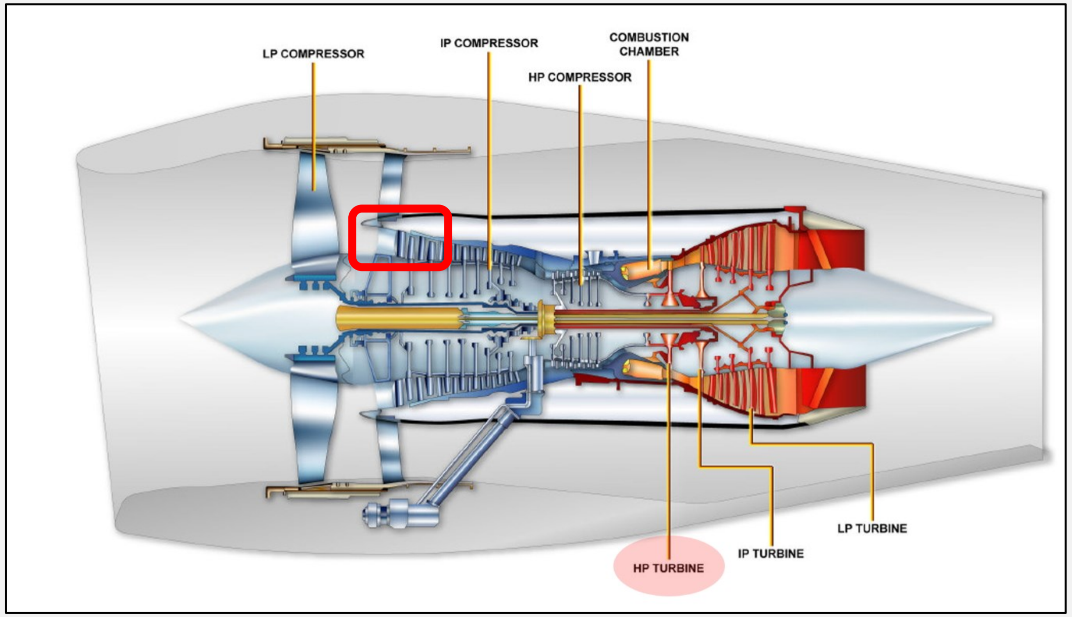
- Test article : HDMI profile – chord = 700 mm
- Main Observations:
  - Expect for LDO, industrials estimate the same ice shape. Horns are more or less accentuated
  - PoliMIce tool estimate a rounded ice shape, which lead to an over estimation of the ice thickness at the leading edge but a correct estimation of the ice thickness further downstream.
  - No tools predict the valley (perhaps due to a constant roughness used in simulations, over time and profile)

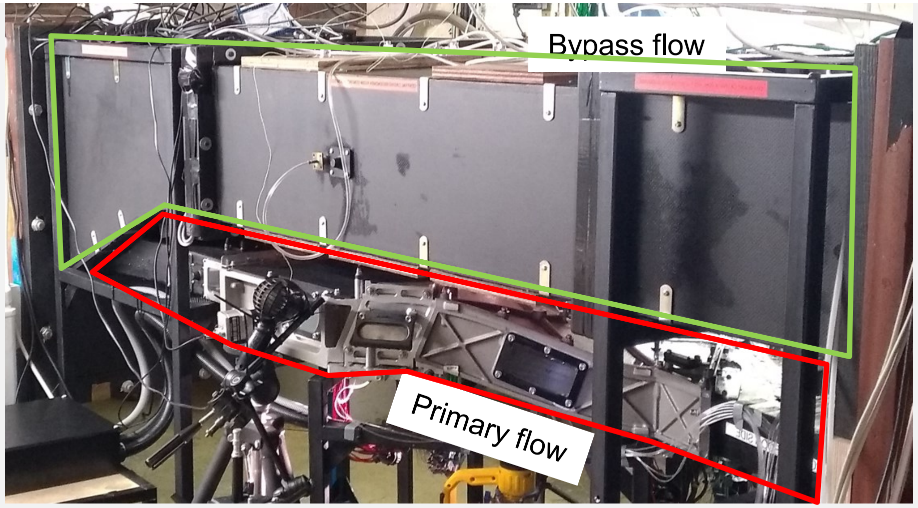


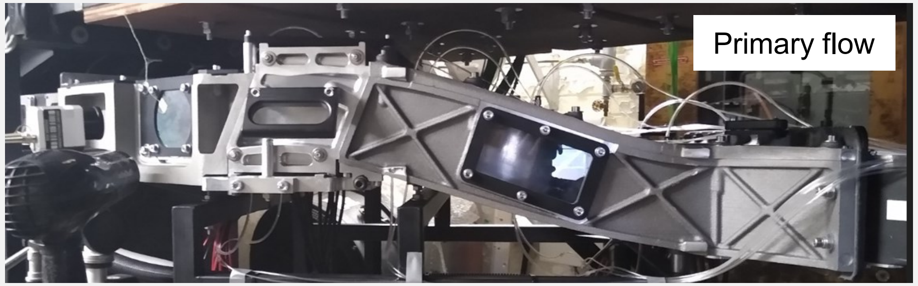


Cascade Rig – Test Campaign

- Generic inlet compressor of a turbofan engine
- Tested at Cranfield University facility – Summer 2022







