ICE GENESIS
Project Overview

ICE GENESIS

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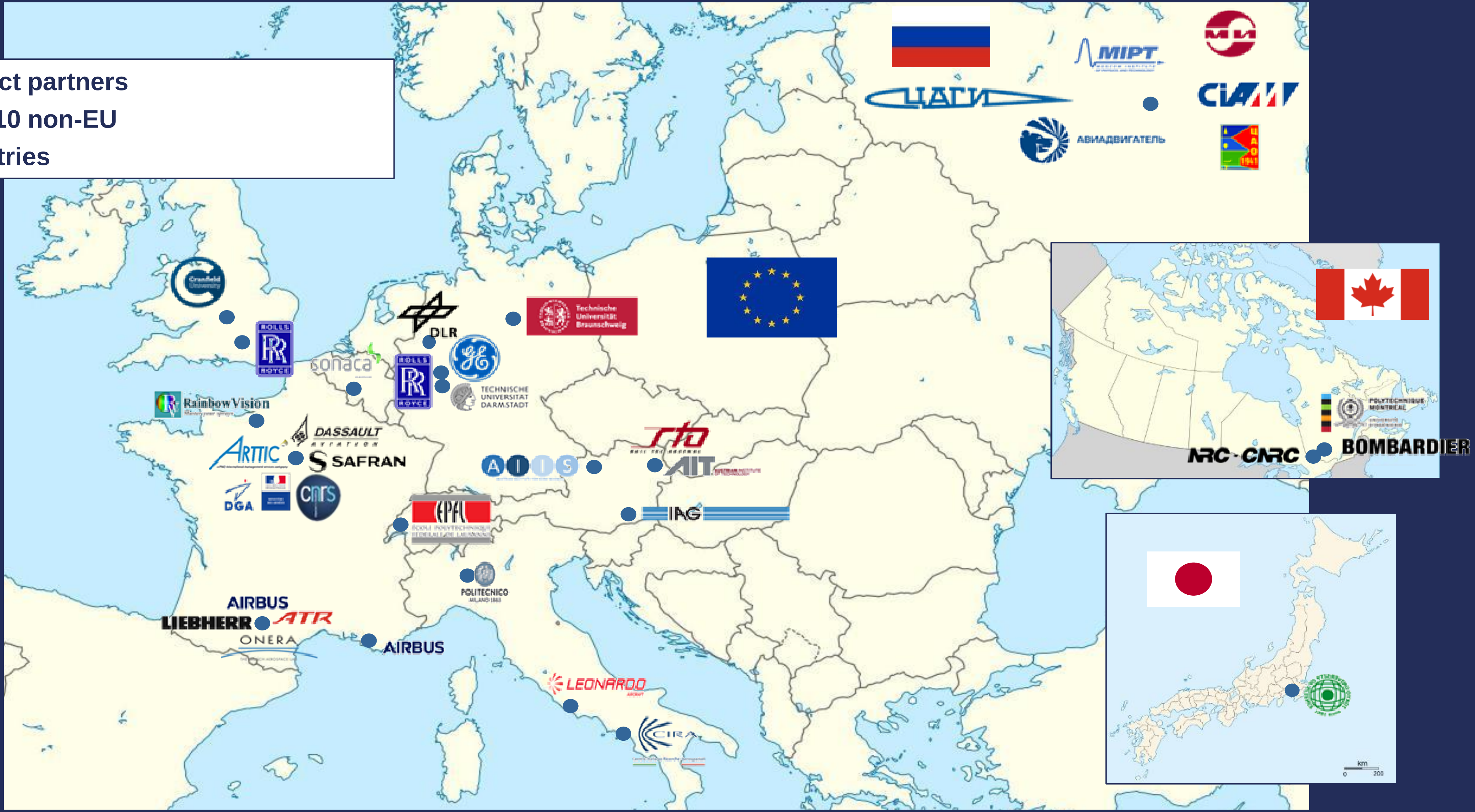
The Consortium

- 37 project partners
- 27 EU / 10 non-EU
- 10 countries



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ICE GENESIS project overview

Creating the next generation of 3D simulation means for icing

- **Duration:** From 1st January 2019 until 31st December 2022
- **Coordinator:** AIRBUS OPERATION SAS

- **Budget:**
  - Max EU Contribution: €11 964 300
  - Total Estimated Project costs: €21 984 549
  - Project effort in Person-months ~ 1858

- **Advisory board:** EASA, FAA, ADSE, AEROTEX,
  AIRBUS Defense&Space, CSTB, DAHER, EMBRAER,PIAGGIO, SAFRAN nacelles

ICE GENESIS project overview

Top level objective

The top level objective of the ICE GENESIS project is to provide the European aeronautical industry with a validated new generation of:

3D icing engineering tools
(numerical simulation and Icing Wind Tunnels capabilities)

addressing

Regulation CS25 Appendix C (well-known icing envionment)

Appendix O (SLD or Supercooled Large Droplet)

and snow conditions,

for safe, efficient and cost effective design and certification of future aircraft and rotorcraft.

Novelties in Europe : 3D ice scanning system
droplet temperature measurement
snow characterization and campaigns

ICE GENESIS project overview

Sub-objectives

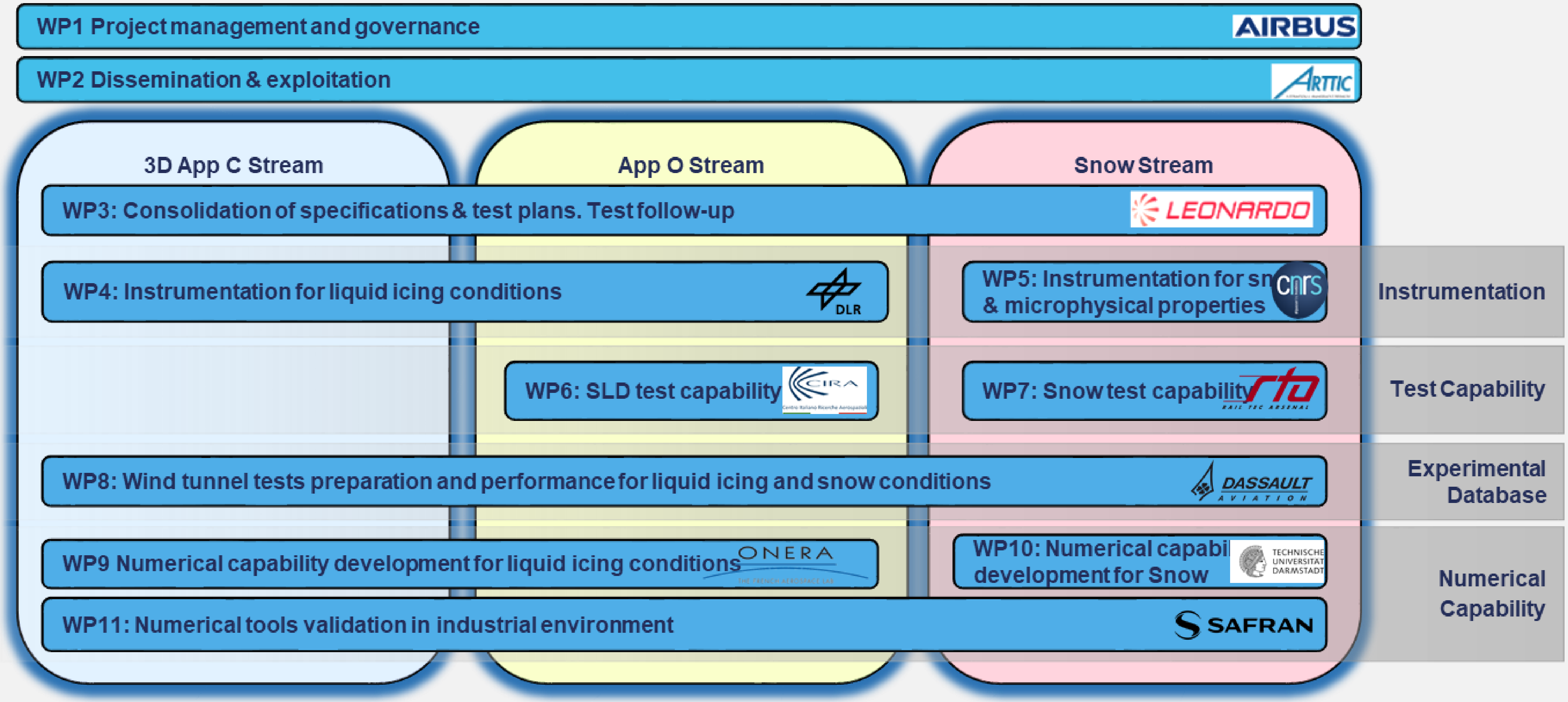
Obj#1: Improve and validate existing **3D numerical tools** to predict ice accretion in Appendix C, Appendix O and Snow conditions.

Obj#2: Upgrade and calibrate **icing wind tunnels** to allow reproduction of:

- **Supercooled Large Droplets (SLD) in FZDZ (Freezing drizzle) conditions**.
- **Snow conditions**
- Additionally, to **assess the potential of current icing wind tunnels to represent SLD in FZRA (Freezing rain) conditions**.

Obj#3: Build a **large scale experimental database** on representative 3D configurations to be used as a solid reference (“ground truth”) for future numerical tools validation.

