General Information and Guide for Customers

CLIMATIC / ICING WIND TUNNEL VIENNA

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1. Scope

The purpose of this document is to provide general information about the Rail Tec Arsenal Climatic Wind Tunnel (CWT) and Icing Wind Tunnel (IWT) situated in Austria, 1210 Vienna, Paukerwerkstraße 3, and its operational capabilities and procedures for icing tests. The document comprises:

- Facility description
- IWT specifications and performance
- RTA services
- Description of test setup for engine inlets, wing sections and rotors
- Summary of facility calibrations

2. Third Party Certifications

RTA is certified to the following standards:

- ISO 9001:2015 Quality Management System;
  Field of activity: Climatic tests on rail and road vehicles as well as aviation
- OHSAS 18001 Occupational health and safety management system
- EN ISO/IEC 17025:2017 accredited testing laboratory[1]

3. Icing Calibration References

- EN ISO/IEC 17025:2017
- SAE ARP5905A[2] Calibration and Acceptance of Icing Wind Tunnels

4. Company

Rail Tec Arsenal (RTA) is a non-profit research organization. As an accredited testing laboratory RTA provides its services impartially and independently and grants all its customers the same terms and conditions.

The official accreditation sets strict requirements and quality guidelines for the correctness and reliability of tests at RTA. RTA monitors the compliance with these requirements and guidelines through its well-established quality management system. The testing equipment and quality management system are kept state-of-the-art through continuous updates in line with the latest technology.

We assist our customers in the optimization and quality management of their products. Our service portfolio helps to minimize both technical risks and costs for our customers, thus providing them with a clear competitive edge on the international market. Targeted market observation enables RTA to recognize the latest trends and tap new market potentials to provide tailored solutions. In the last years RTA has continuously expanded its business model beyond the rail vehicle sector and is now a leading test facility for climatic tests also for aviation, road vehicles and the construction industry.

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[1] The accredited technical fields are published in the list of accredited bodies at www.en.bmwfj.gv.at/accreditation. This standard also guarantees the competence for carrying out calibrations, developing new procedures for climatic conditions and the ability to consistently produce valid results.

[2] ARP5905A : Calibration and Acceptance of Icing Wind Tunnels - SAE International (2025/01/21).: https://www.sae.org/standards/arp5905-calibration-acceptance-icing-wind-tunnels.

Before entering RTA facilities, each customer receives appropriate instruction on general safety and access regulations.

5. Facility

RTA operates two modern Climatic Wind Tunnels (CWTs) that can produce temperatures between - 45 °C to +60 °C. The facility layout is shown in Figure 1. Apart from the CWTs, the facility consists of a control room, a measurement room for each CWT, a soak room, three preparation halls and other rooms with technical equipment, such as power supply units and refrigeration unit. The preparation hall 3 is especially designed for aircraft test object preparation work.

Figure 2 shows a rendering of both CWTs.

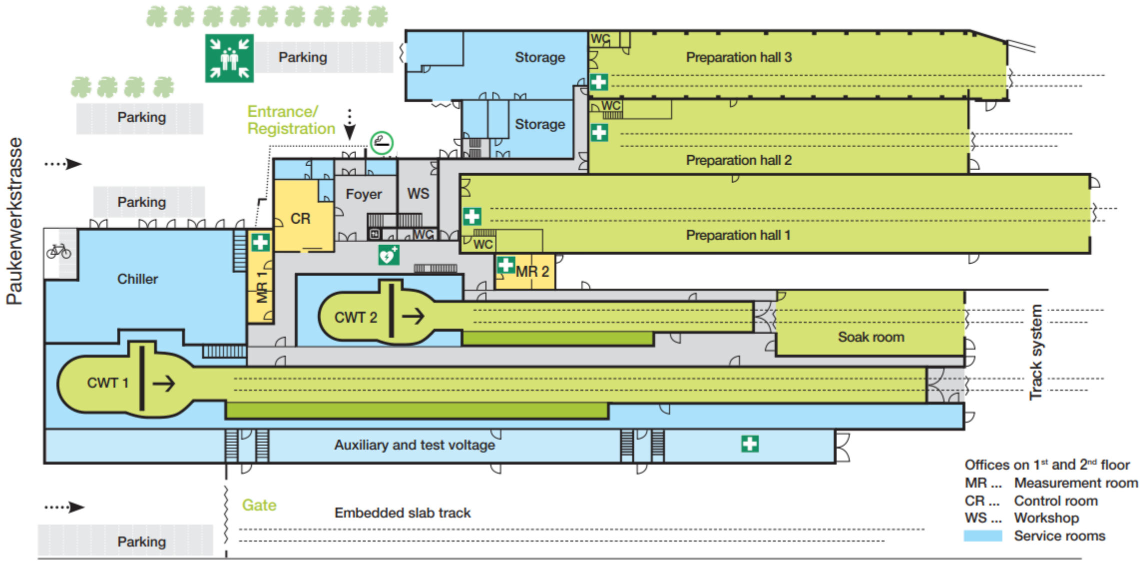

Figure 1: Overview of the RTA facility.

