ICE GENESIS Public Workshop

WP7
RTA Snow Test Capability

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RTA
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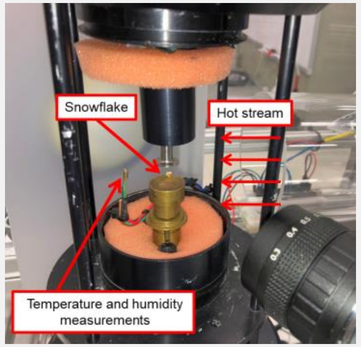
Snow Test Facility Specification

Requirement	Classification	Comment
Falling Snow and **Blowing Snow**	**Essential**	It is expected that particle morphology and PSD could be different between falling snow and blowing snow
Mixed Phase	**Desirable**	Even so regulatory material does not require investigation of mixed phase conditions, this capability could be useful
Dry Snow and **Wet Snow**	**Essential**	It is expected that particle morphology and particle density could be different between dry and wet snow
Particle sizes [$2000\mu m \leq MMD_{max} \leq 3000\mu m$ $50\mu m \leq MMD_{max} \leq 150\mu m$]	**Essential**	Based on Airbus Helicopters F/T measurement, It is expected PSD for blowing snow to differ from falling snow: larger number of small particles (SP) with diameter ~ 100µm
Total Water content (solid phase only) [0.5 – 1g/m³ 0.5 – 3g/m³]	**Essential**	Falling snow: Ice water Content up to 0.9 g/m³ for H/C application (AC29-2C) Blowing snow: Ice water Content up to 3g/m3 for A/C application (CS25)
Snow Bulk Density [40 kg/m³ - 720 kg/m³ 570 kg/m³ - 917 kg/m³]	**Highly Desirable**	Varying snow bulk densities for falling / blowing and wet / dry snow
Velocity Range for H/C [0-150kts]	**Essential**	This requirement covers speed related to the following H/C flight phases and engines settings : Ground Operations, IGE Hover, Level flight, Descent and Landing. Note: it is highly desirable to reach higher speed (up to 225-250kts) for future high speed helicopters
Temperature Range [-15°C ; +2°C]	**Essential**	As defined by regulation (different ranges for wet / dry snow)
Falling Snow / Particle morphology	**Highly Desirable**	Representative size distribution and particle morphology and in any case particle size distribution and particle morphology characterization from calibration
Test duration [0 – 60min]	**Essential**	up to 60 min according to AC29-2C

DEVELOPMENT

- Preliminary investigations with the **SnowFall** in the IAG climatic chamber in June 2019
  - Qualitative and quantitative assessment of different snow settings (25 conditions were investigated in detail) incl. **MASC** measurements supported by **CNRS**
    - Particle size and morphology
    - Snow bulk density
    - Liquid water ratio
  - Snow particle densities, drag coefficients and terminal velocities in investigations in the IAG Climatic chamber (**TUDA**)



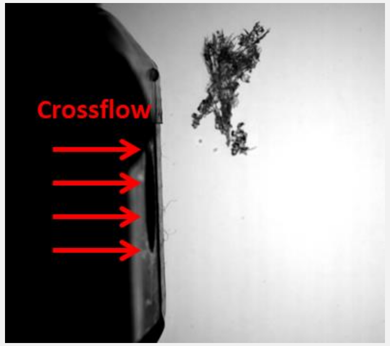


Fig.: Prototype „1A“, melting, breakup and therminal velocity experiments in IAG climatic chamber (**TUDA, AIT**)

Fig.: Prototype „1A“, MASC measurements (**CNRS**)


Fig.: Prototype „1A“ in IAG climatic chamber during 1st workshop, June 2019

DEVELOPMENT

- **Prototype 1** in the **RTA** Climatic Wind Tunnel (CWT)
  - Uniformity investigations with **ICCs** and Laser
  - Snow accretion tests on cylinder
  - Particle size measurement with **PIP (DLR and CNRS)**
  - Successful **TRL2** (2019) and **TRL3** assessment (2020)

- **Prototype 2** built in 2021 at **IAG**
  - Wider and larger snow cylinder
    - Width of 940 mm (instead of 450 mm)
  - Wider outlet region
    - To increase width of uniform snow cloud
    - Improved outlet region heater layout
  - Housing over full width of test section
  - Adjustable injection height

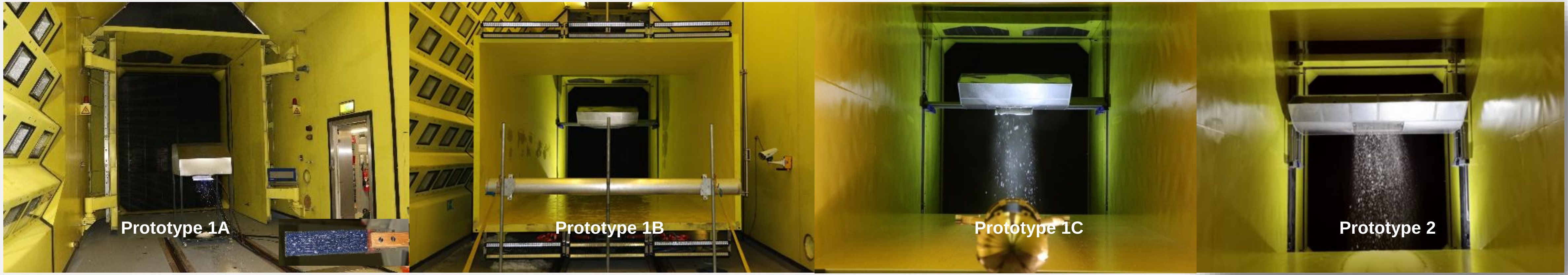


Fig.: Prototype 1 to 2 development / investigations in the RTA Climatic Wind Tunnel (2019, 2020, 2021 and 2022)

DEVELOPMENT

- Concept for upscaling
  - Arrangement (potential) of second snow generation unit to increase TWC
  - Theoretical geometry of outlet region investigation