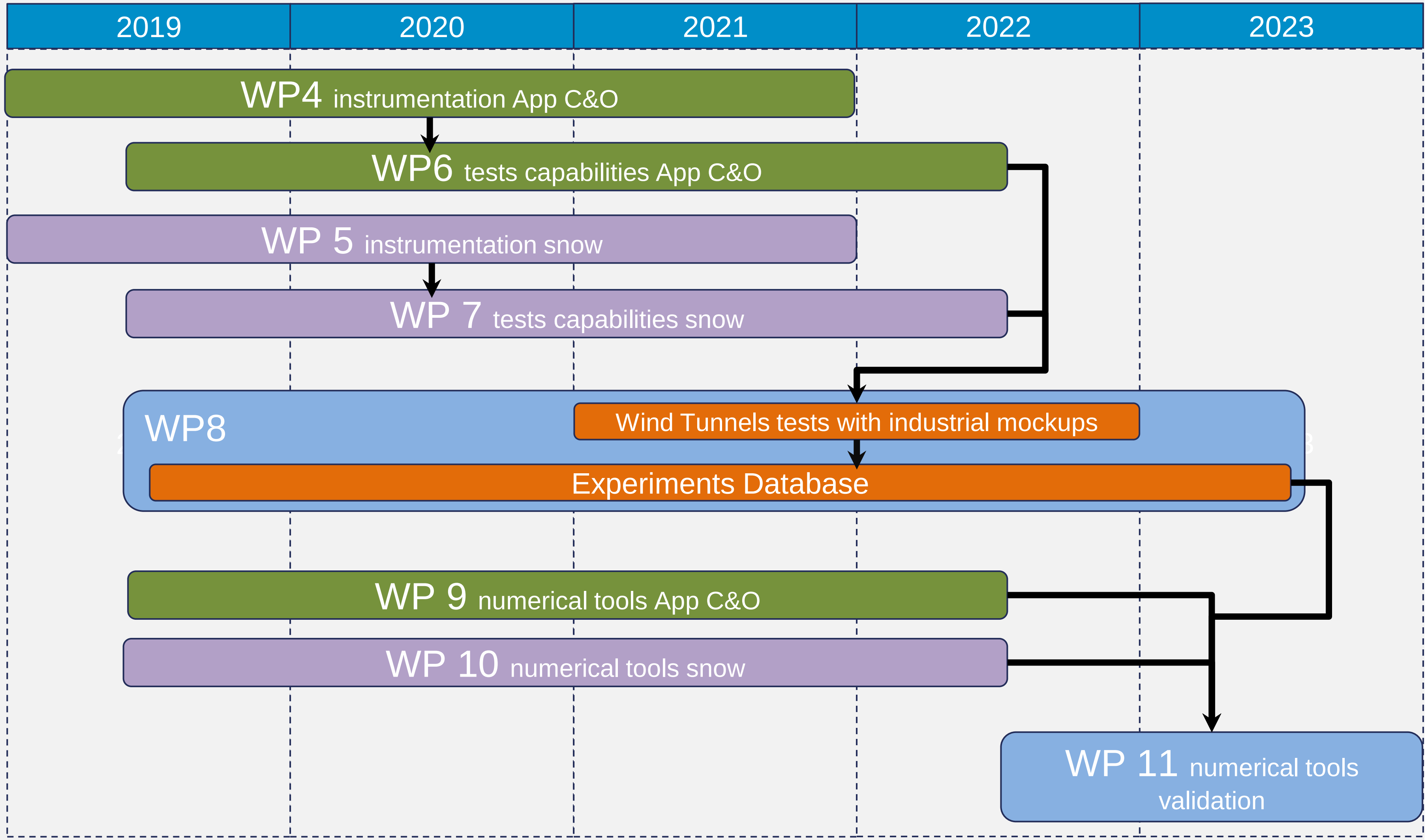
ICE GENESIS Organisation



WP DEPENDENCIES

- Perform wind tunnel tests in liquid icing and snow conditions, in industrial environment (IWT and mockups)

- Provide searchable database of experimental results for validation of numerical tools



Snow numerical tools

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.

Objectives

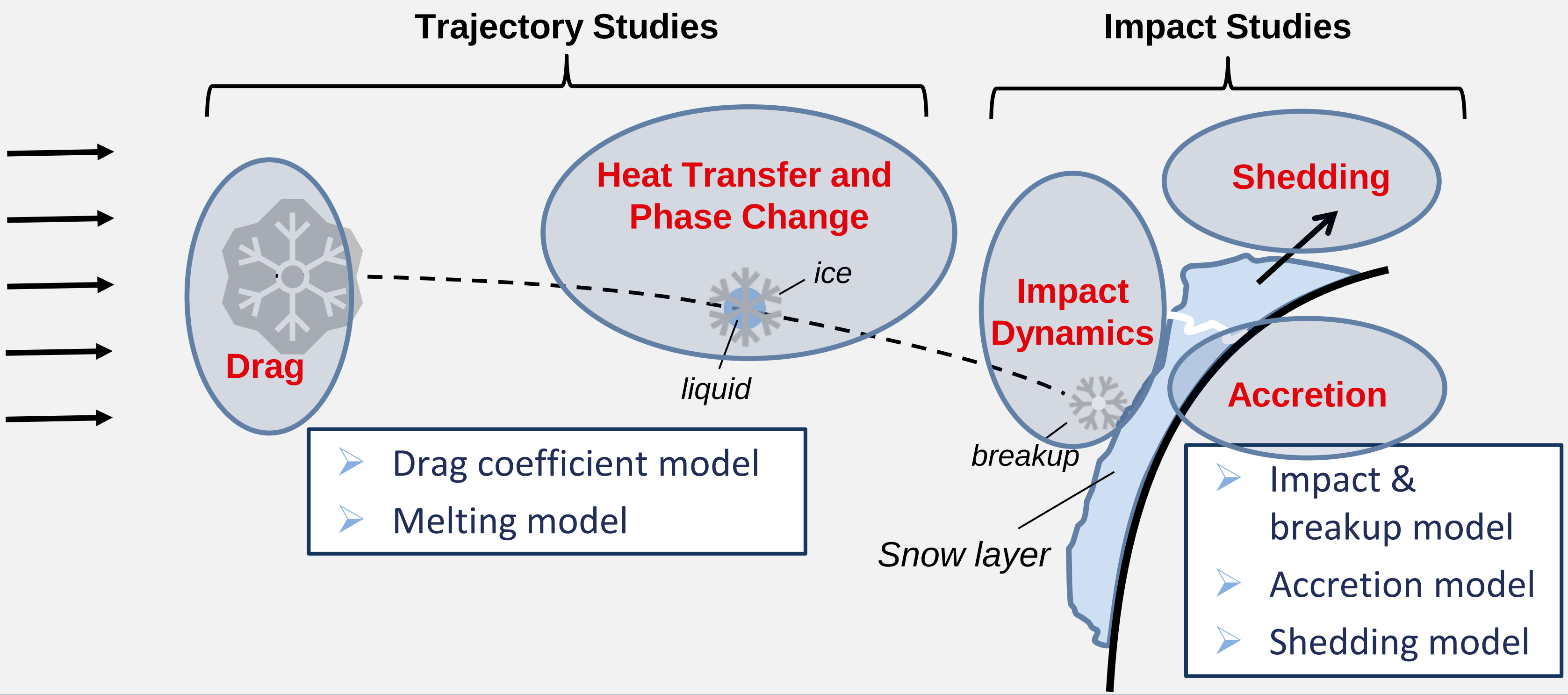
WP 10: Numerical capability development for snow
Objectives: Improve and validate current 2D and 3D numerical tools with respect to snow conditions, so that they can be used for both design and certification of aircraft, rotorcraft and engines.

- Task 10.1 Advanced **experimental investigations** to complement available data (**TUDA,** AIT, NRC, AIH, TSAGI)
- Task 10.2 **Model development**, elementary **validation** and **down-selection** (**ONERA,** AIH, TUDA, POLIMI, TSAGI, MIPT)
- Task 10.3 **Model integration** into 3D tool and preliminary capability assessment (**ONERA,** AIT, POLIMI, MIPT)

Helicopter manufacturers need to demonstrate safe operations in falling and blowing snow conditions

Introduction

WP10: Physical phenomena related to snow conditions



Challenge: Models exist for drops and ice particles, but mechanics, dynamics and thermodynamics of snowflakes are much poorly documented

Content

- **Experiments and models will be presented for the following phenomena:**
  - Drag and trajectory computations of snowflakes
  - Melting of snowflakes in hot air streams, e.g., engine intakes
  - Impact and fragmentation of snowflakes on dry surfaces
  - Accretion of snowflakes on surfaces