ICE GENESIS

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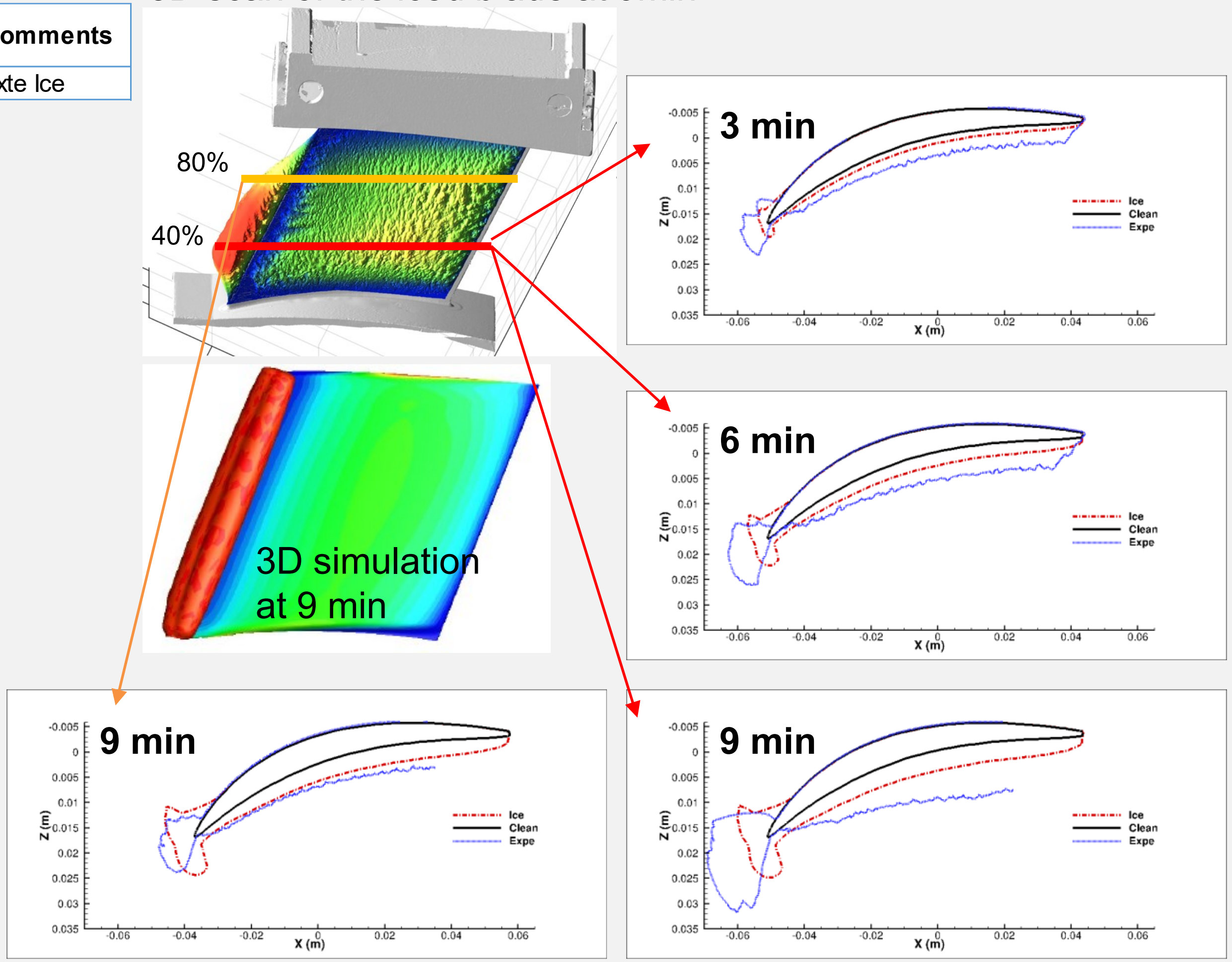
Cascade Rig Simulation

- Test conditions

Run number	Air speed in primary flow pass (m/s)	Total air temerature (°C)	LWC (g/m3)	Accretion time (ice thickness expected)			Comments
#1	55	-10	0.79	3min 00s	6min 00s	9min 00s	Mixte Ice

- Solver used : IGLOO3D – v2.3.1.0
- Main observations:
  - Multistep simulation stops after 2 steps (on 90).
  - Predictor simulation (1 step) under estimate the amount of ice. As corrector simulation reduces the ice shape, this simulation wasn't performed.
  - Ice thickness is almost constant along the high of the blade. This is due to a water ratio at the model input. The water ratio wasn't uniform during the test, especially close to the upper and lower walls.