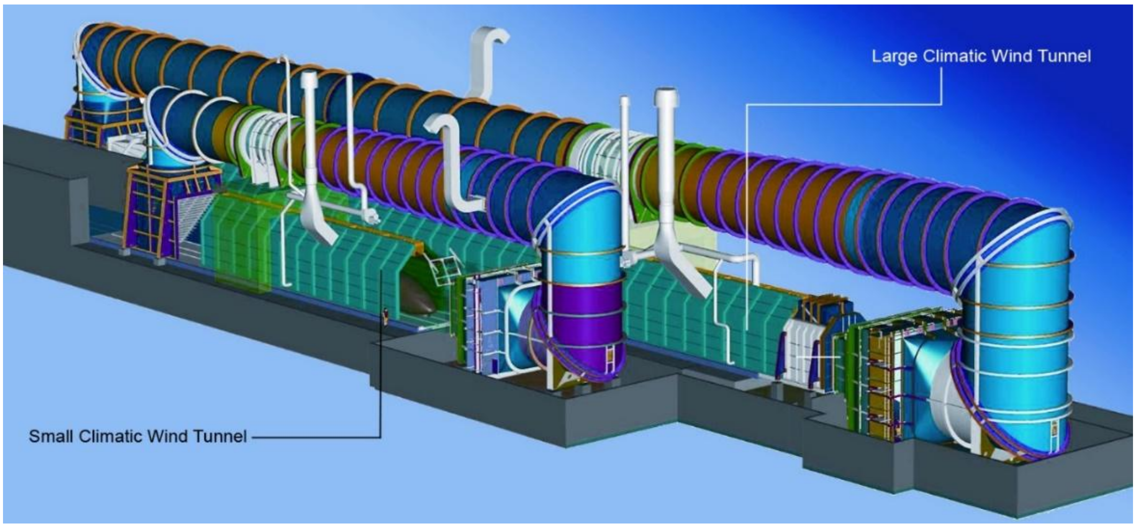

Figure 2: Large and Small Climatic Wind Tunnel.

5.1 Climatic Wind Tunnels

Through the addition of a spray rig both climatic wind tunnels can be transformed into icing wind tunnels (IWTs) and can simulate atmospheric and ground icing conditions. Further equipment is available to simulate many more environmental conditions such as blowing and falling snow, rain and solar radiation.

Both Climatic Wind Tunnels can be used for rail vehicles, road vehicles, technical systems, aircraft (e.g. cold start tests of complete helicopters) and aircraft components (e.g. wing sections). A detailed overview of test capabilities is given in section 6. The two CWTs differ in the conditions that they produce, and RTA advises its customers which tunnel is appropriate for their application in case of wind speed, operation possibilities of engines or rotor, propellers and related max. power (load) possible for a stable, reproduceable environment. A schematic of the small CWT is shown in Figure 3, and a schematic of the large CWT is shown in Figure 4.

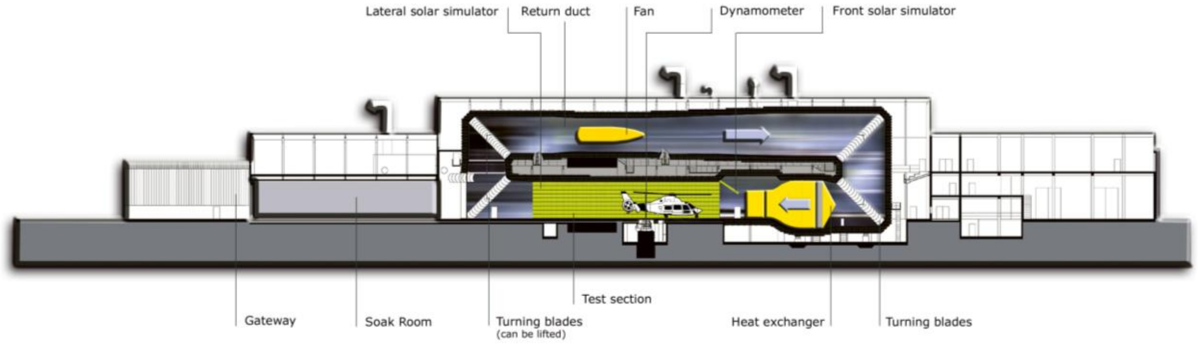

Figure 3: Small Climatic Wind Tunnel / Icing Wind Tunnel Vienna.

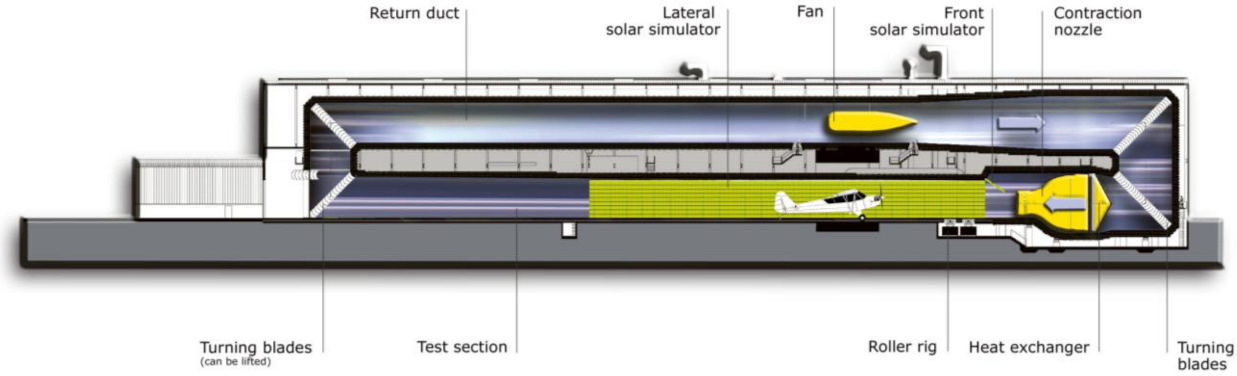

Figure 4: Large Climatic Wind Tunnel / Icing Wind Tunnel Vienna.

The technical data of the Climatic Wind Tunnel and the Icing Wind Tunnel are shown in the following tables (Table 1 to Table 4).

Table 1: Technical data of CWTs / IWTs.