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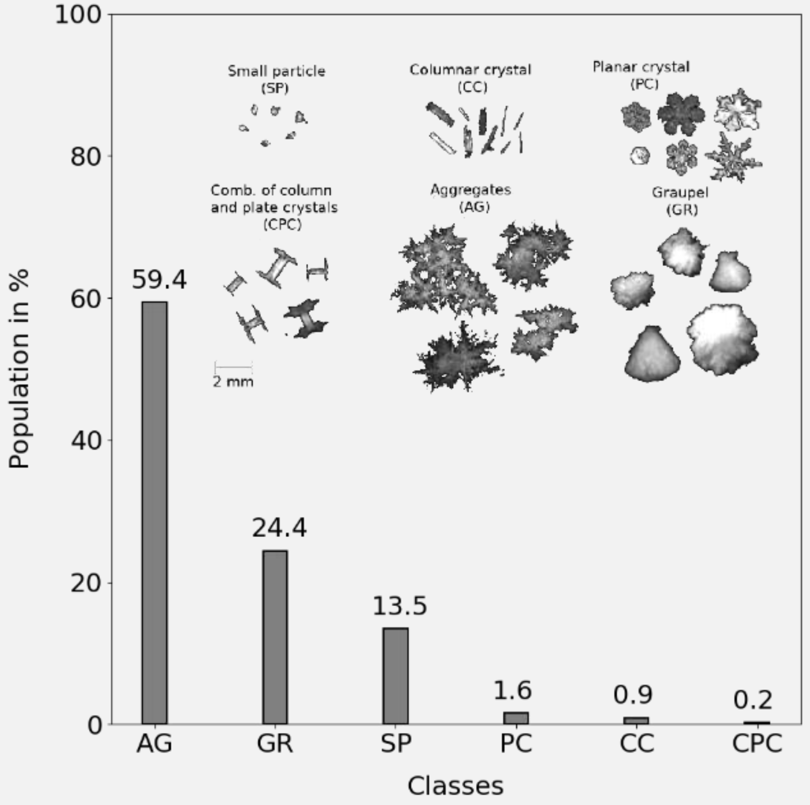
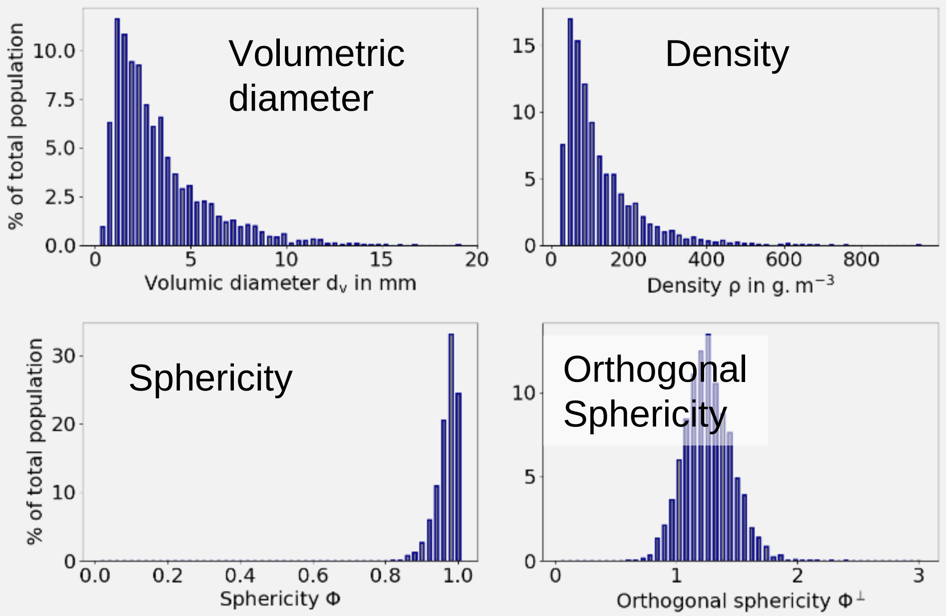
Characterising snowflakes

Estimating geometric parameters necessary for use in existing drag models



Example parameters required, depending on model



From HAIC:
C_D required for Re<1000 and 1<St<100

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PU

Drag and trajectory of snowflakes

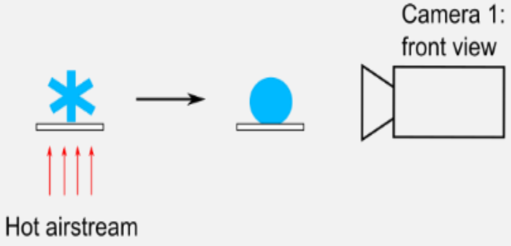
Several experiments have been performed and two models are being pursued.

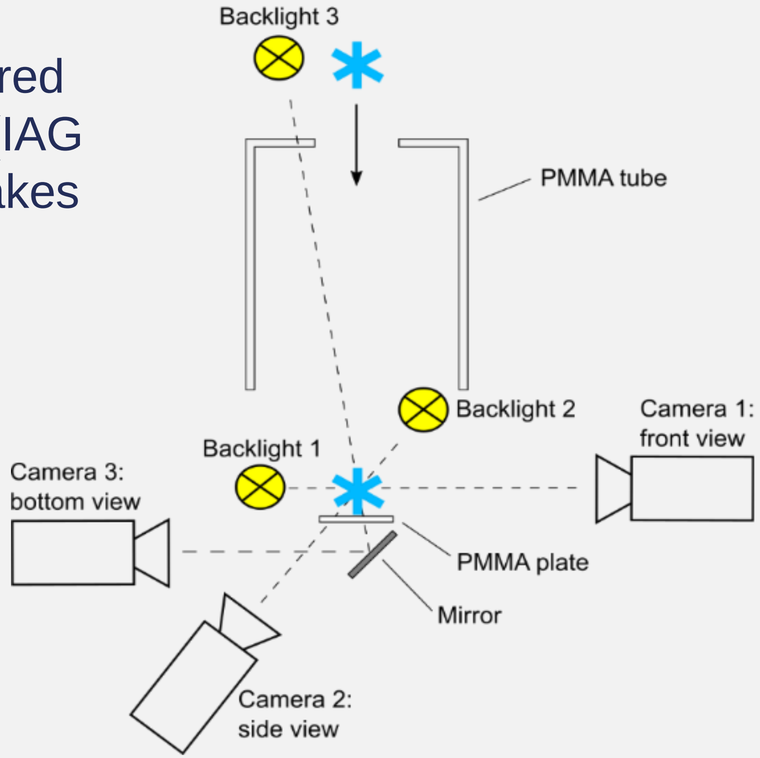
Experiment 1: free falling snowflakes

$$F = C_D A \frac{1}{2} \rho U^2 = mg$$

- Terminal velocity is measured using artificial snowflakes (IAG SnowFall) and real snowflakes
- Mass of snowflake is subsequently measured

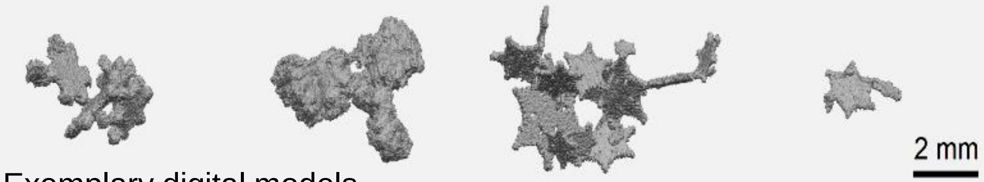
Snowflake melting and mass measurement





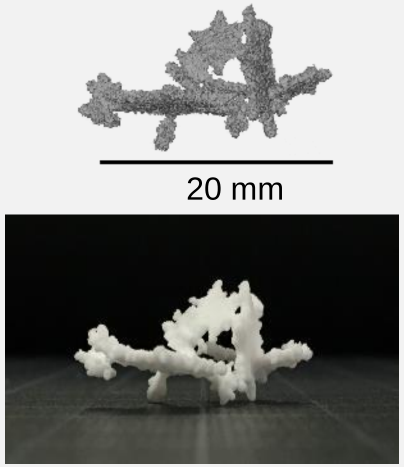
Drag and trajectory of snowflakes

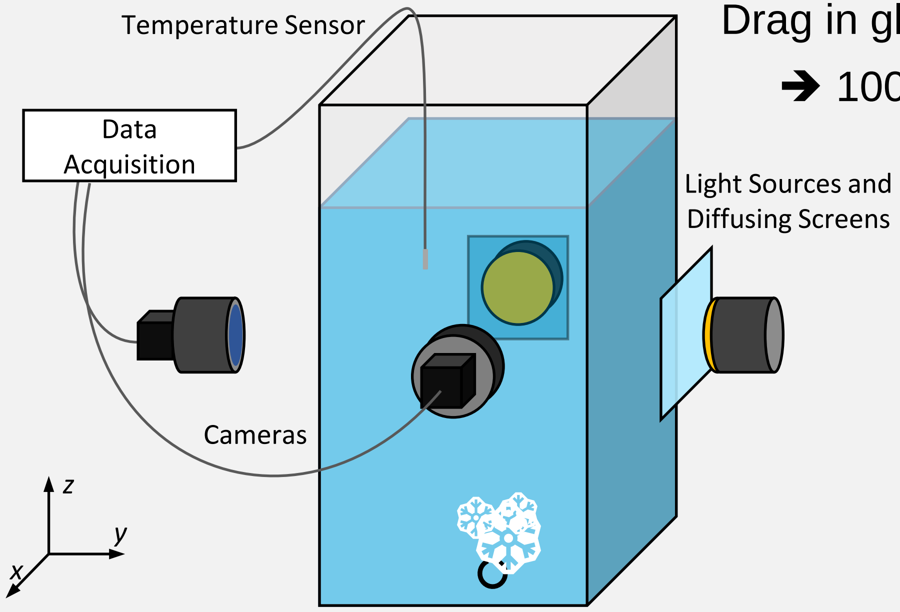
Experiment 2: Terminal velocity of 3D-printed snowflakes