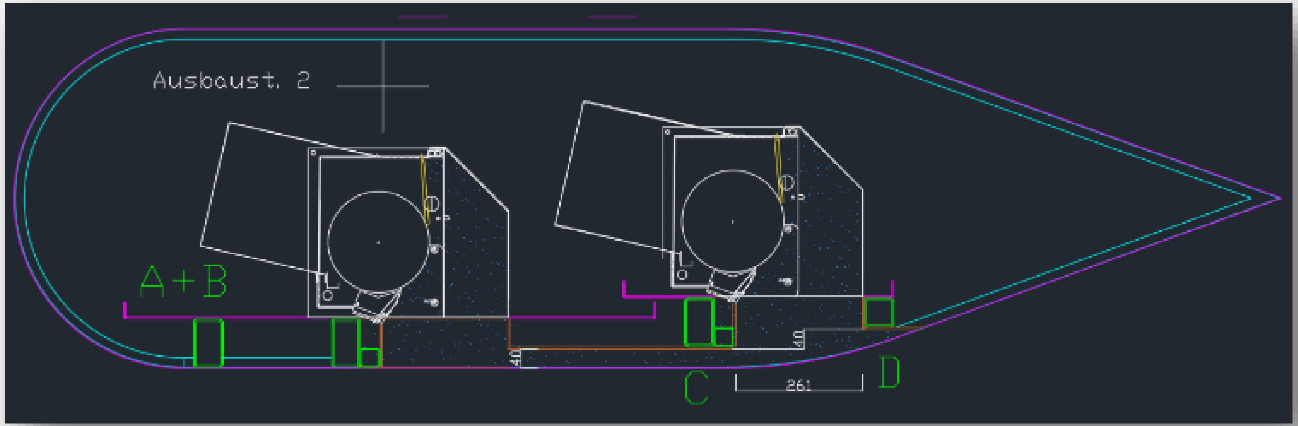


Fig.: Schematic of **IAG** SnowFall Prototype 2 snow generation unit with upgrade possibility

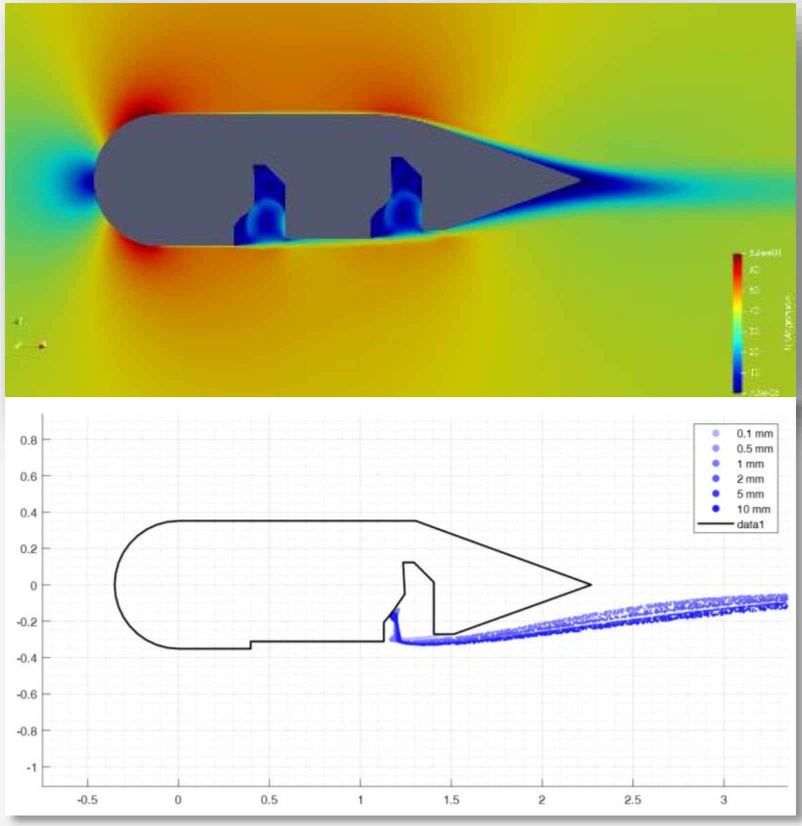


Fig.: Example results from CFD Investigation

DEVELOPMENT

- Concept of integration in the RTA Climatic Wind Tunnel:
  - Modular system – SnowFall system can be attached to the contraction nozzle of the CWT
  - Direct injection of snow particles in the CWT (no transport issues)

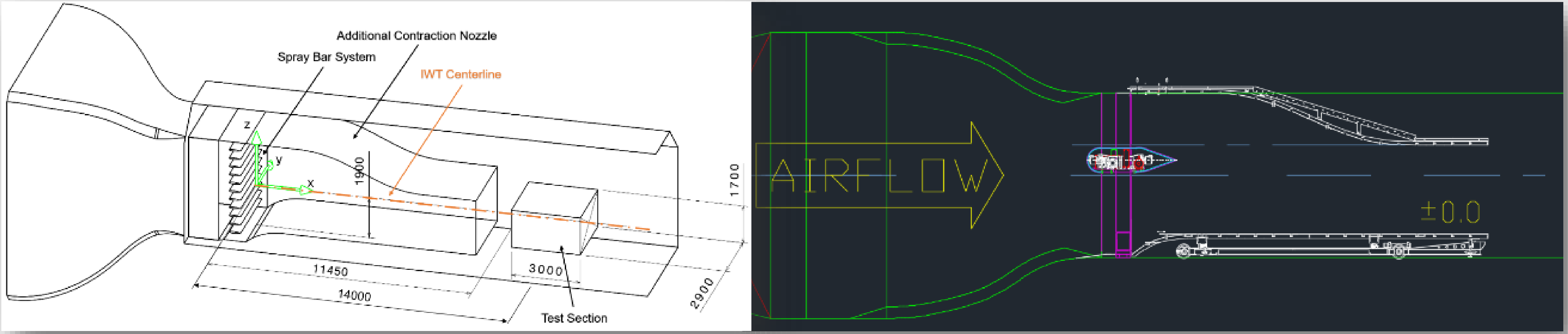


Fig.: SnowFall Technology integration concept in the RTA Climatic Wind Tunnel

DEVELOPMENT

- Two calibration campaigns with **Prototype 2** in the **RTA CWT** in August 2021 / March 2022
  - TWC centreline measurements with **IKP (CU)** and **ICCs**
  - **PIP** centreline and uniformity measurements supported by **CNRS** and **DLR**
  - Uniformity investigations with **ICCs** and **PIP**
  - **NACA0012** snow accretion tests
  - Successful **TRL4** assessment passed in July 2022

Fig.: Prototype 2 calibration in the RTA CWT

CALIBRATION

- The calibration was performed for three SnowFall settings:
  - SF160 „**dry** snow“
  - SF280 „**medium** snow“
  - SF480 „**wet** snow“
- Settings with largest particle sizes and highest water content for the different snow types
  - TWC can be controlled via oscillating motion of the snow generation unit, which increases the affected area
  - Particle sizes can not be adjusted easily without affecting the other parameters

CALIBRATION

- **Snow bulk density** measured using defined container and ICCs
  - ICC measurement within ±10%
- **Liquid water ratio (LWR)** measured using calorimetry
- *<u>SF160 – "dry snow"</u>*
  - Bulk density: ~160 kg/m³
  - Liquid water ratio: ~15%
- *<u>SF280 – "medium snow"</u>*
  - Bulk density: ~280 kg/m³
  - Liquid water ratio: ~25%
- *<u>SF480 – "wet snow"</u>*
  - Bulk density: ~480 kg/m³
  - Liquid water ratio: ~45%