Description	**small CWT / IWT**	**large CWT / IWT**
CWT contraction nozzle dimensions width / height / area	3.5 m / 4.6 m / 16.1 m²	
Contraction ratio of main nozzle	3.98	5.72
Test section width height cross-sectional area	4.9 m to 5.1 m 5.9 m to 6.0 m 27.2 m² to 28.7 m²	4.9 m to 5.6 m 5.9 m to 6.2 m 27.2 m² to 32.2 m²
Test section length	33.8 m	100.0 m
Dimensions of lateral solar simulator length / height	30.0 m / 4.3 m	60.0 m / 4.3 m
Maximum airspeed[3]	33 m/s	80 m/s
Maximum temperature range	-45 °C to +60 °C	
Maximum temperature gradient in the temperature range -20 °C to +60 °C	10 K/h	
Relative humidity at temperatures > +10 °C	10% to 98%	
Solar intensity of lateral solar simulator at fixed 30° angle of incidence operating temperature > -10 °C	200 W/m² to 1,000 W/m²	
Solar intensity of front solar simulator maximum airspeed: at incidence angles < 45 ° up to 120 km/h at incidence angles >= 45 ° up to 50 km/h operating temperature > -10 °C	200 m² to 1,000 W/m²	

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[3] In case of significant thermal loads or large blockages, the maximum airspeed may not be achievable.

Description	**small CWT / IWT**	**large CWT / IWT**
General rain, snow and ground icing systems	• Ceiling-mounted rain system • Icing system • Mobile snow nozzles • Blowing snow for hover, parking and flight mode (complete cross section) • Ceiling-mounted natural like falling snow system for hover and parking mode • Natural like falling snow system for flight mode (prototype)	• Ceiling-mounted rain system • Icing system • Mobile snow nozzles • Blowing snow for hover, parking and flight mode (complete cross section) • Natural like falling snow system for flight mode (prototype)

Table 2: Auxiliary and test voltages for large CWT / IWT.

Available voltage supply	**Max. current**
200 – 1,000 V DC	2 x 175 kVA 350 A max
1,000 – 3,600 V DC	350 kVA 235 A max
3x200–1,000 V 40 – 60 Hz	350 kVA 500 A max
200 – 1,200 V 16 2/3 Hz	350 kVA 350 A max
500 – 1,800 V 40 - 60 Hz	350 kVA 350 A max
3 x 230 V Y / 400V Δ 50 Hz	350 kVA 500 A max
20 – 200 V DC	200 A max
3 x 115 V Y / 200V Δ 400 Hz	60 kVA (170 A max)

5.2 Preparation Halls

The three preparation halls are used not only for the setup and dismantling of the measuring equipment but also for retrofitting and optimization performed by client technicians. The halls are secured by a separate access control system, which allows any of the two preparation halls to be made available exclusively to a specific customer, if required. Preparation halls 1 and 3 have ground-controlled gantry cranes and can be used for setting up heavy equipment.

Table 3: Technical data of preparation halls.

	Preparation Hall 1	**Preparation Hall 2**	**Preparation Hall 3**
Dimensions length / width / height	100 m / 11 m / 8.5 m	60 m / 11 m / 7.5 m	60 m / 8.5 m / 7.5 m
Ground-controlled gantry crane	5t, along entire hall length	-	3.2t, along entire hall length

5.3 Soak Room

A soak room is directly attached to the small CWT. This facility can be used for temperature conditioning of vehicles (adaptation of material temperatures) and for preparation and adjustment work.

Table 4: Technical data of soak room.

Dimensions length / width / height	30 m / 8 m / 6 m
Temperature range	+5 °C to + 60 °C
Relative humidity at temperatures > +10 °C	10% to 98%

5.4 Measurement Rooms

A measurement room with a separate meeting room is available close to the entrance of each CWT. RTA’s customers can observe and evaluate the test from these rooms, which are equipped with office workplaces, filing cabinets, wardrobes, PCs with internet access and a telephone. Live data from the tunnel can be shown on the displays in the room. Furthermore, the measurement room provides the opportunity to edit or process specific representations and evaluations separately from the data visualisation and evaluation performed by the RTA engineers in the control room. The test object can be observed continuously with the help of an integrated video monitoring system featuring several cameras (with optical zoom) and practically unlimited remote-control capabilities in both CWTs.

6. Icing Wind Tunnel

6.1 Setup Description

The small and large CWT for climatic tests on rail vehicles can be transformed into one of the largest icing wind tunnels worldwide by the temporary installation of a spray bar system (SBS) located at the CWT contraction nozzle exit. Test setup 1 with 16.1 m² contraction nozzle (as shown in Figure 5) is especially suitable for low-speed tests up to 20 m/s.