Exemplary digital models

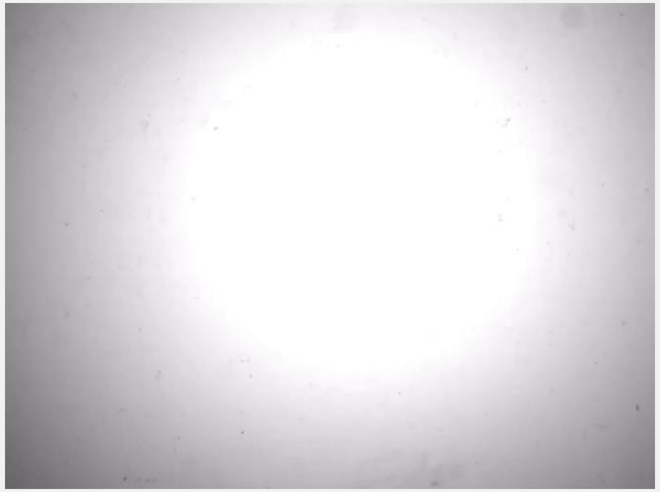
3 – 30 monomers





Drag in glycerol–water mixture

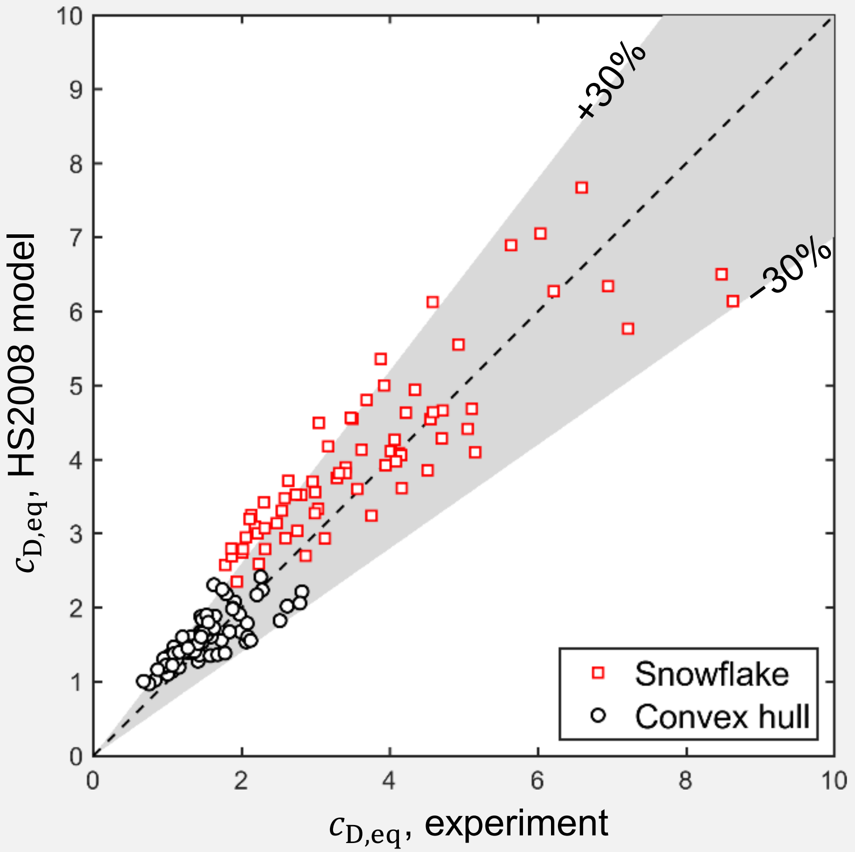
➔ $100 < Re_{D_{max}} < 1000$

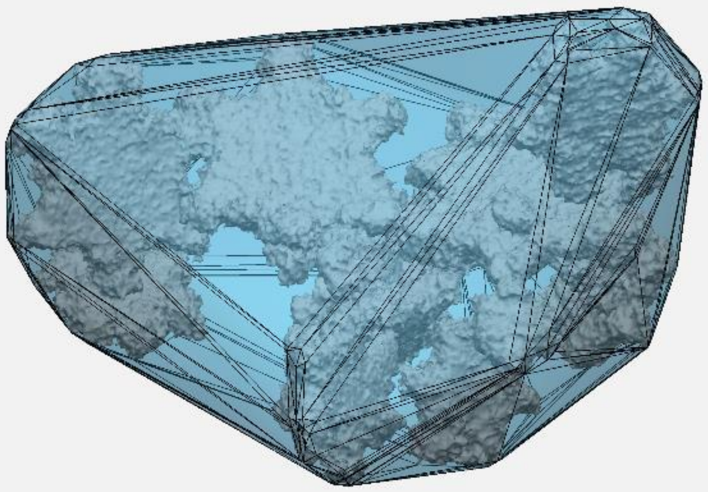


Drag and trajectory of snowflakes

- **Modification of existing drag models for non-spherical particles, using geometric snowflake descriptors, e.g.:**
  - Hölzer and Sommerfeld (H&S) (2008)
  - Heymsfield and Westbrook (H&W) (2010)

Drag and trajectory of snowflakes



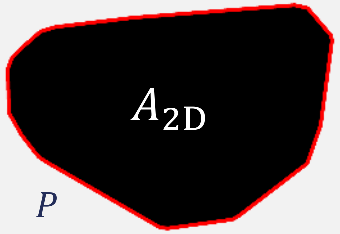


Approach: Simplifying the shape by using convex hull instead of real snowflake shape