3D scan of the iced blade at 9min

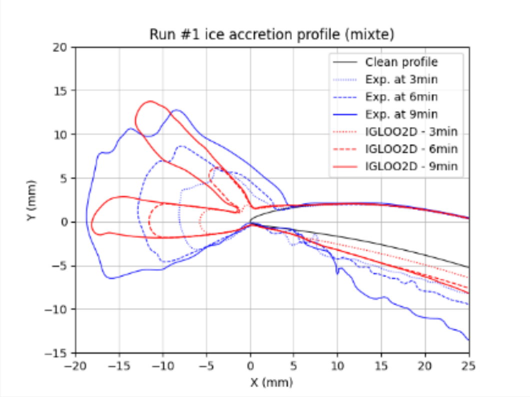


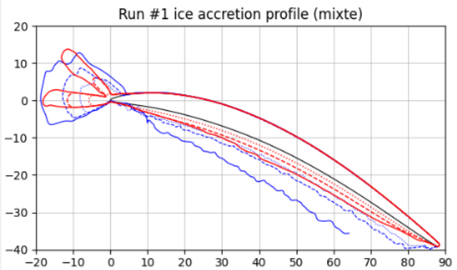
Cascade Rig Simulation

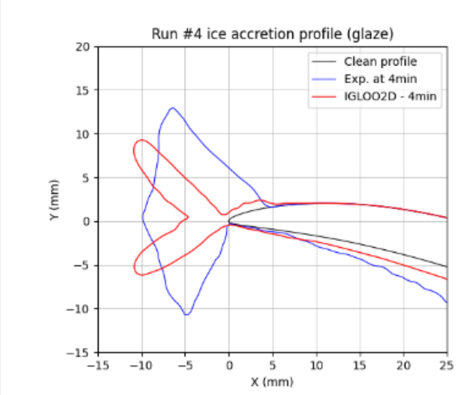
- Test conditions

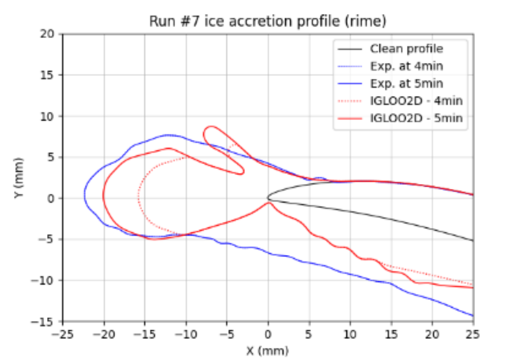
Run number	Air speed in primary flow pass (m/s)	Total air temerature (°C)	LWC (g/m3)	Accretion time (ice thickness expected)			Comments
#1	55	-10	0.79	3min 00s	6min 00s	9min 00s	Mixte Ice
#4	80	-5	0.74		4min 00s		Glaze Ice
#7	80	-20	0.74		4min 00s	5min05s	Rime Ice

- Solver used : IGLOO2D – v2.1.06
- Main observations:
  - Smoothing solver is disabled, unlike simulations of common cases.
  - All simulations underestimate ice accretion on pressure side (about twice less than in the tests).
  - The simulation given the shape of the rime ice is relatively close to the experience. There is a lack of ice just behind the leading edge (pressure side)
  - For two others, the simulations are different from the test. The two horns should be merged.
  - SAF-AE previous best pratice gives a similar result. These pratices are defined on rime ice shape.







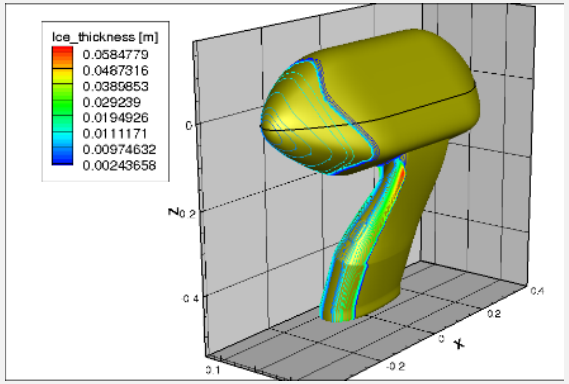


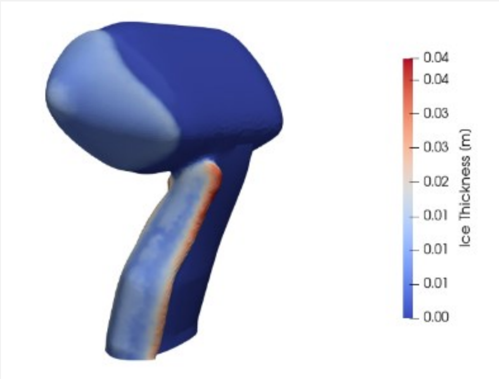
Rescue hoist simulation

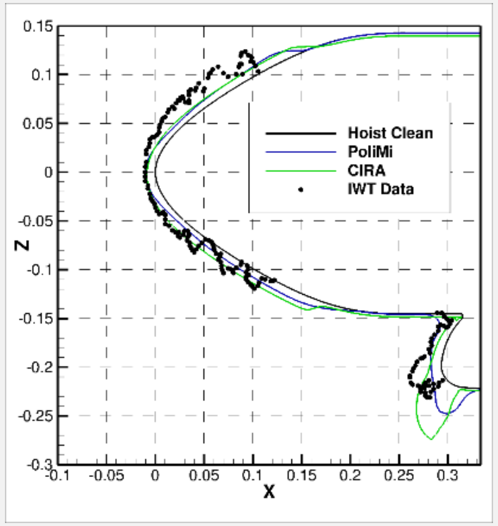
- Test conditions

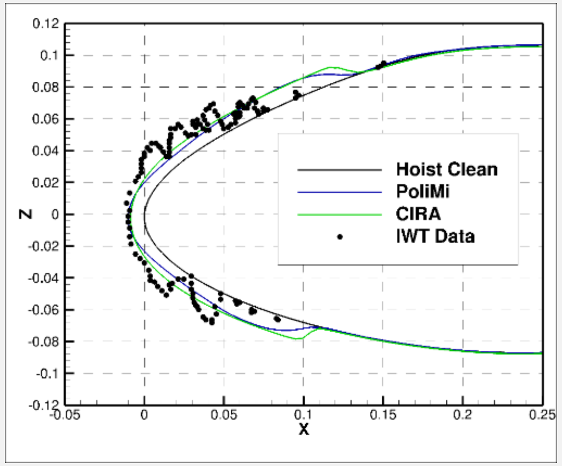
SAT [°C]	Altitude [m]	Airspeed [m/s]	Mach [-]	AoA [°]	MVD [μm]	LWC [g/m^3]	ExposureTime [min]
-3.5	0	66	0.20	0	35.4	0.36	30