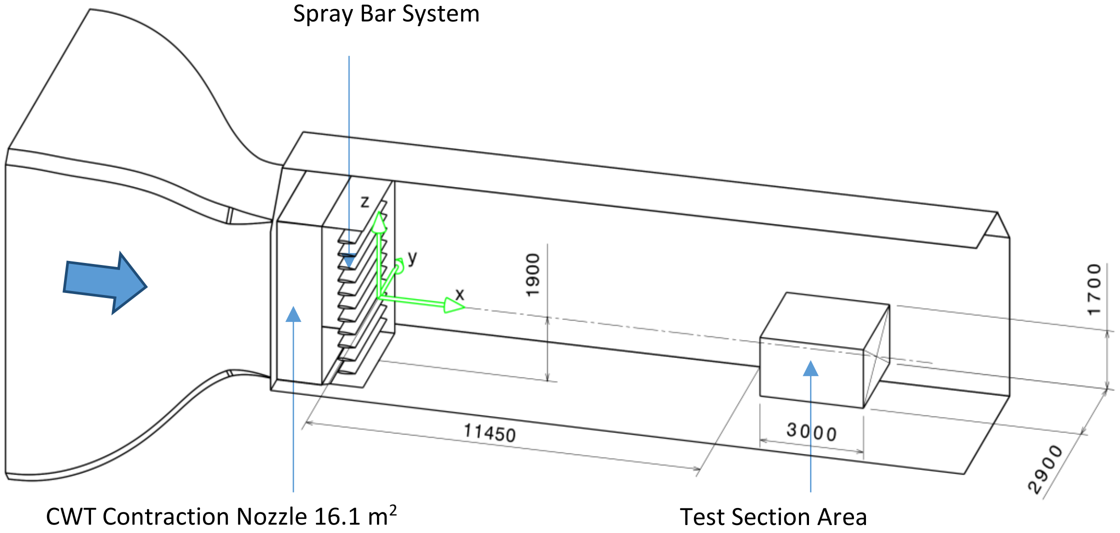

Figure 5: Test setup 1 with 16.1 m^2 cross-sectional area.

With an additional contraction nozzle as shown in Figure 6 speeds from 20 m/s up to 80 m/s can be achieved in the test section area.

The liquid water content (LWC) and droplet size distribution that can be produced in the two icing wind tunnels (IWT) depend on airspeed and temperature. Details on the capabilities of the large IWT can be found in Table 5, while the capabilities of the small IWT can be found in Table 6. In both tunnels, restrictions apply to the airspeed at low temperatures. This can be seen for the large IWT in Figure 8. The values provided in the Figure are guidelines and also depend on whether the test object generates additional heat (e.g. if a running engine is tested). Often, the desired airspeed can be achieved even at colder temperatures than depicted in Figure 8, if a slight drift in temperature over time is accepted. Based on their long experience in running the IWTs, RTA will advise its customers on what conditions are possible when the test setup is specified.

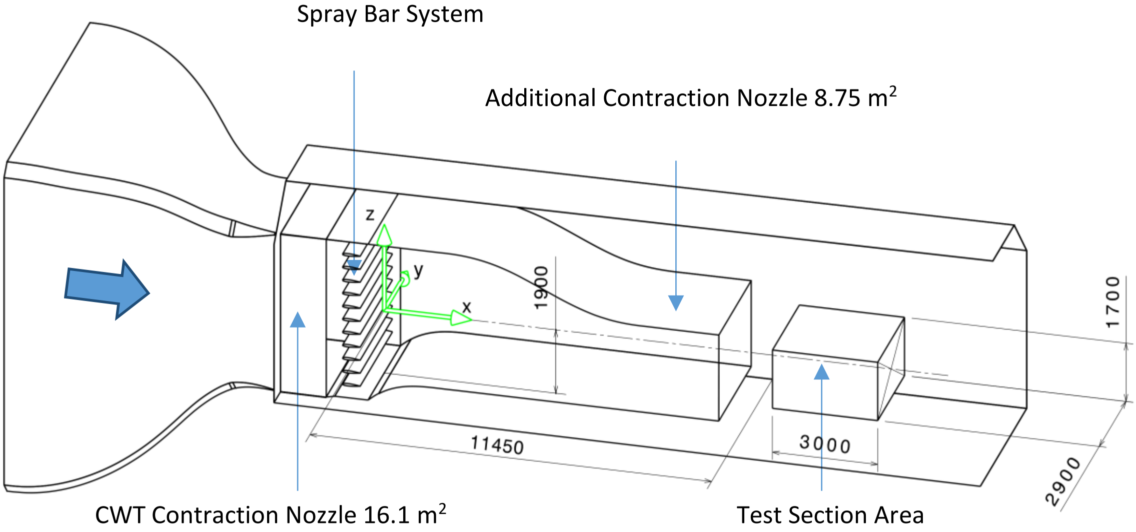

Figure 6: Test setup 2 with 8.75 m^2 cross-sectional area.

The dimensions of the cross-sectional area for test setup 2 (view in wind direction) are shown in Figure 7 below. The calibrated test section area (according to SAE ARP5905A) is marked in cyan.

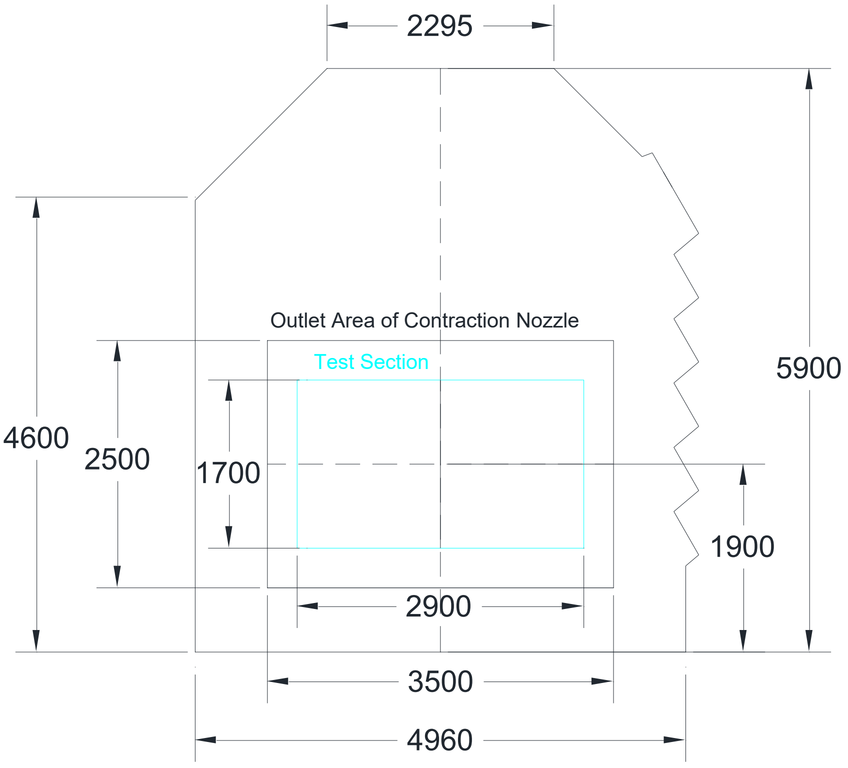

Figure 7: Cross-sectional area and test section area in the CWT for test setup 2 with 8.75 m^2.