Convex hull model: Simplified shape & better prediction

Drag and trajectory of snowflakes

Approach 1: Adapt 3D Hölzer & Sommerfeld drag model for 2D parameters



$$D_{2D} = \sqrt{\frac{4A_{2D}}{\pi}}$$

$$\Phi_{2D} = \frac{\pi D_{eq,2D}}{P}$$

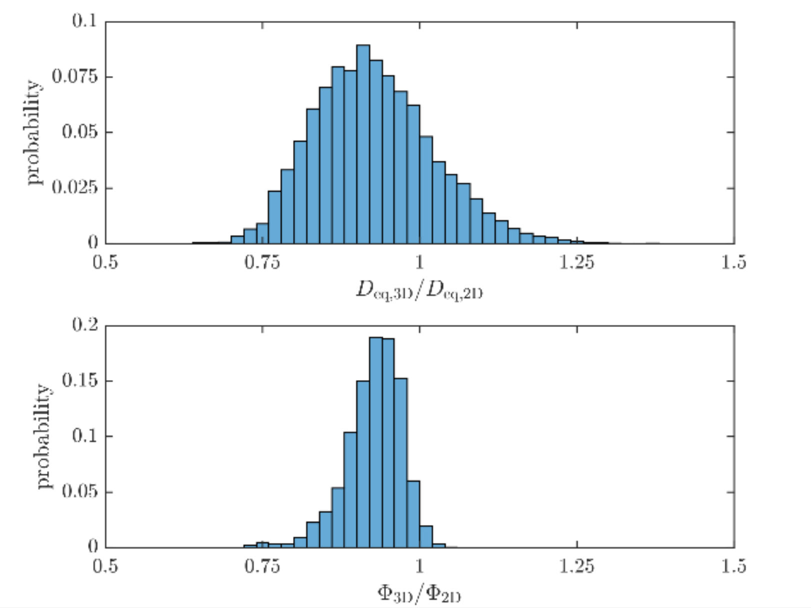
$$\Phi_{2D} = \frac{\pi D_{eq,2D}}{P}$$

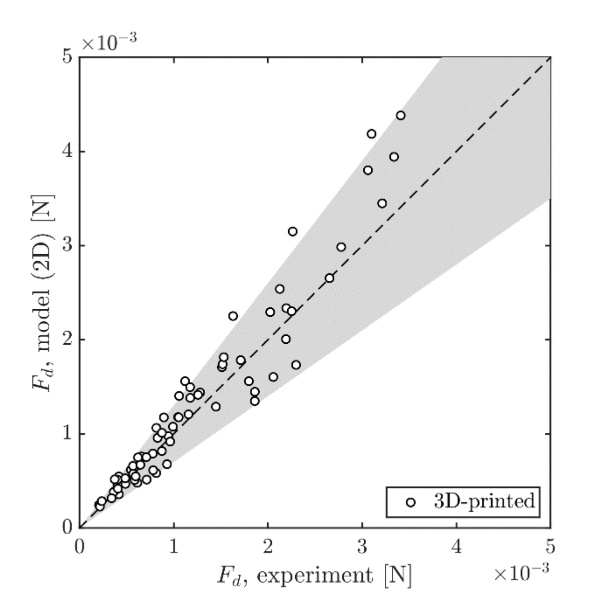
$$\Phi_{\perp} = 1$$

$$Re_{2D} = \frac{D_{2D} U}{\nu}$$

Hölzer & Sommerfeld drag model

$$F_D = \frac{\rho}{2} U^2 A_{2D} \boldsymbol{C_D}$$



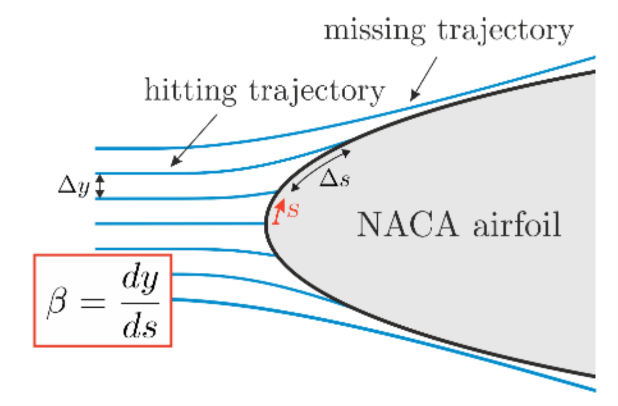


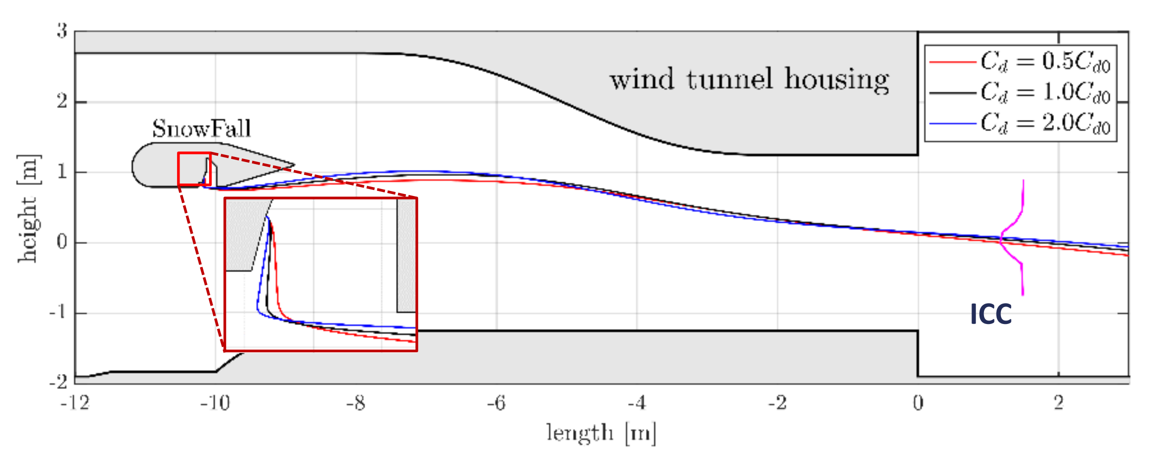
Drag and trajectory of snowflakes

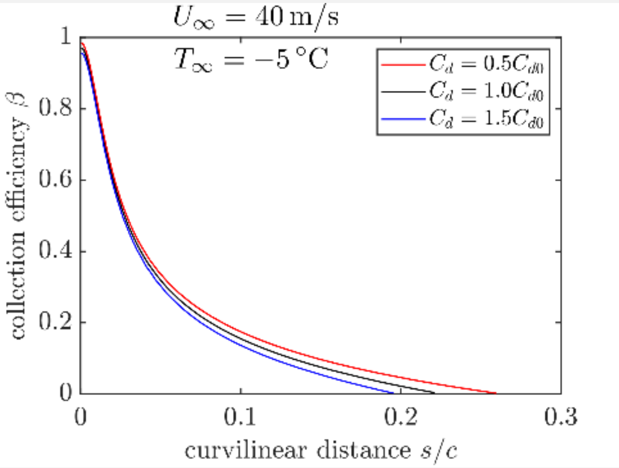
Approach 1: Results

Sensitivity study of drag coefficient (Stokes Number!)

- Trajectory simulations using adapted H & S model in RTA Climatic W/T and around a NACA0012 airfoil (collection efficiency)
- Parametric study of the drag coefficient influence on the W/T trajectory and the collection efficiency β







Drag and trajectory of snowflakes

Approach 2: Assuming a snowflake as an oblate or prolate spheroid

RAW - Image

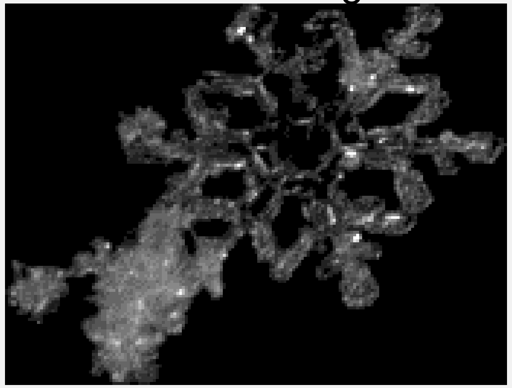
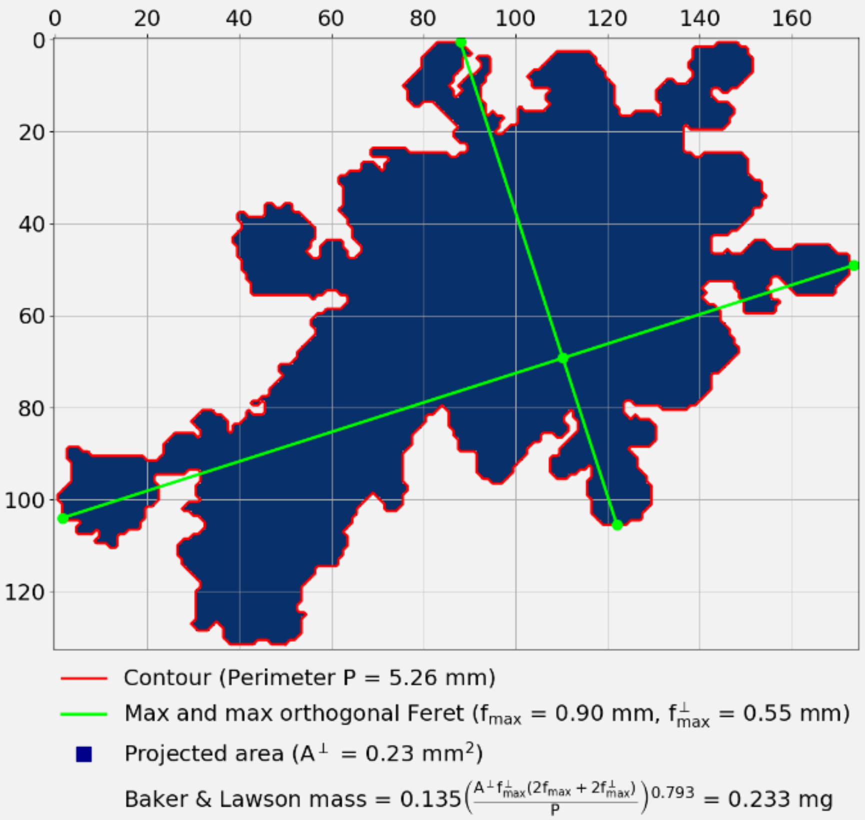
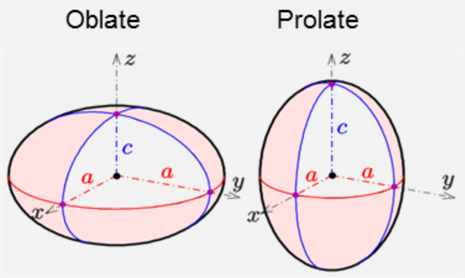


Image processing



Calculation of shape and 3D-descriptors

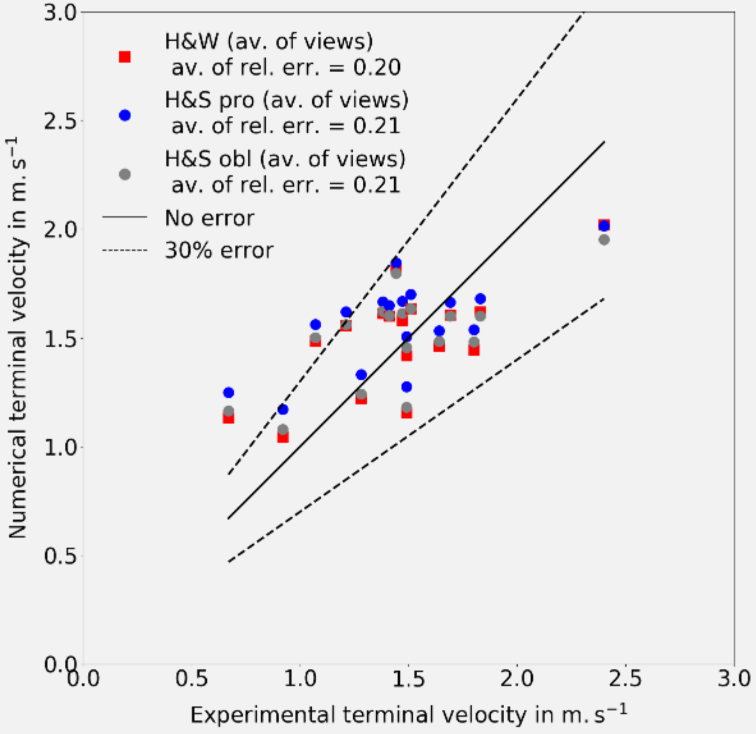


$$\phi = \frac{\pi d_V^2}{A_{spheroid}} \qquad \phi^{\perp} = \frac{(\pi/4)\, d_{eq}^2}{A^{\perp}}$$