- Solver used : PoliMice & SIMBA
- Main observations:
  - LDO-CIRA and LDO-POLIMI numerical results are very similar
  - Good match on the leading edge for both section A and B
  - Comparable thickness but with missing horns for the lower surface for both section A and B
  - Different thickness and missing horns for the upper surface especially for section A
  - Ice shape predicted on the arm but with different angle.



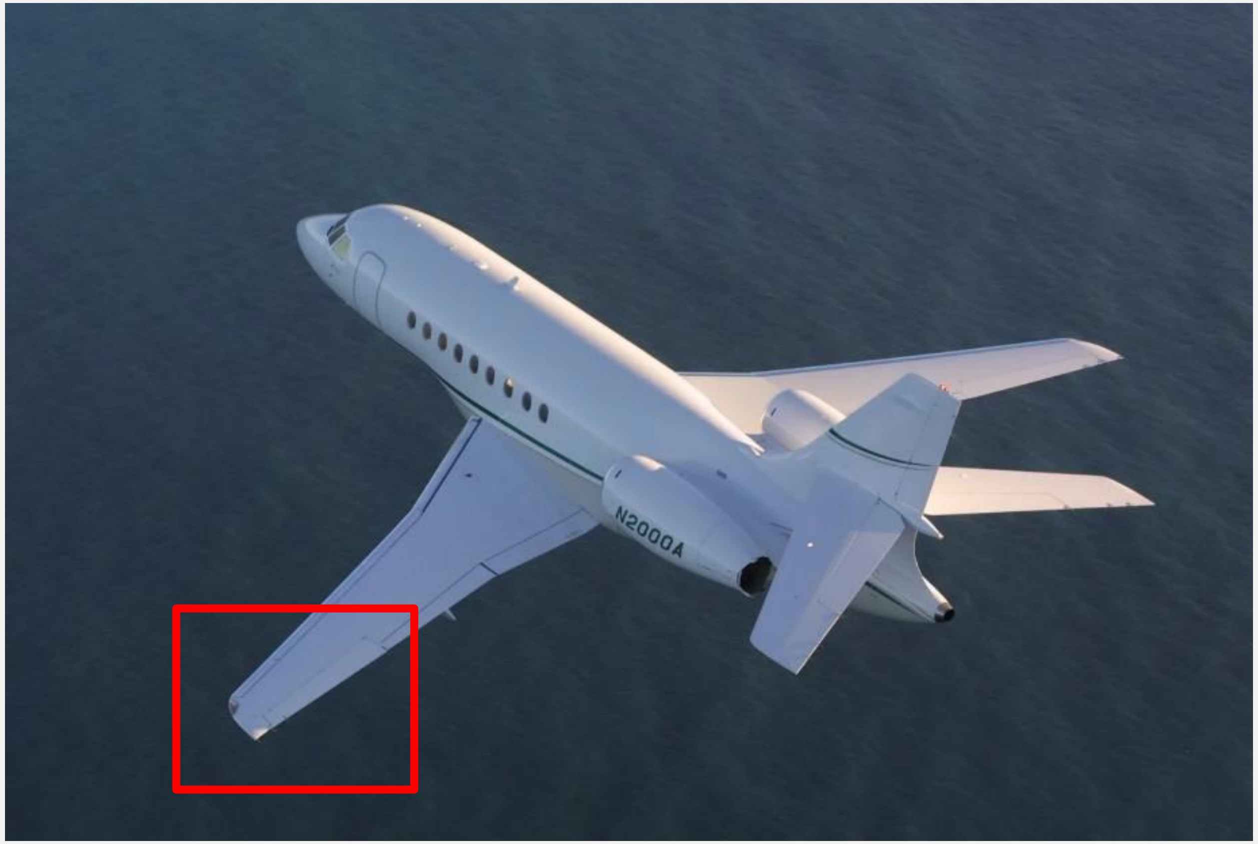






3D swept Wing simulation – Test Campaign

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



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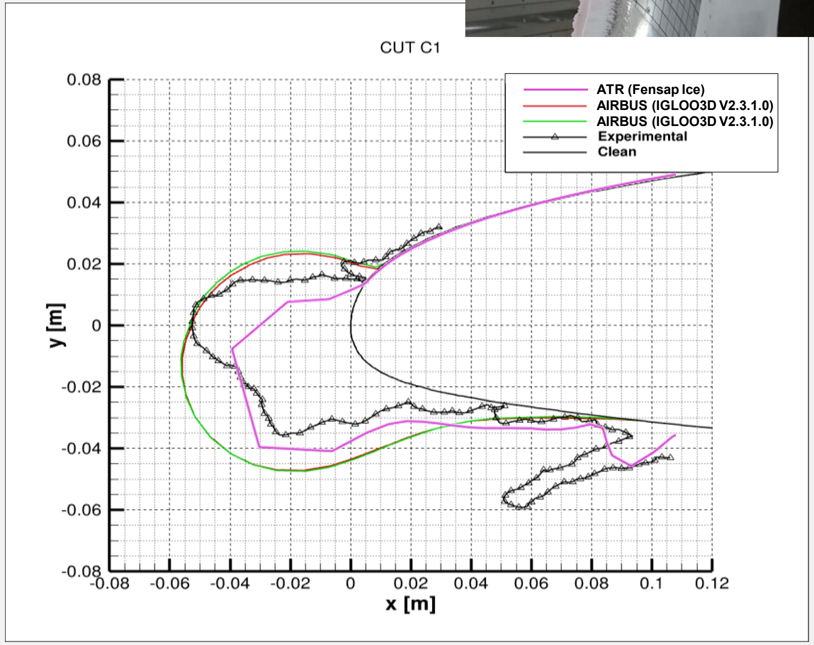
3D swept Wing simulation - Run #13

Test conditions

SAT [°C]	Altitude [m]	Airspeed [m/s]	Mach [-]	Humidity [%]	AoA [°]	δflap [°]	MVD [µm]	LWC [g/m^3]	ExposureTime [min]
-15.6	4572	115.6	0.359	91	4.5	0	18.5	0.40	45

Main observations:

- 3D simulation in App. C conditions