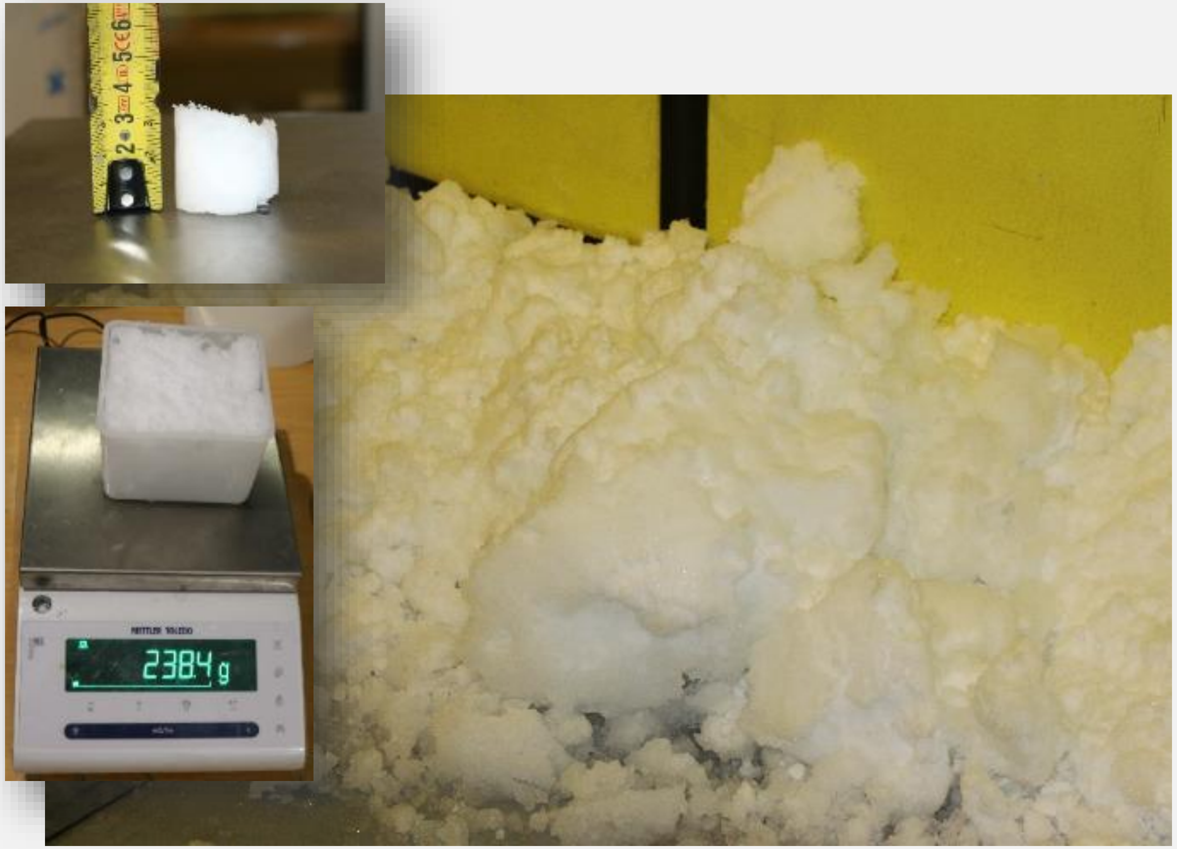


Fig. 9: Snow bulk density investigations and photograph of „leftover“ snow in the CWT

CALIBRATION

- Snow morphology
  - MASC measurements in the **IAG** climatic chamber
  - Mainly aggregates and graupels
  - Number of small particles increases for wetter settings
  - Number of columnar crystals decreases for wetter settings
  - Increasing particle sizes for wetter settings

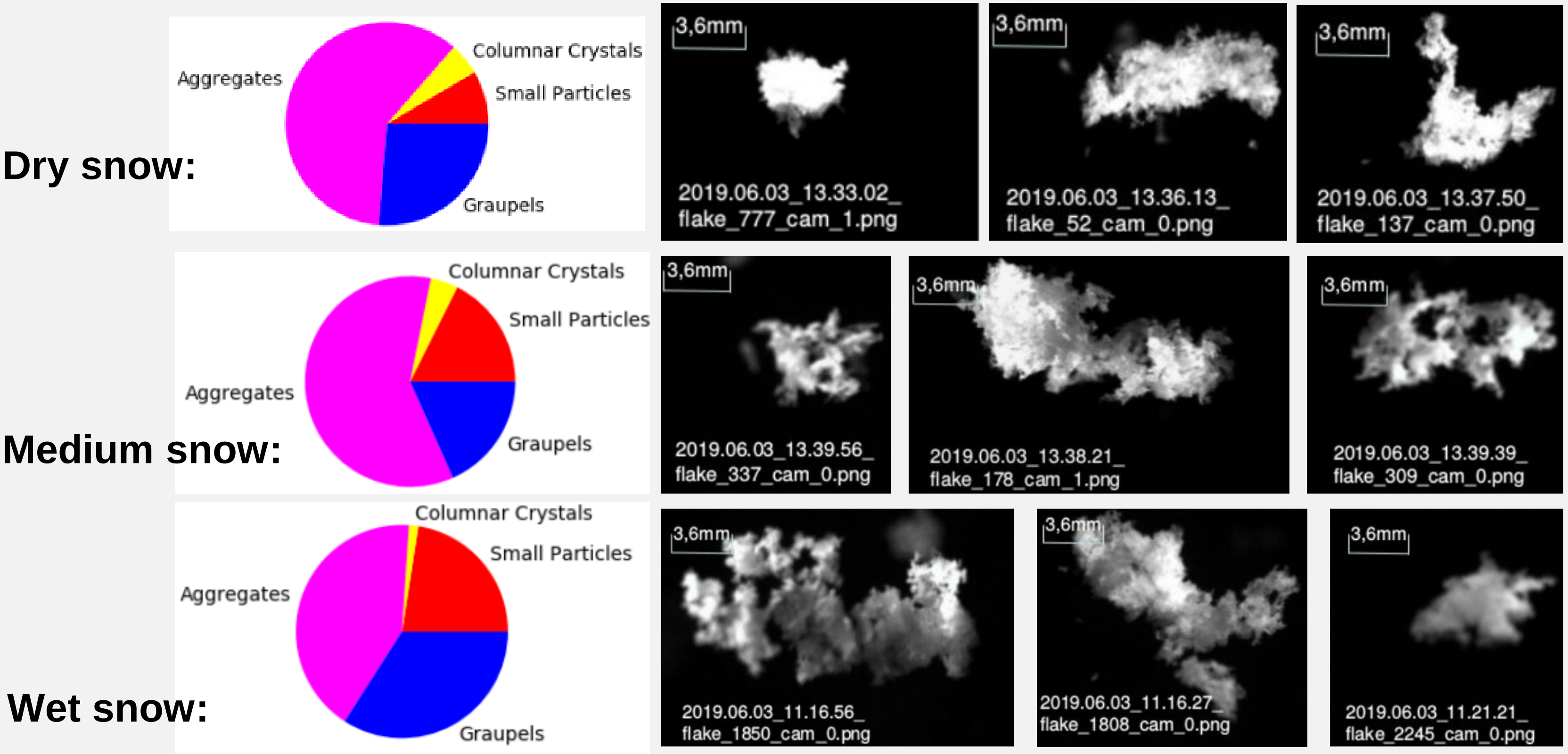


Fig.: SnowFall snowflake morphology results from MASC measurements

CALIBRATION

- **MMDs** between 550-650 µm for all three snow types
  - Max. sizes ~ 5 mm („centre –in“)
  - Good agreement between TS centre measurement and TS Mapping average (over 1 m² region)
  - Good repeatability
  - Dry snow – less of the very large particles