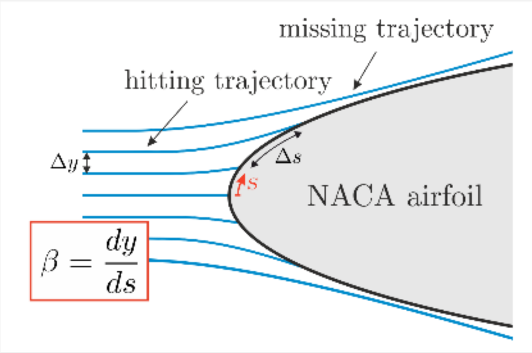
Drag and trajectory of snowflakes

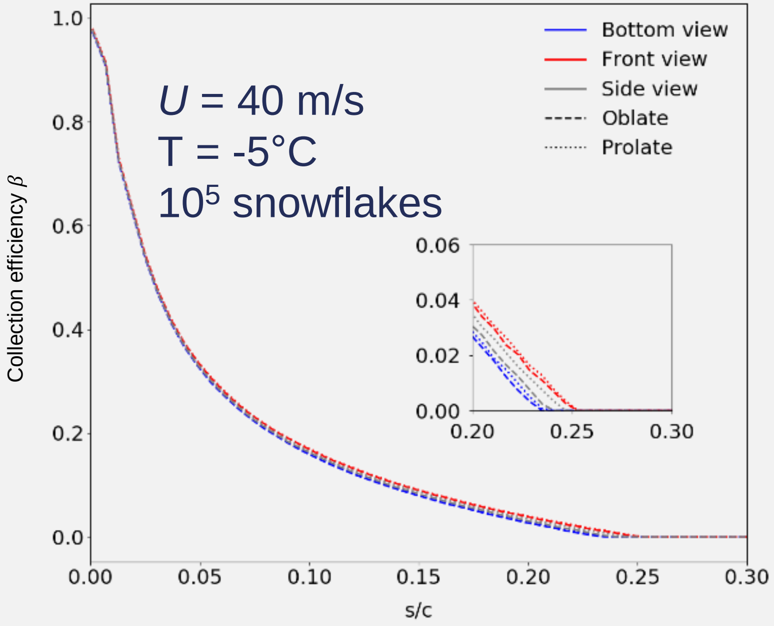
Approach 2: Results

Terminal velocity



Collection efficiency





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Melting of snowflakes

- Snowflakes melt in engine intake, influencing state upon impact and impact outcome
- Icing severity is strongly affected by liquid water content

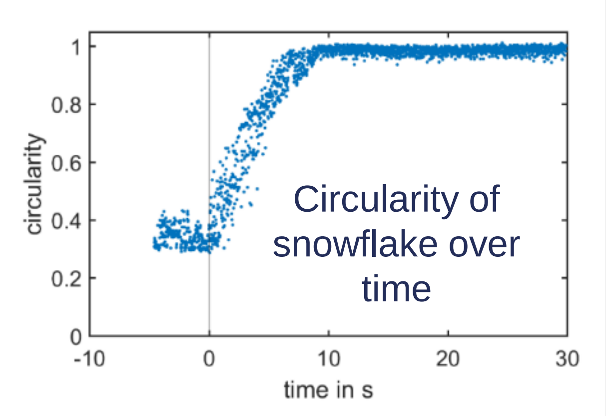
- **Difficulty:** Liquid water content of a snowflake cannot be measured
- **Solution:** Melt time is measured and compared with models.
  Verified models can then be used for prediction.

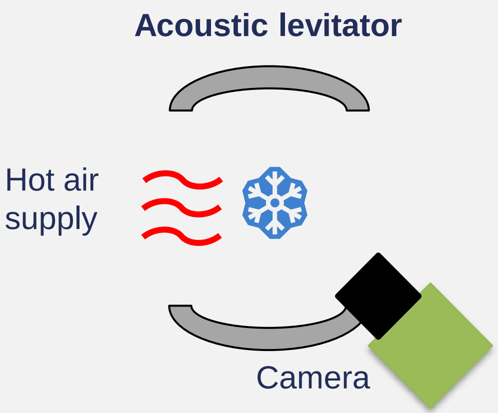
Experiments → Melt time → Models ✓

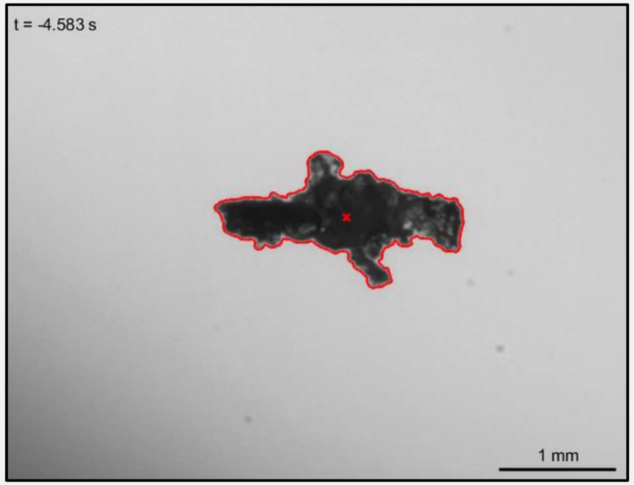
Melting of snowflakes

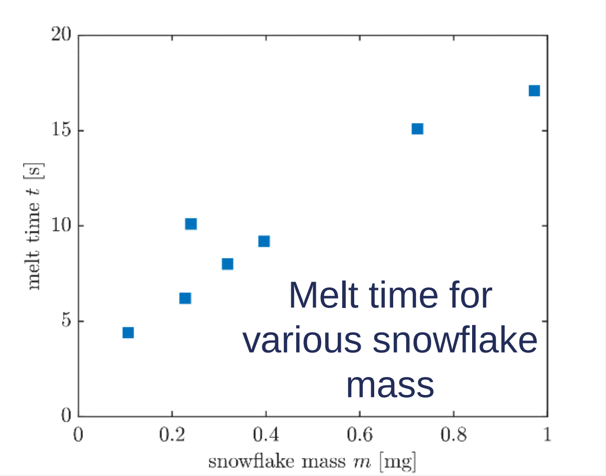
Experimental setup: Melting of snowflakes

- Snowflakes observed in acoustic levitator
- Hot air stream melts snowflake
- Melt time is extracted from captured video









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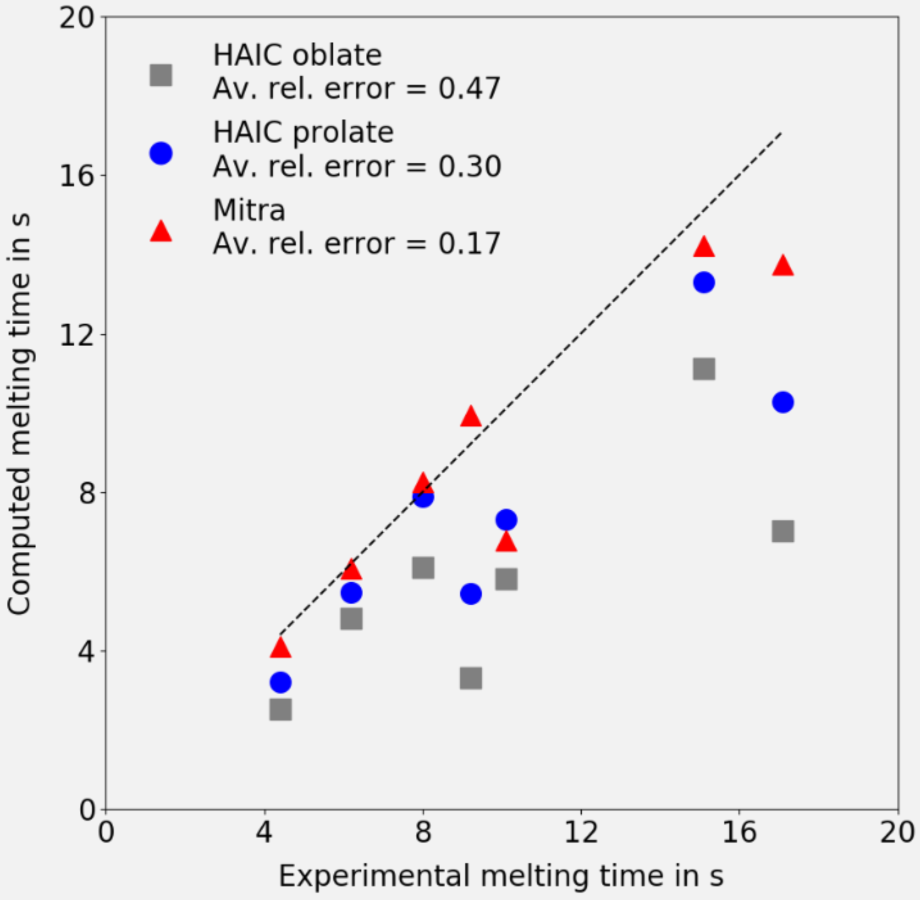
Melting of snowflakes

Comparison measured and computed melt times



HAIC melting model:

$$L_f \frac{dm_i}{dt} = -\pi d \frac{Nu}{\phi} k_a (T_a - T_f) + L_v \frac{dm_w}{dt}$$

$$Nu = 2\sqrt{\phi} + 0.55 Pr^{1/3} Re_p^{1/2} \phi^{1/4}$$

Mitra melting model:

$$(Le = 1)$$

$$L_f \frac{dm_i}{dt} = -\, 4pi\ \bar{f}_h C k_a (T_a - T_f) + L_v \frac{dm_w}{dt}$$

$$\bar{f}_v = \begin{cases} 1 + 0.14 (Sc^{1/3} Re_p^{1/2})^2 & \text{si} \quad Sc^{1/3} Re_p^{1/2} \leq 1 \\ 0.86 + 0.28 Sc^{1/3} Re_p^{1/2} & \text{si} \quad Sc^{1/3} Re_p^{1/2} > 1 \end{cases}$$