Table 5: Technical data of icing conditions in the large IWT.

Description	**IWT cross-section 16.1 m²**	**IWT cross-section 8.75 m²**
CWT contraction nozzle dimensions width / height	3.5 m / 4.6 m	3.5 m / 2.5 m
Contraction ratio of additional contraction nozzle	-	1.84
Distance between spray bars and start of test section	~ 11.5 m	
Test section length	3 m	3 m
Maximum temperature range for icing cloud simulation	-2 °C to -30 °C	
Maximum airspeed[4][5] restrictions at low temperatures	40 m/s	80 m/s
-20 °C	35 m/s	70 m/s
-30 °C	30 m/s	60 m/s
LWC at 20 µm MVD at min. airspeed	0.22 – 1.12 g/m³	0.21 – 3.11 g/m³
LWC at 40 µm MVD at min. airspeed	0.42 – 2.64 g/m³	0.36 – 2.66 g/m³
LWC at 20 µm MVD at max. airspeed	0.11 – 0.56 g/m³	0.05 – 0.78 g/m³
LWC at 40 µm MVD at max. airspeed	0.21 – 1.32 g/m³	0.09 – 0.83 g/m³
LWC FZDZ MVD < 40 µm at max. airspeed	-	0.05 – 0.17 g/m³
LWC FZDZ MVD > 40 µm[6] at max. airspeed	-	0.32 – 0.36 g/m³
LWC FZRA MVD > 40 µm[6] at max. airspeed	-	0.25 g/m³
Icing Rig water conditioning (temperature / conductance)	+2 °C to +80 °C / 0.06 – 0.15 µS/m	
Icing Rig compressed air conditioning	up to +80°C	

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[4] depending on thermal load or blockage in the IWT

[5] An additional contraction nozzle must be inserted to achieve these airspeeds. This reduces the cross-section of the test section

[6] LWC of FZDZ and FZRA depends on airspeed, only limited adjustability can be offered

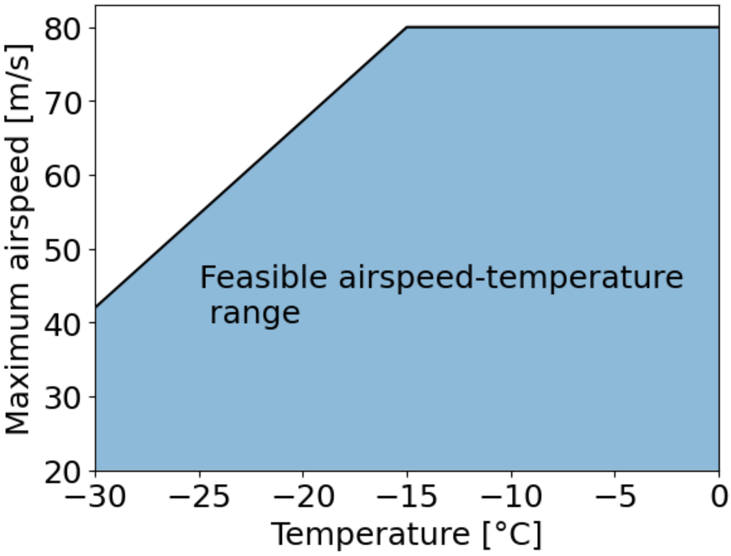


Figure 8: Airspeed limitations depending on temperature for the large IWT with the additional contraction nozzle installed.

Table 6: Technical data of icing conditions in the small IWT.

Description	**IWT cross-section 16.1 m²**	**IWT cross-section 8.75 m²**
CWT contraction nozzle dimensions width / height	3.5 m / 4.6 m	3.5 m / 2.5 m
Contraction ratio of additional contraction nozzle	-	1.84
Distance between spray bars and start of test section	~ 11.5 m	
Test section length	3 m	3 m
Minimum airspeed Maximum airspeed Restrictions at low temperatures at -20 °C at -30 °C	10 m/s 20 m/s 20 m/s 20 m/s	20 m/s 40 m/s 35 m/s 30 m/s
Maximum temperature range for icing cloud simulation	-2 °C to -30 °C	
LWC at 20 µm MVD at min. airspeed LWC at 40 µm MVD at min. airspeed LWC at 20 µm MVD at max. airspeed LWC at 40 µm MVD at max. airspeed LWC FZDZ MVD < 40 µm at max. airspeed LWC FZDZ MVD > 40 µm[4] at max. airspeed LWC FZRA MVD > 40 µm[4] at max. airspeed	0.22 – 1.12 g/m³ 0.42 – 2.64 g/m³ 0.11 – 0.56 g/m³ 0.21 – 1.32 g/m³ - - -	0.21 – 3.11 g/m³ 0.36 – 2.66 g/m³ 0.11 – 1.56 g/m³ 0.18 – 1.67 g/m³ 0.1 – 0.34 g/m³ 0.64 – 0.72 g/m³ 0.5 g/m³
Icing Rig water conditioning (temperature / conductance)	+2 °C to +80 °C / 0.06 – 0.15 µS/m	
Icing Rig compressed air conditioning	up to +80°C	

6.2 Spray Bar System (SBS)

The spray bar system (SBS) consists of eleven spray bars, each equipped with 24 nozzles, i.e. 264 nozzles in total. The spray nozzles used are air atomizing nozzles which mix compressed air and liquid prior to the nozzle exit and use the kinetic energy of the air to atomize the liquid. Each of the spray bars features two independent supply circuits, each of them with supply lines for water and air. The separate control for every second spray nozzle enables the operation of only half of the nozzles for low Liquid Water Content (LWC) requirements or settings with bimodal droplet size distributions as necessary for the simulation of Supercooled Large Droplets (SLD). Furthermore, it allows a separate control of the water and air supply temperatures of each circuit, to ensure supercooling of the larger droplets and to prevent freeze-out of small droplets.