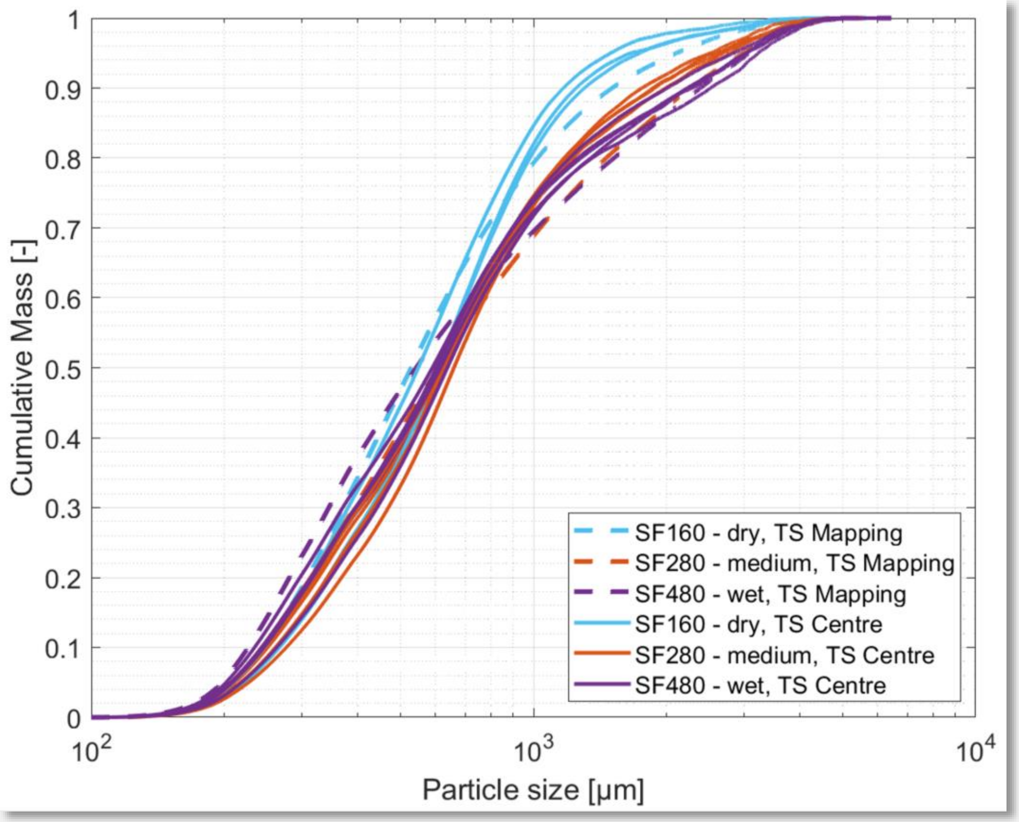


Fig.: Mass size distributions, DLR measurements

CALIBRATION

- **Calibrated TWC** at 40 m/s based on **IKP** and **ICC** measurements:
  - **SF160** (dry): 0.34 g/m³
  - **SF280** (medium): 0.42 g/m³
  - **SF480** (wet): 0.59 g/m³

➢ Average results agree within ±10%

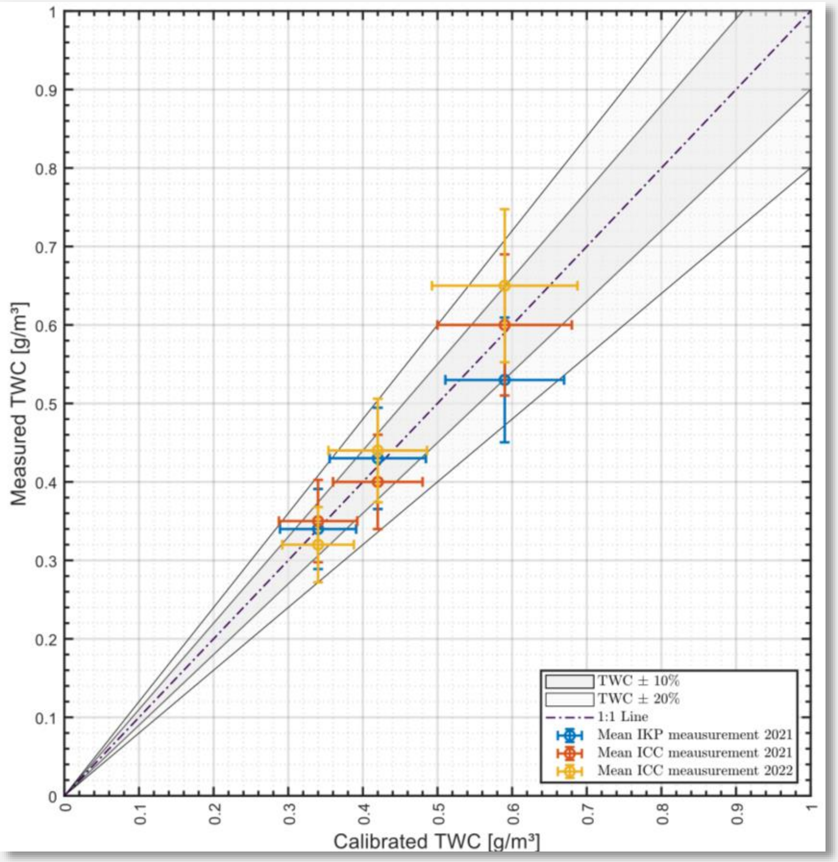
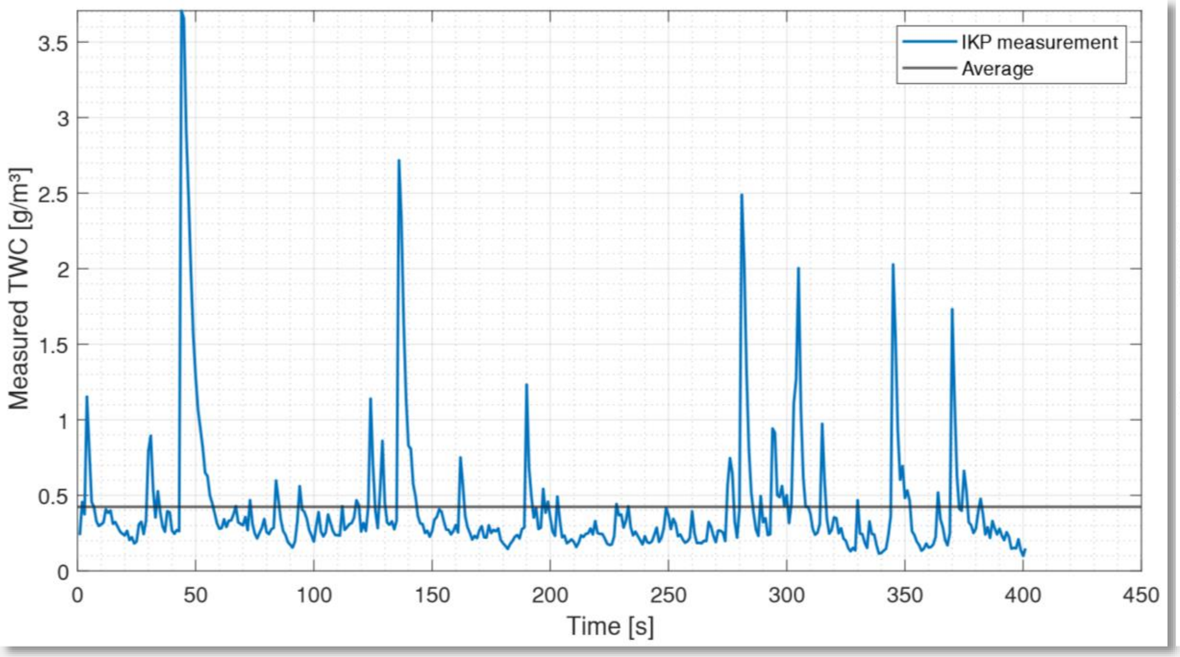