- 4 steps simulation for ATR, 1 step for AIRBUS.
- Ice accretion limit well estimated
- The rounded ice shape predicted by AIRBUS is due to the 1 step simulation.
- In multistep, ATR predicts a correct ice shape on the lower side up tothe second horn.
- Marginal effect of the HTC method (red = HTC Theta, green = HTC cf rough)



App O numerical capability

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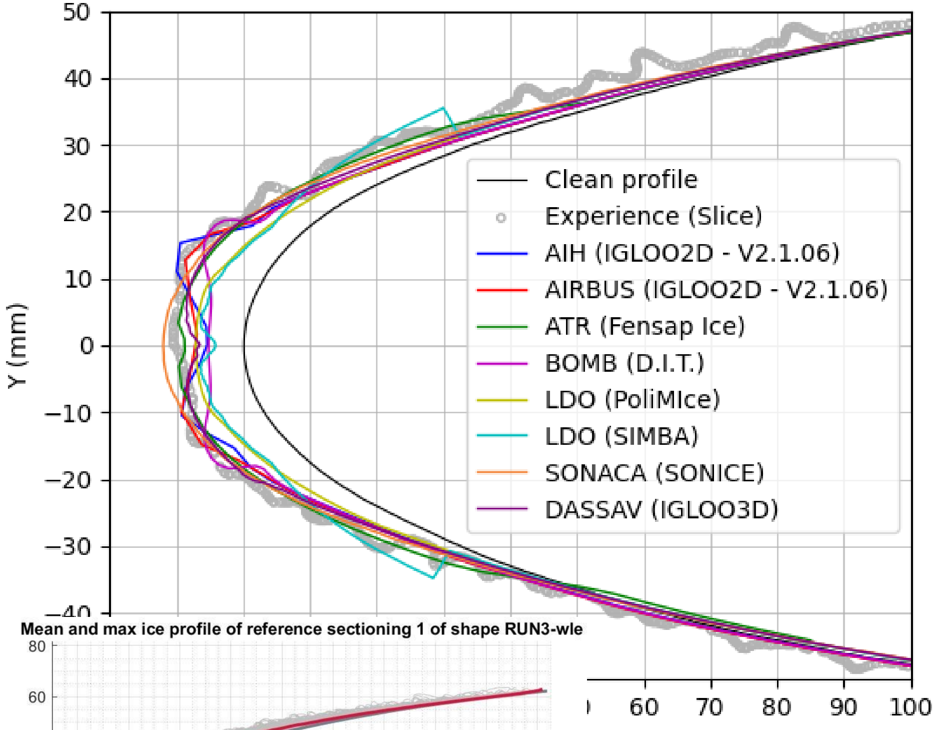
Common Cases - FZDZ

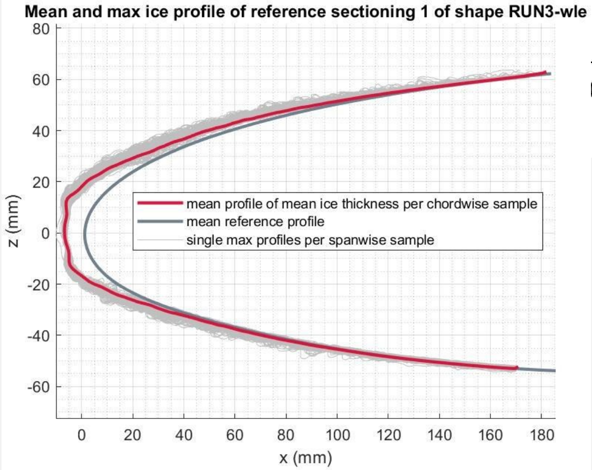
- Test conditions :

SAT [°C]	Altitude [m]	Airspeed [m/s]	Mach [-]	AoA [°]	MVD [µm]	LWC [g/m^3]	ExposureTime [min]
-11.4	0	60	0.19	0	87.9	0.48	7.5

- Test article : NACA0012 profile – chord = 1.0 m
- Main observations
  - Fair agreement on accretion limits
  - Fair agreement on ice thickness at stagnation point
  - Better agreement with SLD model activated
  - Small horns in FZDZ conditions.