Result: Comparison for 7 snowflakes

- Models are similar with minor differences in Nu and $\overline{f_v}$
- Mitra model describes physics best

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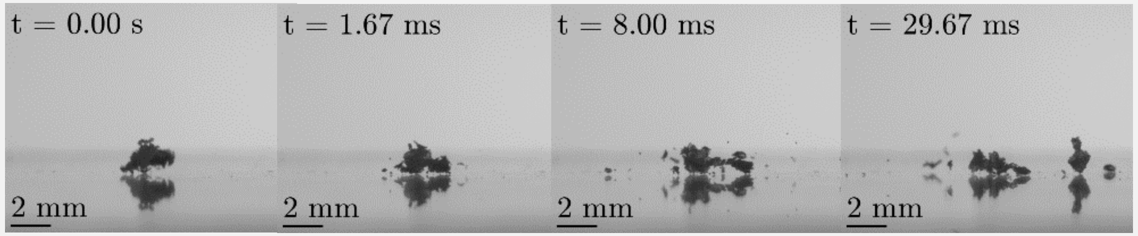
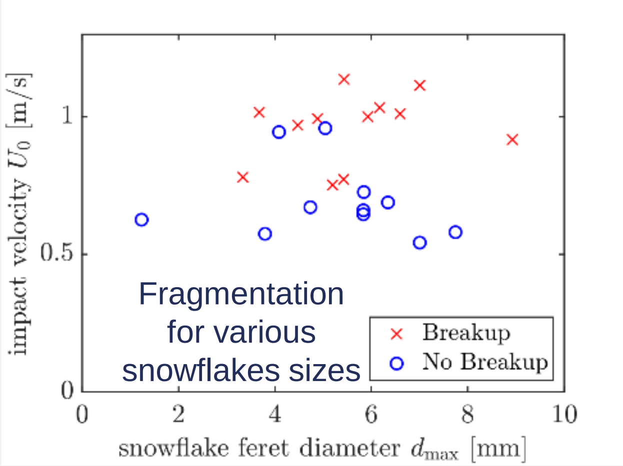
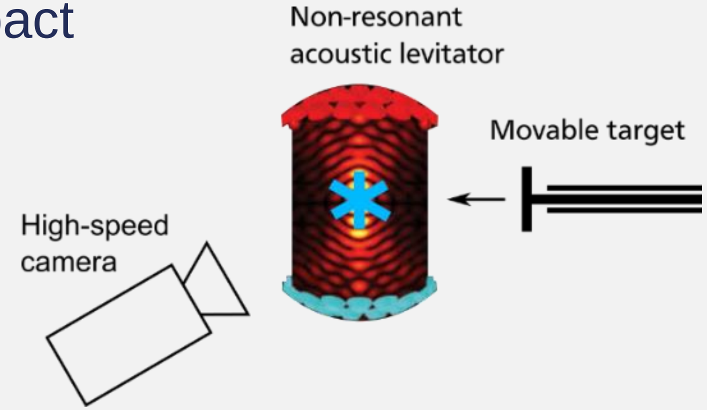
Impact and fragmentation of snowflakes

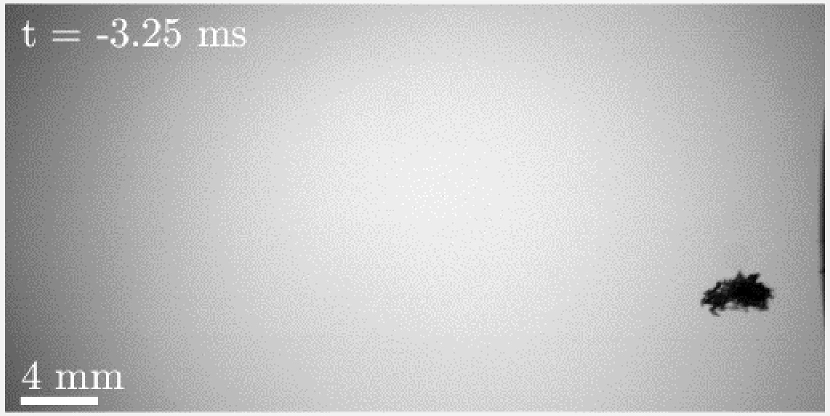
Observations: snowflakes can fragment already at terminal velocity ($U_0 \sim 0.7\ \mathrm{m/s}$)





Experimental setup to investigate snowflake impact





U_{impact} < 30 m/s

- Investigation of fragmentation threshold
- Determination of fragment sizes and velocities

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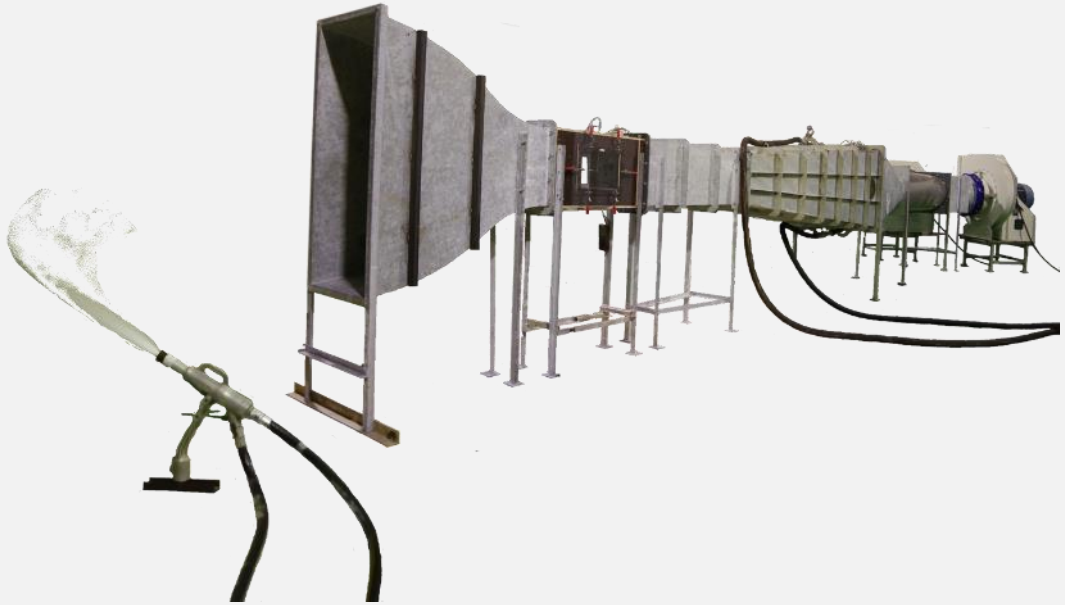
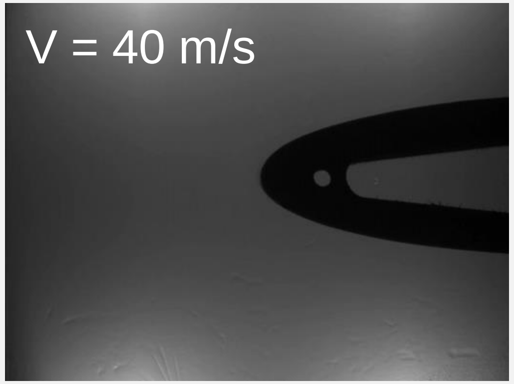
Accretion of snowflakes on surfaces

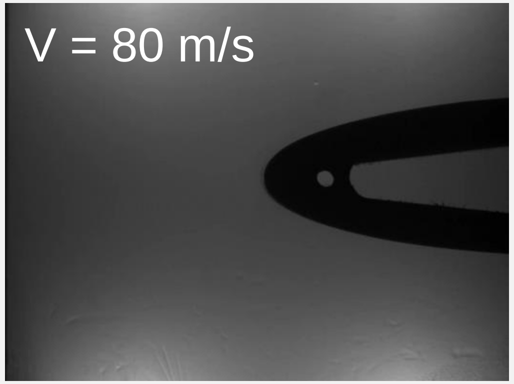
- High speed test bench (80m/s)

- Specific instrumentation to characterize snow cloud
  - AIRBUS Nephelometer, MALVERN (laser diffraction)
  - SEA WCM-2000 probe

- Test Matrix
  - 4 OAT: -1 ; -3 ; -5 ; -7°C
  - 2 TAS: 40 ; 80 m/s



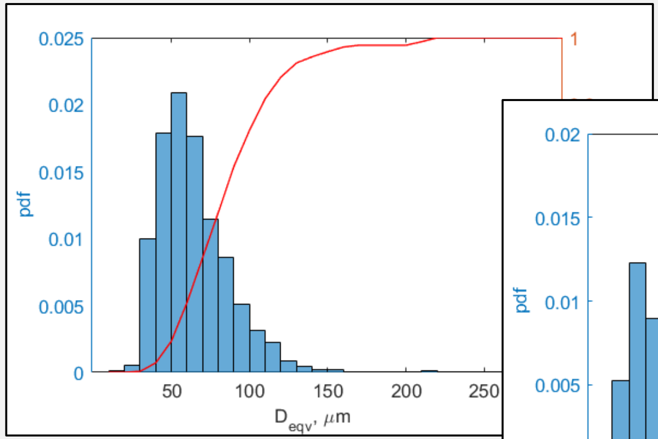




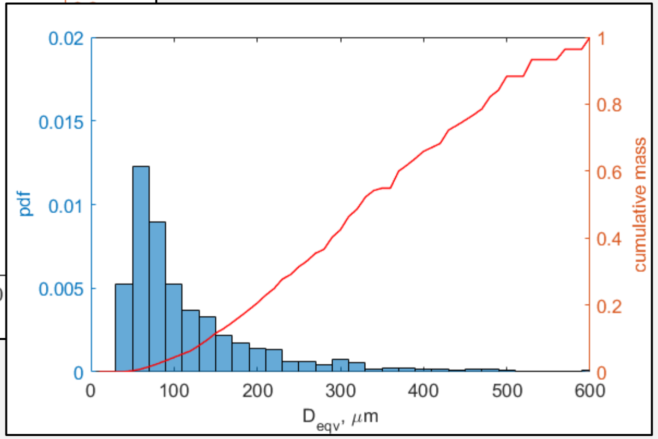
Accretion of snowflakes on surfaces

After calibration of TsAGI EU-1 wind tunnel accretion tests onto a NACA airfoil are performed for artificial ice crystals and natural snow conditions for different flow and icing conditions.