Fig.: Calibrated ICC versus average measurement results from IKP

CALIBRATION

TWC investigations

- SF-480 with and without oscillation
- TAS: 60 m/s, SAT: -3°C



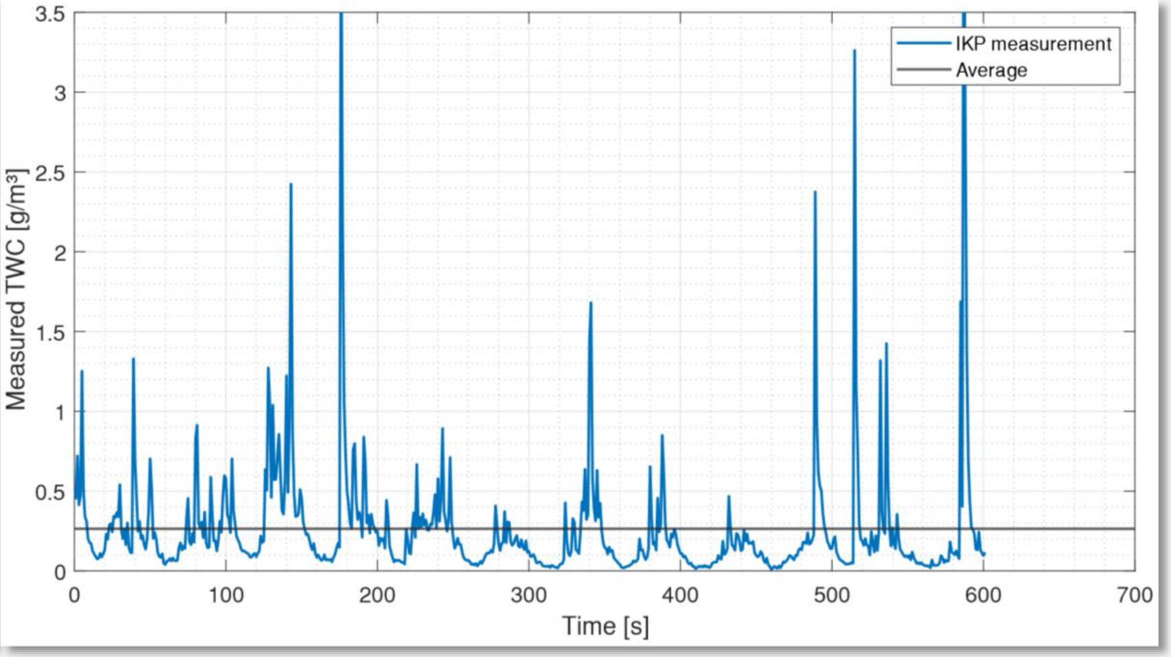


Fig.: CU IKP measurement – time data for with injection height at 3100 mm (left) and with SF oscillation from 2350

CALIBRATION

Uniformity Investigations

- Measurements taken at 30 positions
- Hold for 60s
- 2 Airspeeds / 3 SnowFall Settings
  - 20 m/s & 40 m/s
  - SF160, SF280 & SF480