- Remarks
  - SLD models (LEWICE, PHYSICE and ICE GENESIS) are equivalent.





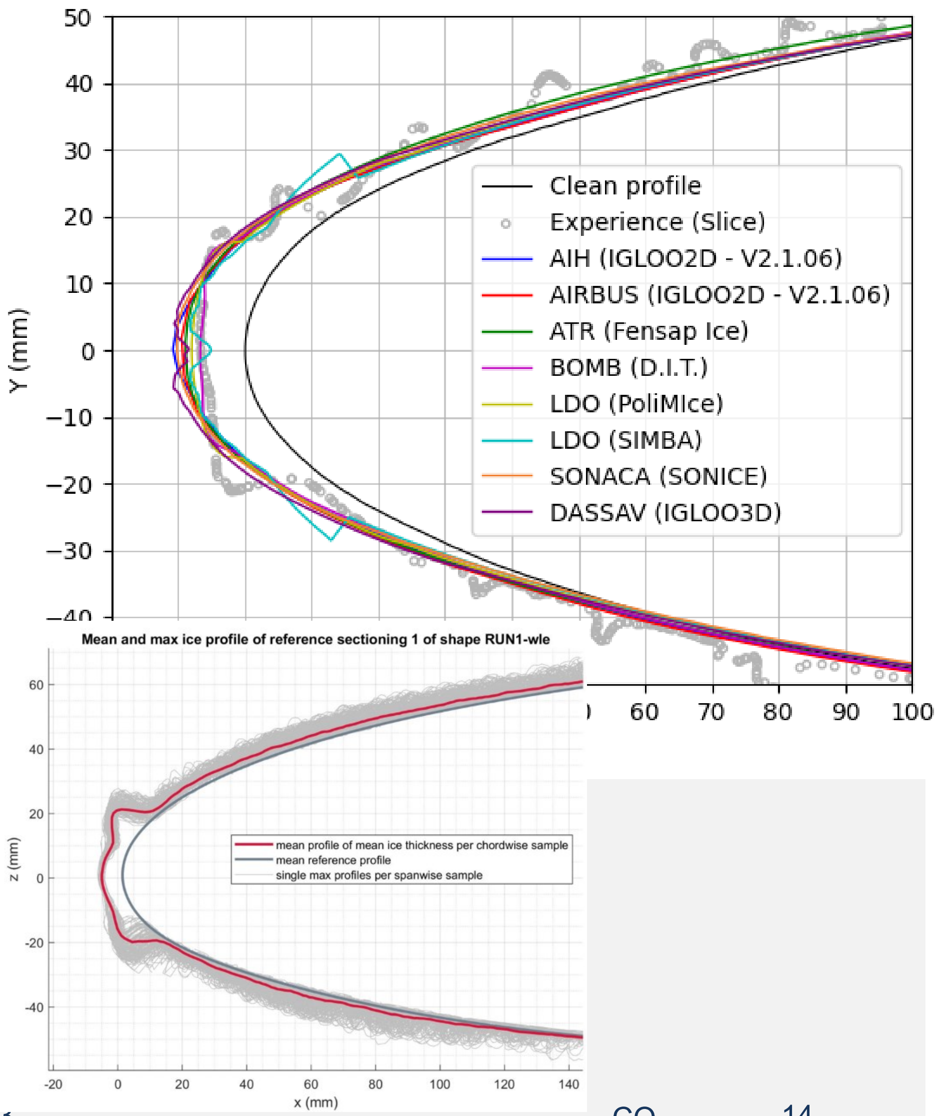
Common Cases - FZRA

- Test conditions :

SAT [°C]	Altitude [m]	Airspeed [m/s]	Mach [-]	AoA [°]	MVD [µm]	LWC [g/m^3]	ExposureTime [min]
-11.5	0	60	0.19	0	535	0.33	10

- Test article : NACA0012 profile – chord = 1.0 m
- Main Observations
  - Fair agreement on accretion limits
  - Discrepancies on ice thickness at stagnation point
  - Weak effect of SLD model (FZRA outside of SLD models range of validity)
  - Horns simulated, not in-line with experimental observations

- Remarks
  - SLD models (LEWICE, PHYSICE and ICE GENESIS) are equivalent.