Pressure sensors are placed at the inlet of each spray bar to compensate for barometric pressure differences. They are used for the control of the water and air pressure. Water flow meters are used to monitor the flowrates and to check proper operation of all nozzles during test runs.

6.3 Icing Conditions

6.3.1 Continuous maximum and Intermittent maximum icing conditions

The continuous and intermittent maximum intensity of atmospheric icing conditions is defined by the static air temperature, the LWC and the mean effective diameter of the supercooled droplets. Figure 9 and Figure 10 show the IWT capabilities of the LWT in comparison to the design icing characteristics envelope according to EASA CS-25 [1] and CS-29 Appendix C (respectively FAR Part 25 Appendix C [2]) in terms of LWC (g/m^3) vs. median volume diameter MVD (µm). The IWT icing cloud operative envelope is shown for the minimum (20 m/s) and maximum airspeeds (80 m/s) of Test Setup 2. Operative envelopes for Test Setup 1 can be provided on request.

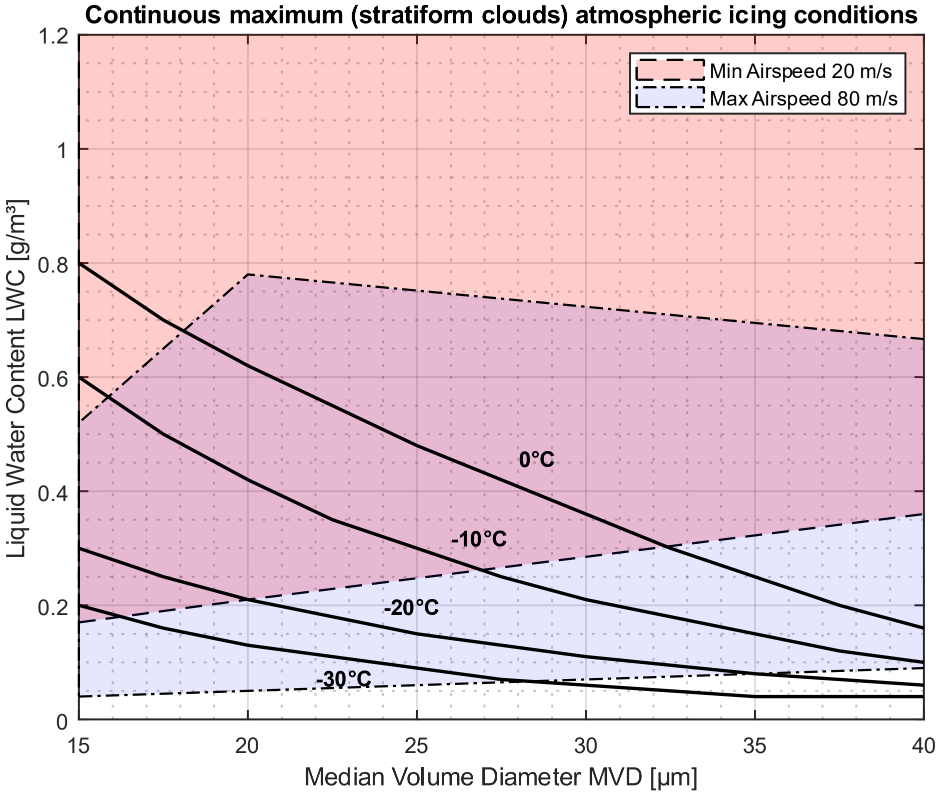


Figure 9: IWT capabilities for continuous maximum (stratiform clouds) atmospheric icing conditions. Violet color represents the LWC/MVD range that can be achieved at 20 and 80 m/s. The solid black lines indicate the icing envelopes of Appendix C and should not be confused with temperature restriction that apply to the facility.