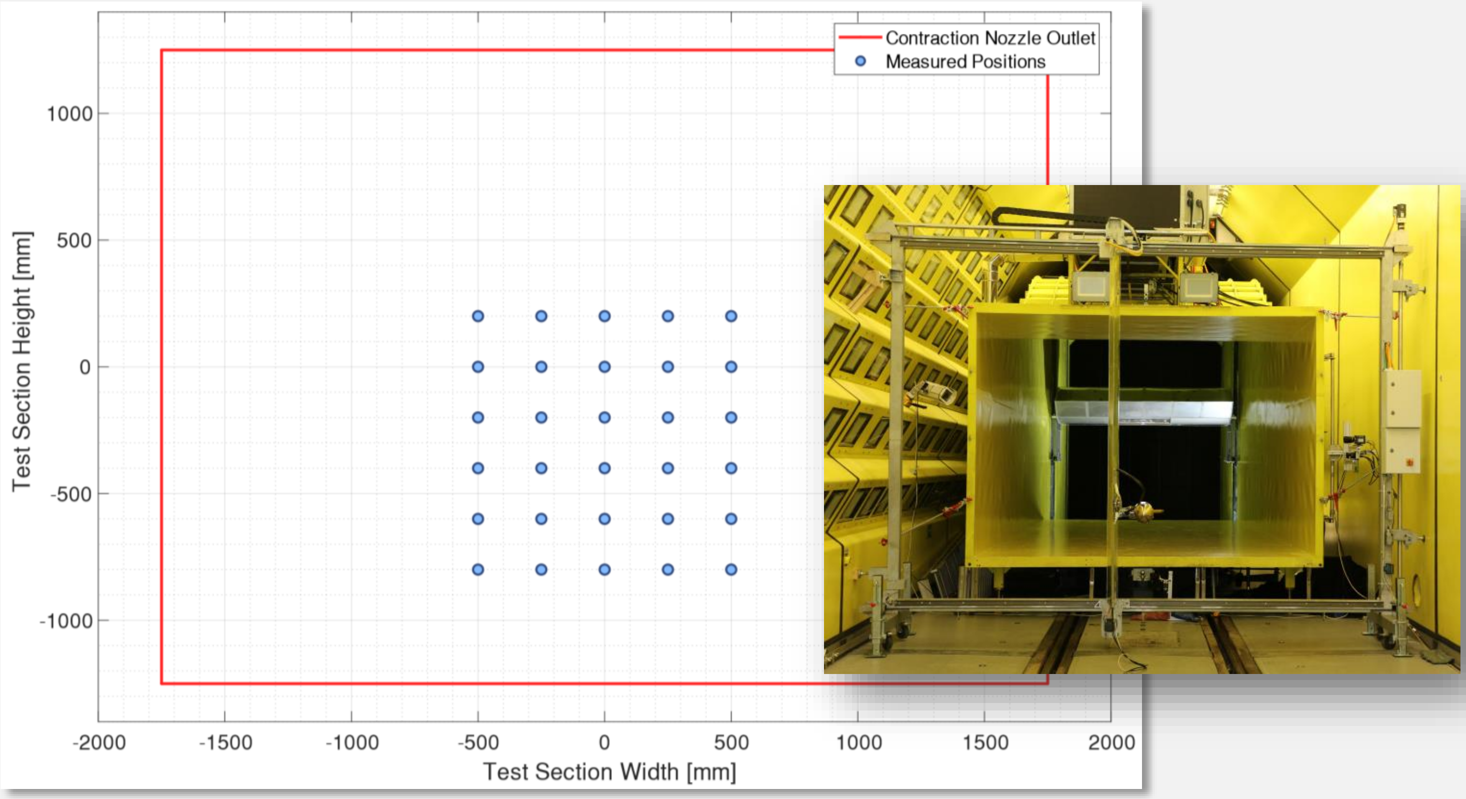


Fig.: Probe locations for uniformity investigations

CALIBRATION

- **SF280 – “medium snow”**
  - SF injection height = 3000 mm
  - TAS = 40 m/s
  - SAT = -3°C

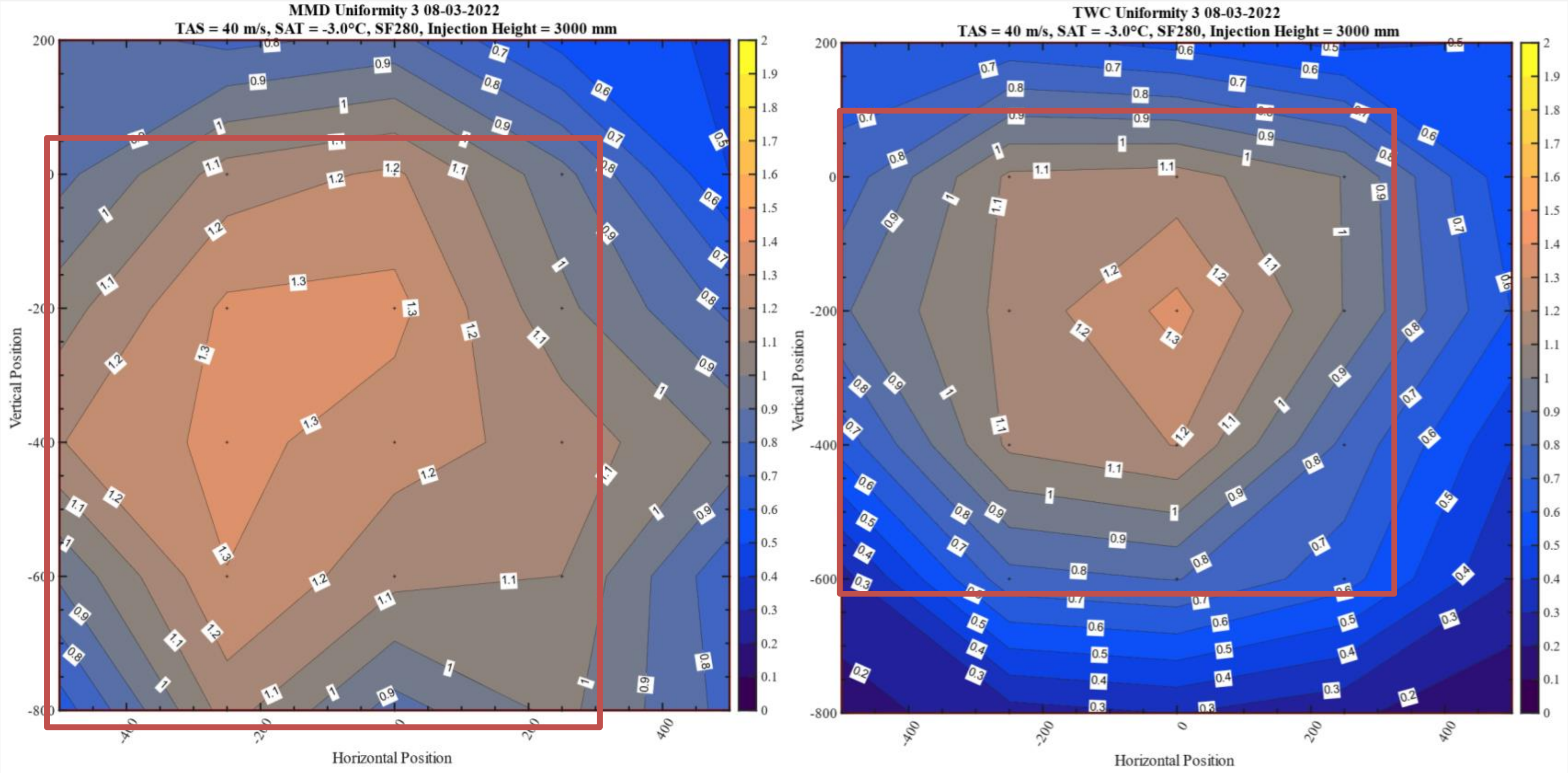


Fig.: MMD and TWC uniformity

CALIBRATION

- Comparison with **ICC** measurements in the LWT
  - August 2021
  - SF160 “dry snow”
  - Injection height = 3000 mm
  - 40 m/s
  - -3°C