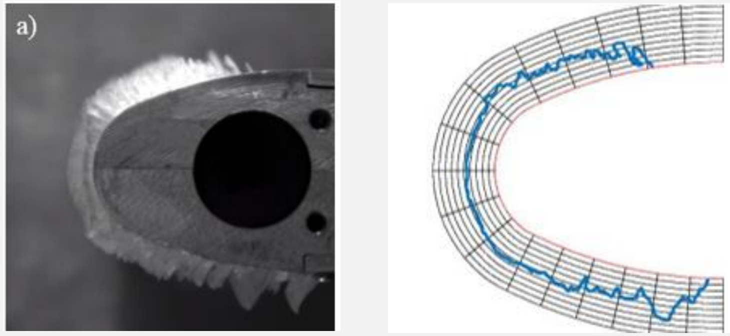
Artificial ice crystal



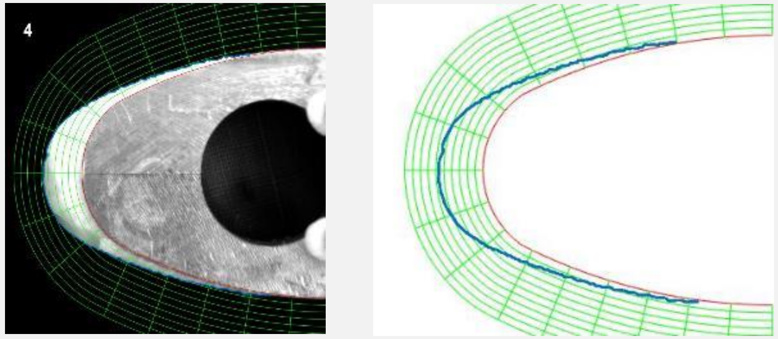
Natural snow



Accretion in artificial crystal conditions



Accretion in natural snow conditions



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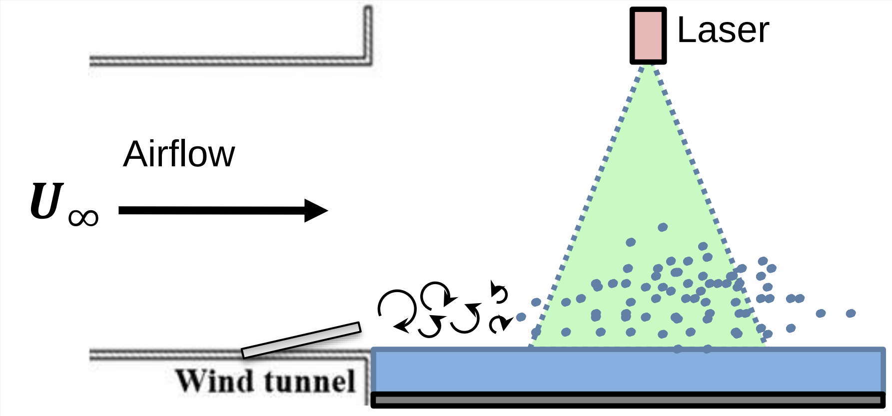
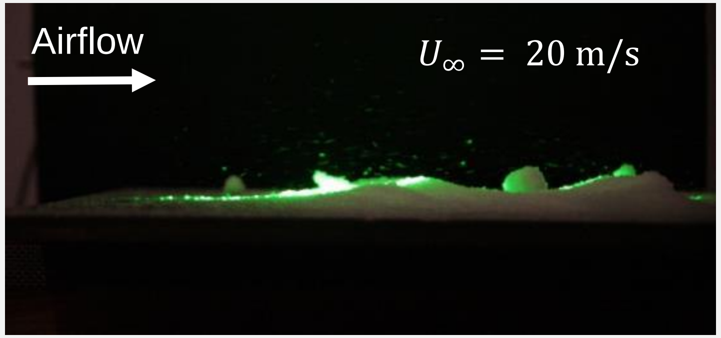
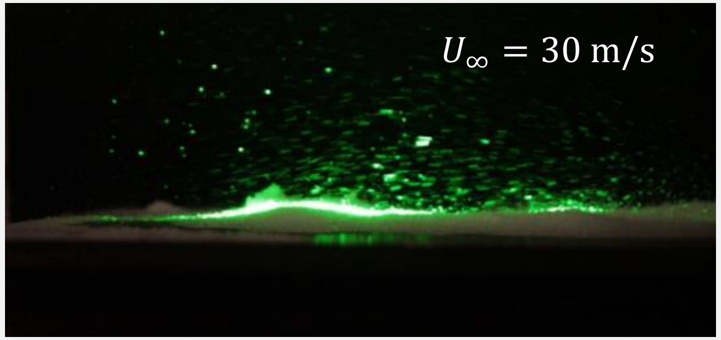
Saltation of natural snow layers

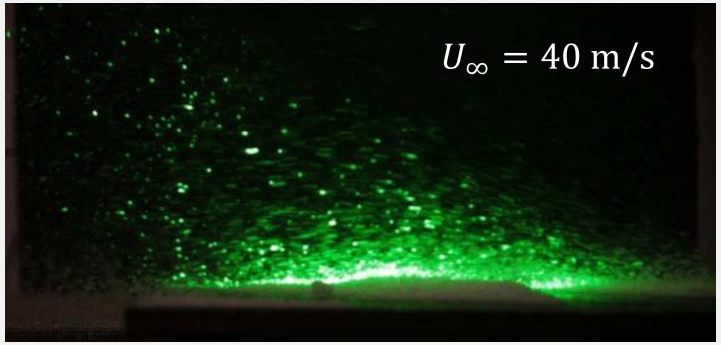
The saltation of natural snow layers is being investigated at different flow velocities up to 50 m/s. In the test setup a laser light sheet and high speed camera are used to observe the snow layer saltation. The particles sizes and concentration are being analyzed via image post-processing for the various flow conditions.

Saltation test setup







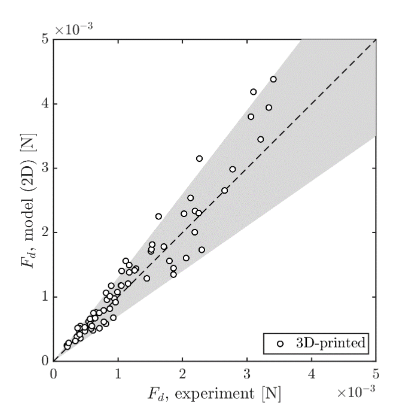


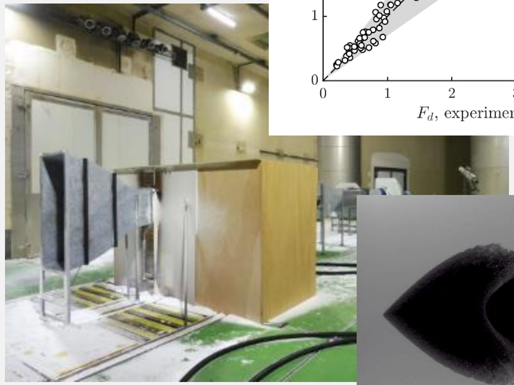
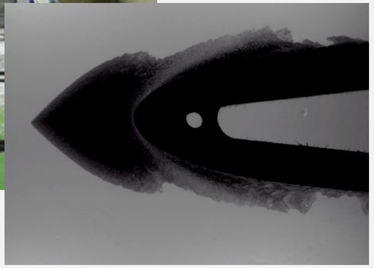
Conclusion & Way forward

WP10 - Numerical Capability Development for Snow

comprising experiments, modelling and simulations has extended existing knowledge concerning drops, SLD and ice crystals to the case of snow flakes/crystals.

- ❑ Multiple drag experiments and trajectory computations were performed
  ➔ HAIC models adapted for snowflakes
- ❑ Melting of snowflakes in levitator
  ➔ Mitra model exhibits best results
- ❑ Snowflake impact and fragmentation onto a surface ongoing
- ❑ Snow accretion tests ongoing
  ➔ model development will start in soon



THANK YOU FOR YOUR INTEREST

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