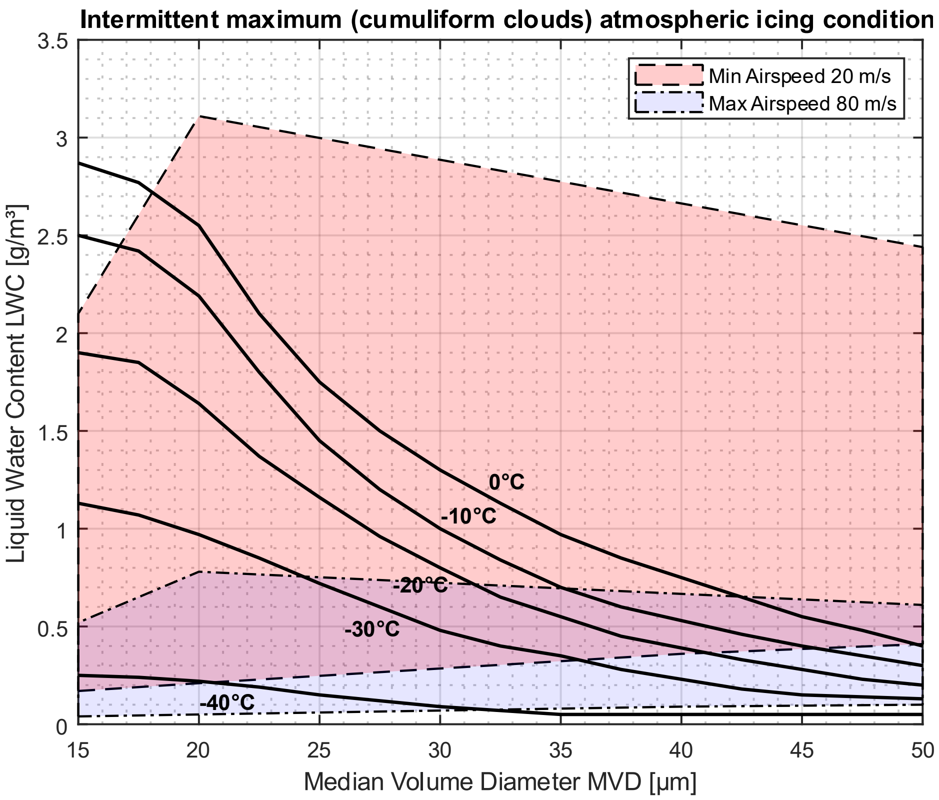


Figure 10: IWT capabilities for intermittent maximum (cumuliform clouds) atmospheric icing conditions. Violet color represents the LWC/MVD range that can be achieved at 20 and 80 m/s. The solid black lines indicate the icing envelopes of Appendix C and should not be confused with temperature restrictions that apply to the facility.

6.3.2 Supercooled Large Droplets (SLDs)

Supercooled large droplet (SLD) icing conditions are commonly divided into freezing drizzle (FZDZ) and freezing rain (FZRA) conditions. Freezing drizzle conditions contain drops with maximum diameters between 100 and 500 µm, while freezing rain conditions contain drops with diameters larger than 500 µm. Both, freezing drizzle and freezing rain conditions, often also include small cloud droplets with diameters below 100 µm, resulting in bimodal droplet mass distributions.

Figure 11 shows the cumulative mass distribution of FZDZ, MVD < 40 µm at RTA compared to the mean distribution from the Appendix O regulation (EASA CS25 Appendix O and 14 CFR Part 25 Appendix O). Figure 12 shows the LWC range that can be achieved at RTA.

In Figure 13, the cumulative mass distribution for FZDZ MVD > 40 µm in comparison to the respective distribution from the Appendix O regulation (EASA CS25 Appendix O and 14 CFR Part 25 Appendix O) for Freezing Drizzle MVD > 40 µm can be seen. The achievable LWCs in the IWT for FZDZ MVD > 40 µm are generally higher than those specified by the Appendix O envelopes (depending on the air speed and temperature). This is shown in Figure 14. The lowest possible LWC at 80 m/s is about 0.32 g/m³.

Furthermore, an experimental nozzle setup can be installed in the IWT to simulate Freezing Rain (FZRA) MVD > 40 µm conditions, with some limitations concerning the cloud uniformity, droplet temperature and droplet velocity. Figure 15 and Figure 16 show the measured droplet size distribution and liquid water content capabilities for FZRA, respectively. Please note that the FZRA setting is still a prototype solution and may cause malfunctions during operation.

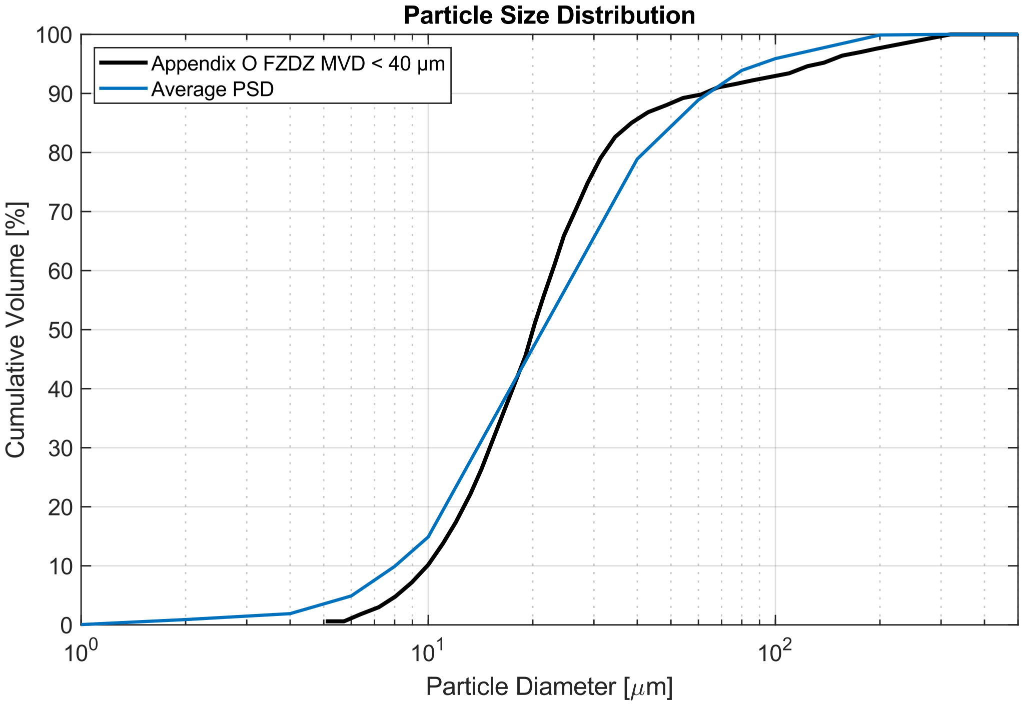


Figure 11: Cumulative volume distribution of a FZDZ condition at RTA (blue) and the average distribution from the Appendix O regulations for Freezing Drizzle MVD < 40 µm (black).