PIP – IWC Mapping **ICC – Grid**

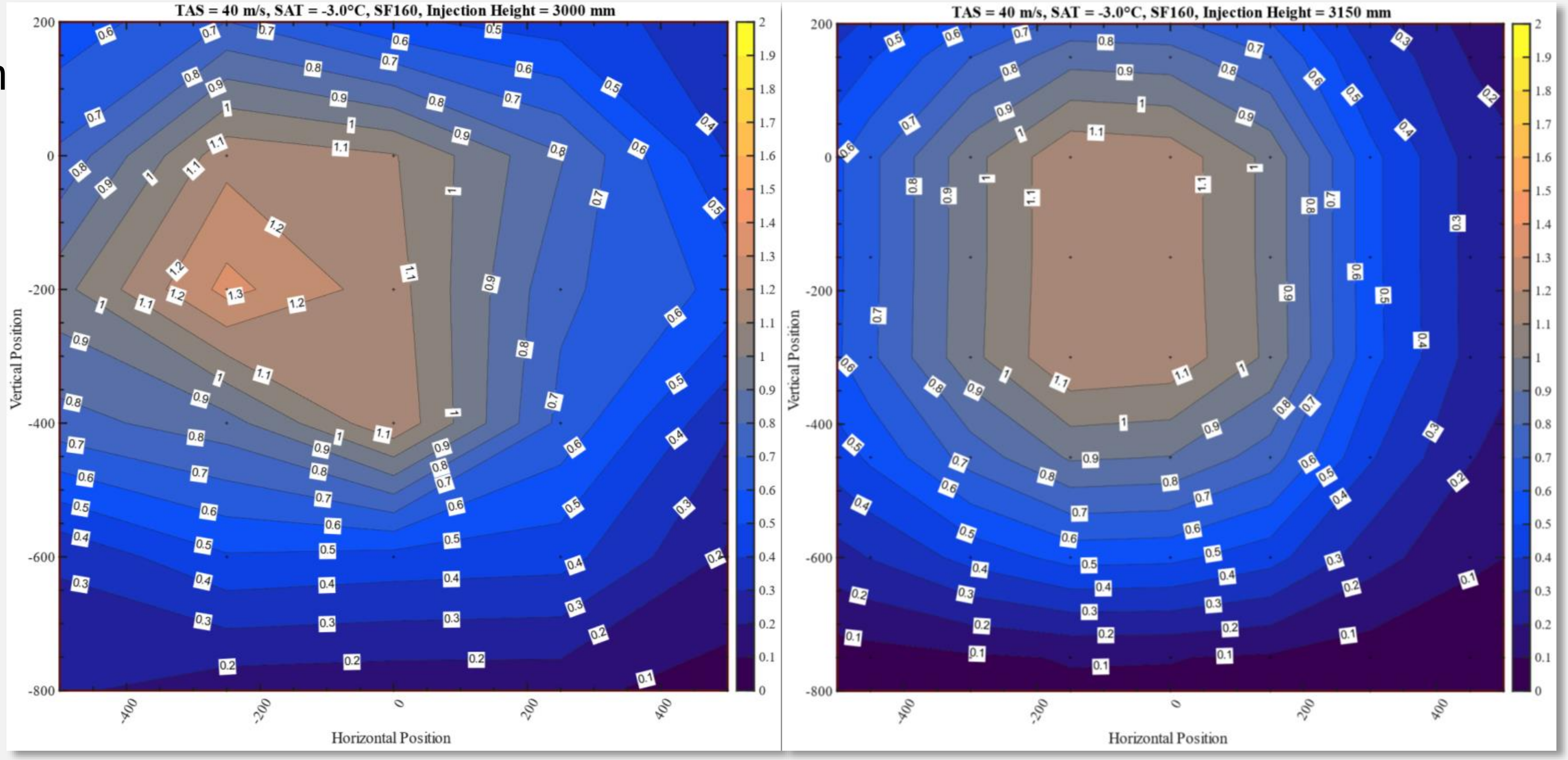
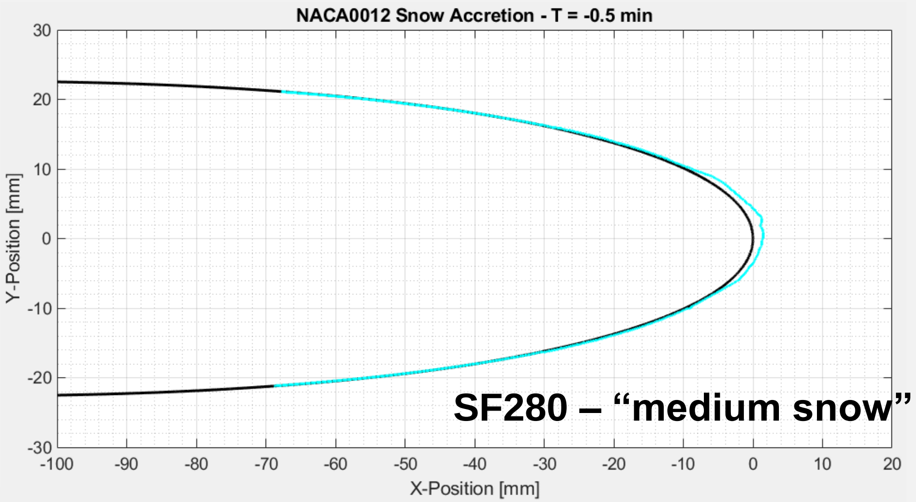