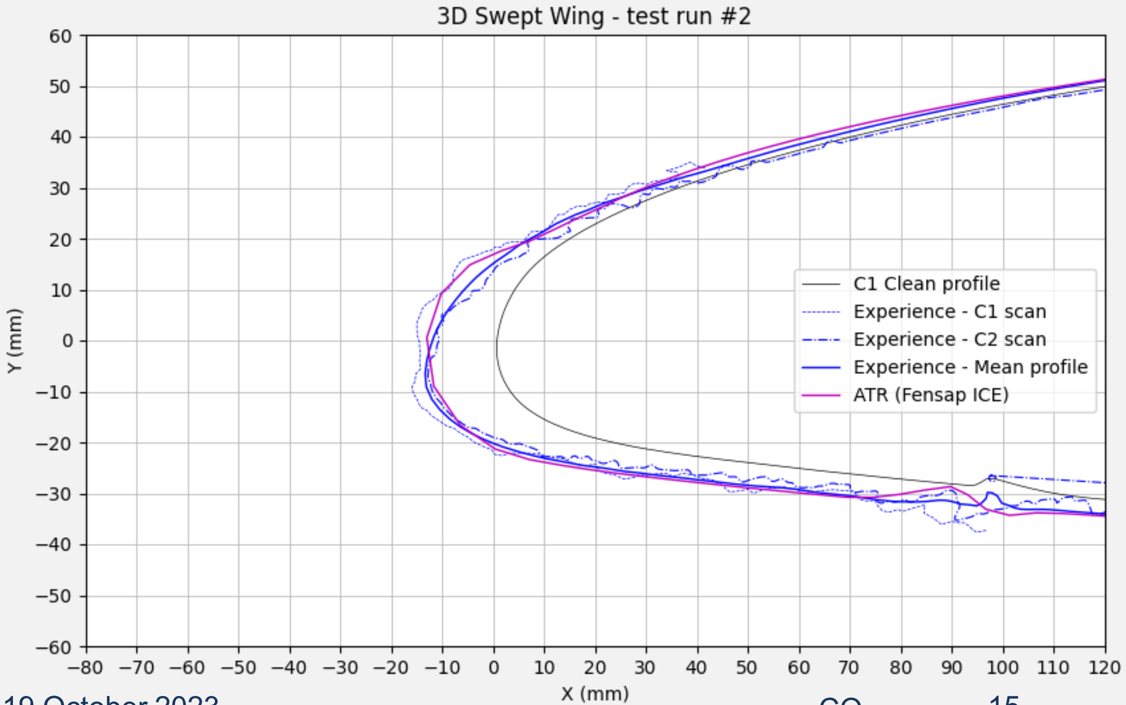
3D swept Wing simulation - Run #2

Test conditions

SAT [°C]	Altitude [m]	Airspeed [m/s]	Mach [-]	Humidity [%]	AoA [°]	δflap [°]	MVD [μm]	LWC [g/m³]	ExposureTime [min]
-16.0	4572	116.5	0.362	91	4.5	0	65	0.20	15

Main observations:

- Time exposure is short : The ice thickness is almost constant along the span.
- The SLD model is within the range of droplet diameters evaluated during the ICE GENESIS project.
- Ice shape well estimated, slightly overestimation on the upper side

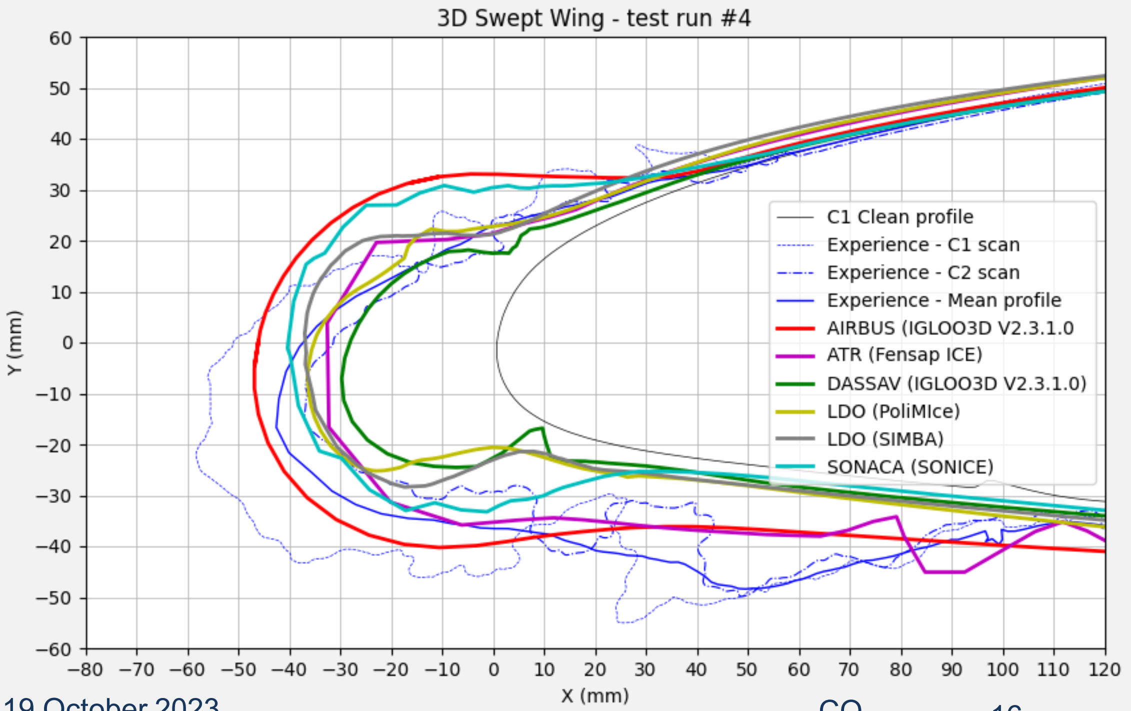


3D swept Wing simulation - Run #4

- Test conditions

SAT [°C]	Altitude [m]	Airspeed [m/s]	Mach [-]	Humidity [%]	AoA [°]	δflap [°]	MVD [µm]	LWC [g/m^3]	ExposureTime [min]
-16.2	4572	116.0	0.361	91	4.5	0	65	0.20	45

- Main observations:
  - The same case as the previous one, but exposed 3 times longer.
  - The SLD model is within the range of droplet diameters evaluated during the ICE GENESIS project
  - The overestimation on the upper side is more emphasized in all simulations (except for DASSAV).
  - Good estimation of the accretion limits.
  - No or wrong prediction of the ice bump on the lower side
  - All predicted ice shapes are rounded. It is due to the method used : 1 step or Predictor/Corrector.