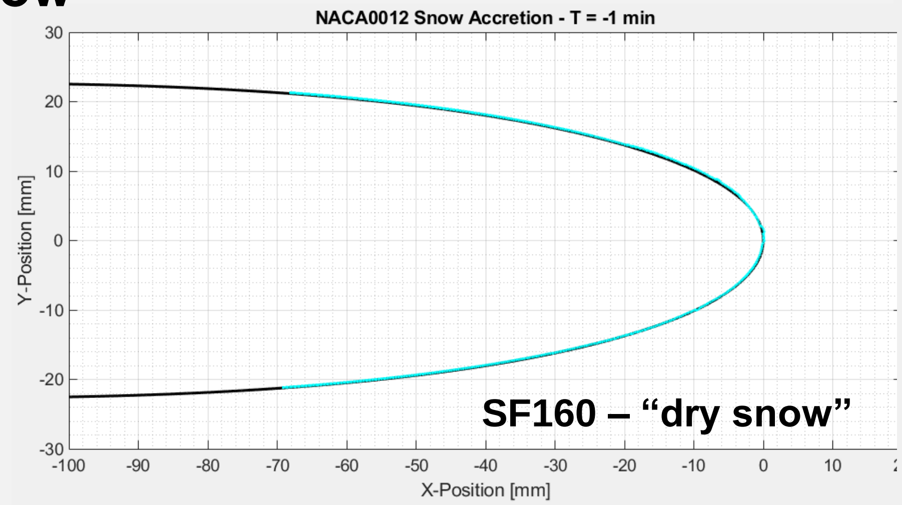
Fig.: TWC uniformity comparison PIP

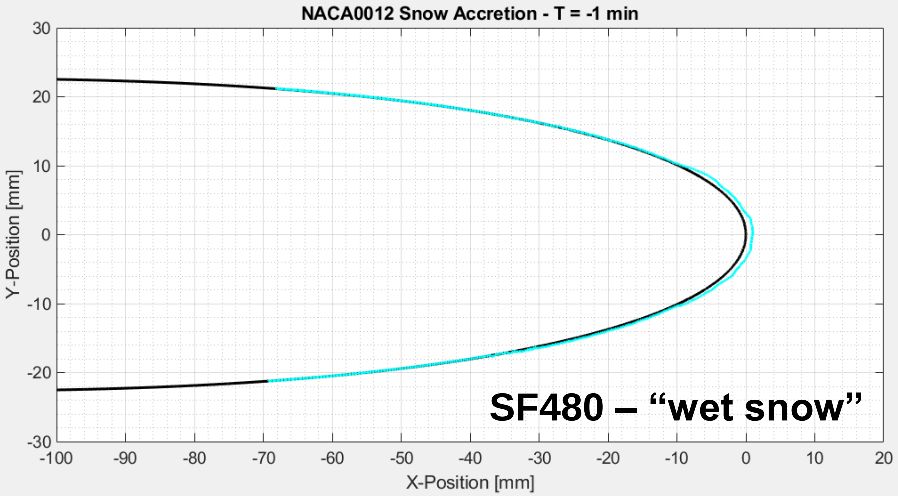
CALIBRATION

- **NACA0012 snow accretion**
  - SAT = -3°C
  - TAS = 40 m/s
  - 10 min exposure
- **SF160 – "dry snow"**
  - GR= 0.03 mm/min
  - Max. Thick. = 1.4 mm
- **SF280 – "medium snow"**
  - GR= 0.35 mm/min
  - Max. Thick. = 5.4 mm
- **SF480 – "wet snow"**
  - GR = 0.50 mm/min
  - Max. Thick. = 7.6 mm

NACA0012 snow accretion for different snow types







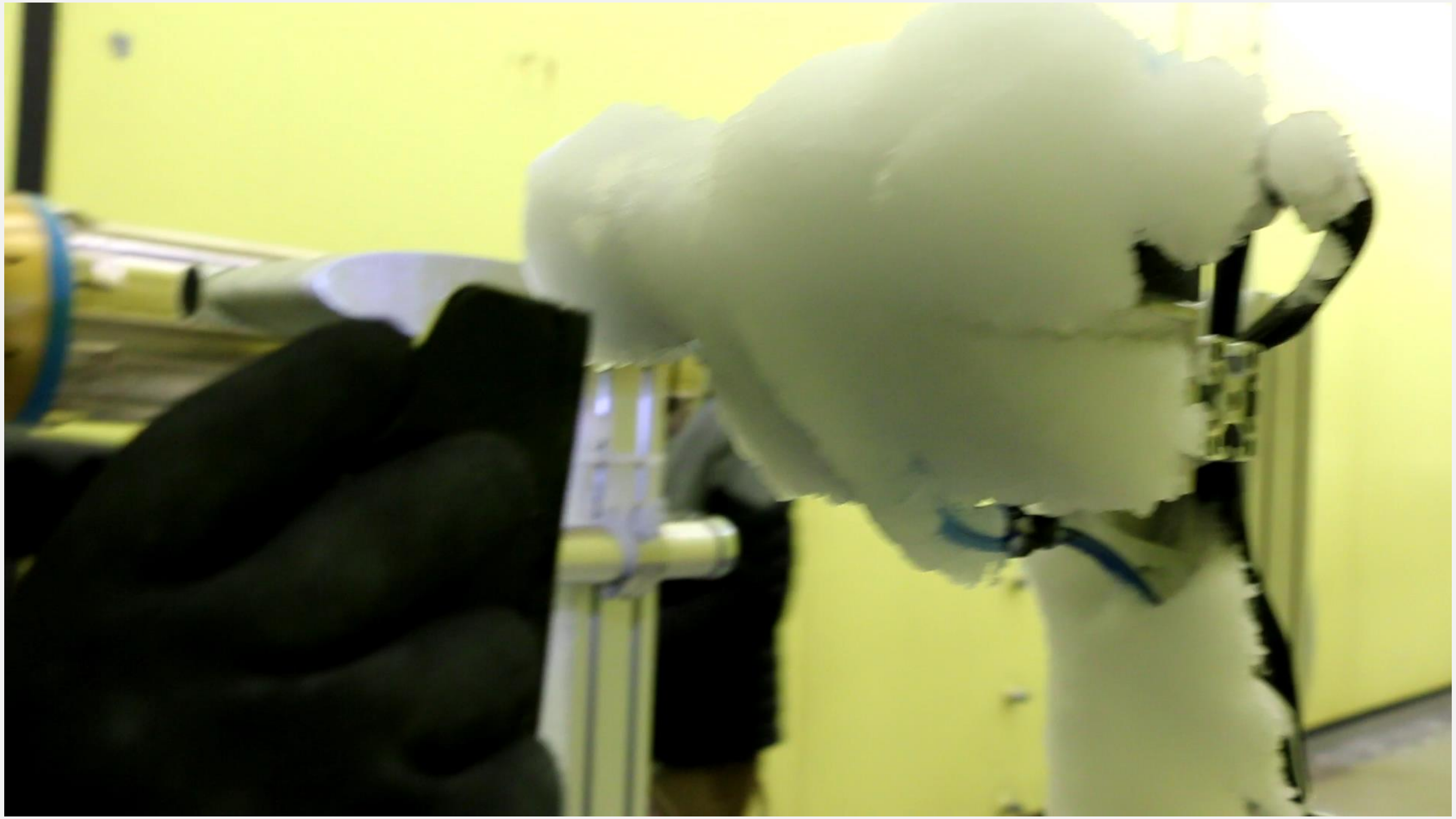
CALIBRATION

SF480 – “wet snow”

- SF injection height = 3000 mm
- TAS = 40 m/s
- SAT = -3°C
- ~10 minutes

CALIBRATION

- **SF280 – “medium snow”**
  - SF injection height = 3000 mm
  - TAS = 40 m/s
  - SAT = -0.8°C
  - ~10 minutes



SUMMARY

- **SnowFall final Prototype**
  - ✓**MMDs** in the range up to 1000 µm (max. over complete cross section) up to 80 m/s (155 kts)
    larger particles with diameter >2000 µm in the cloud
    CNRS flight test campaign from 2021 have shown MMDs vary between 1000 to 4000 µm
  - ✓**Snow Bulk Density:** from 160 to 480 kg/m^3
  - ✓**Temperature range:** from +2 to -15°C
  - ✓**Particle morphology**: close to natural snow (mainly aggregates and graupels)
  - ✓**Test duration**: > 60min
  - **TWCs** from ~0.20 to ~0.60 g/m^3 at 40 m/s (max. TWC at 80 m/s (155 kts) ~0.30 - 0.40 g/m^3)
  - Uniform area without oscillation = ~0.70 m x 0.70 m = ~0.50 m^2
  - **Uniform area** with oscillation = ~0.75 m x 1.00 m = **~0.75 m^2**

- **Potential upgrade** with 2nd snow generation unit:
  - **TWCs** ~ 1.20 g/m^3 at 40 m/s and ~0.60 - 0.80 g/m^3 at 80 m/s