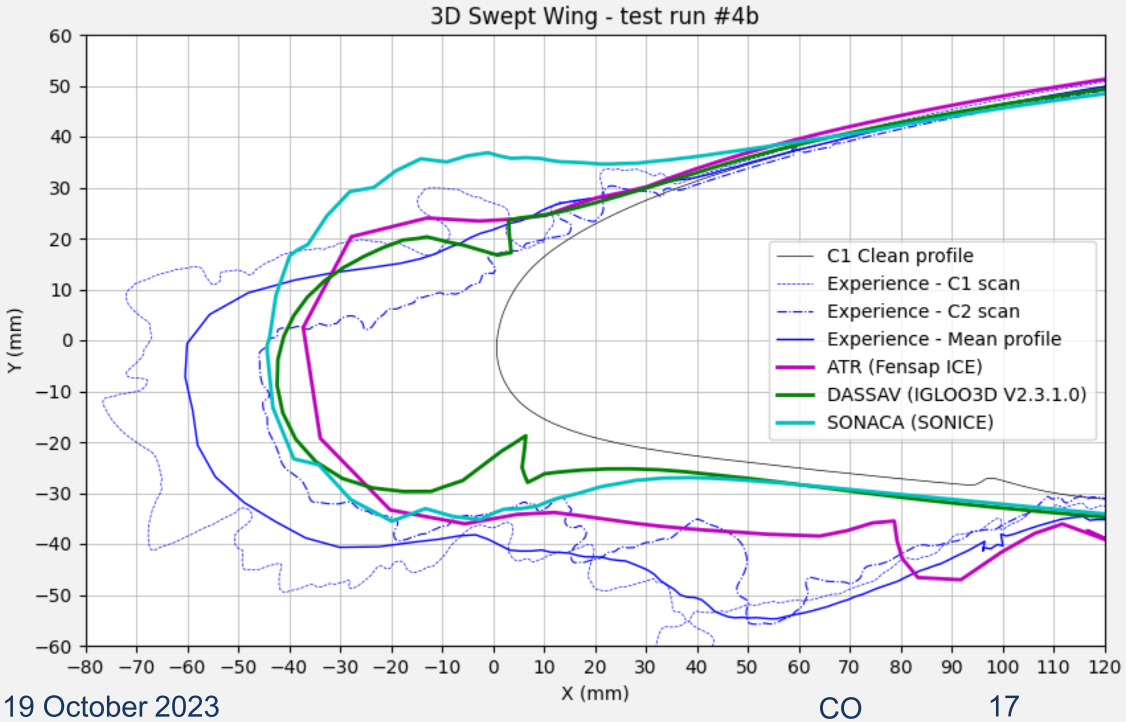
3D swept Wing simulation - Run #4b

Test conditions

SAT [°C]	Altitude [m]	Airspeed [m/s]	Mach [-]	Humidity [%]	AoA [°]	δflap [°]	MVD [µm]	LWC [g/m^3]	ExposureTime [min]
-15.2	4572	115.8	0.360	91	4.5	0	98	0.21	45

Main observations:

- The same case as the previous one, with an higher MVD (98 µm vs 65 µm). FZDZ conditions
- The SLD model is outside the range of droplet diameters evaluated during the ICE GENESIS project
- Good estimation of the accretion limits.
- The overestimation on the upper side is more emphasized in all simulations (except for DASSAV).
- All simulation underestimates the ice thickness at the leading edge and on the lower side. No or wrong prediction of the ice bump.
- All predicted ice shapes are rounded.



Synthesis of achievements & remaining gaps

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Achivement

- Validation data:
  - Lots of 2D validation tests were carried out by academic partners.
  - 3 industrial test campaigns were carried out by CIRA, CU and NRC (3D wing, Cascade rig and rotor blade). 2 are available on AIIS database. 1 test is available on rescue hoist campaign. Several analyses are done and will be continued after Ice Genesis project.
  - Accurate data available thanks to 3D scans.
  - AIIS database collects all validation data produced in Ice Genesis project (and more).

- Models Improvements in Ice Genesis:
  - 2D & 3D tools:
    - 2D validation test cases in FZDZ conditions are correctly predicted but there is still room for improvement.
  - 3D tools :
    - Now available to industrial partners, paving the way for more complex and realistic simulations.
    - Difficulties still exist : automatic remeshing process still need human interventions. Today tools still used with a conservative approach. Conservatism needs to be reduced.

Investigation beyond Ice Genesis

- SLD topics :
  - Generate more data in App O conditions, especially in FZRA conditions.
  - Investigate high velocity and altitude effects on mass deposition (splashing/bouncing/erosion)
  - Improve secondary droplet re-emission models.
  - SLD impact on wet or rough iced surfaces to be further characterized.
- Roughness topics:
  - HTC prediction is still a gap worldwide.
  - Perform more tests in different conditions and at different scales.
- Remeshing method for 3D tools :
  - Reduce human intervention in remeshing process (unsupervised computations)
  - Reduce mesh dependency and improve the robustness.
  - Complex design (full aircraft, small scale, rotating components…)
  - Better handling of ice shape and geometry interaction.