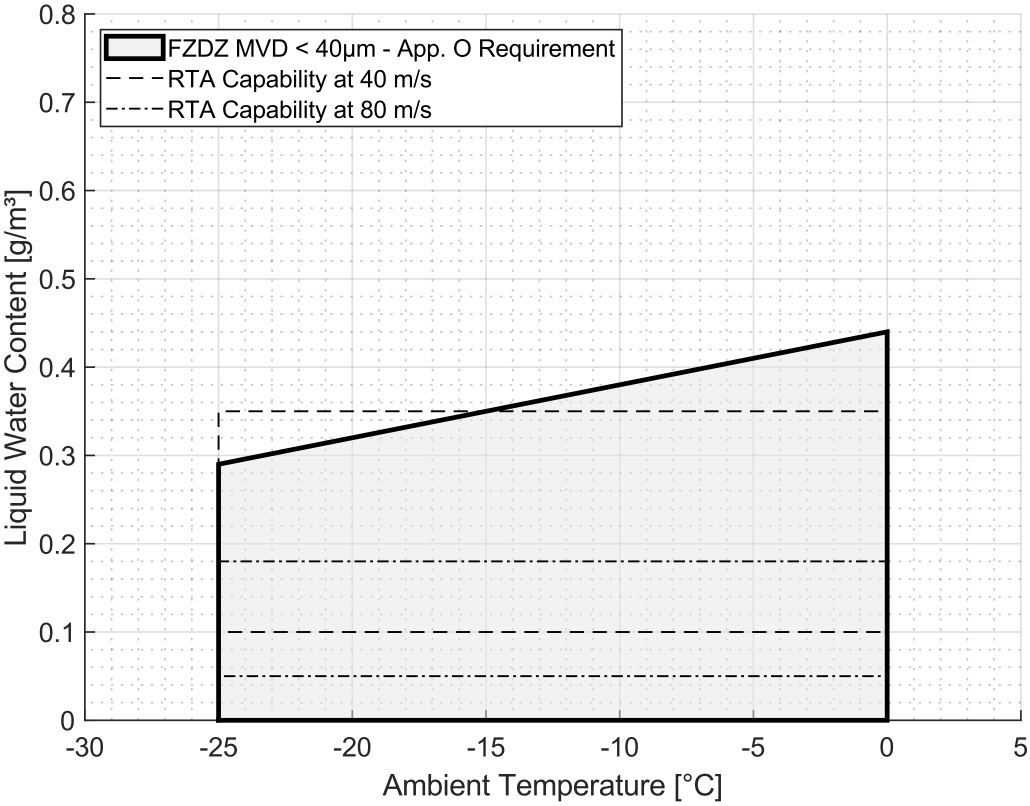


Figure 12: LWC capabilities for Freezing Drizzle MVD < 40 µm.

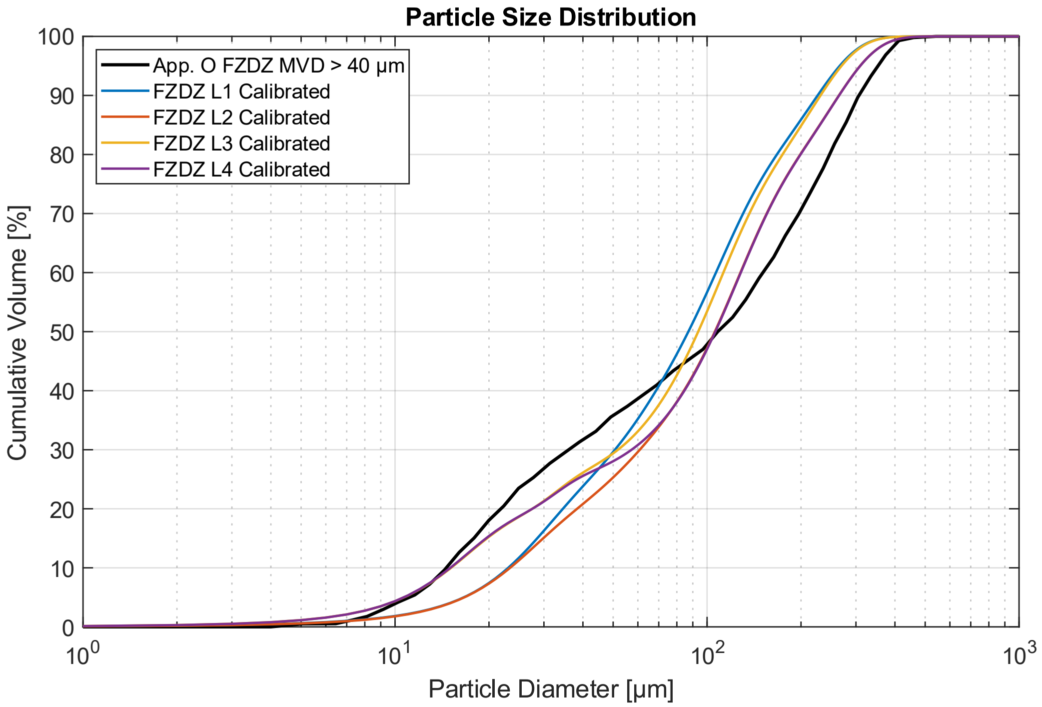


Figure 13: Cumulative volume distributions of drops for Freezing Drizzle MVD > 40 µm and the average distribution from the Appendix O regulations for Freezing Drizzle MVD > 40 µm (black).

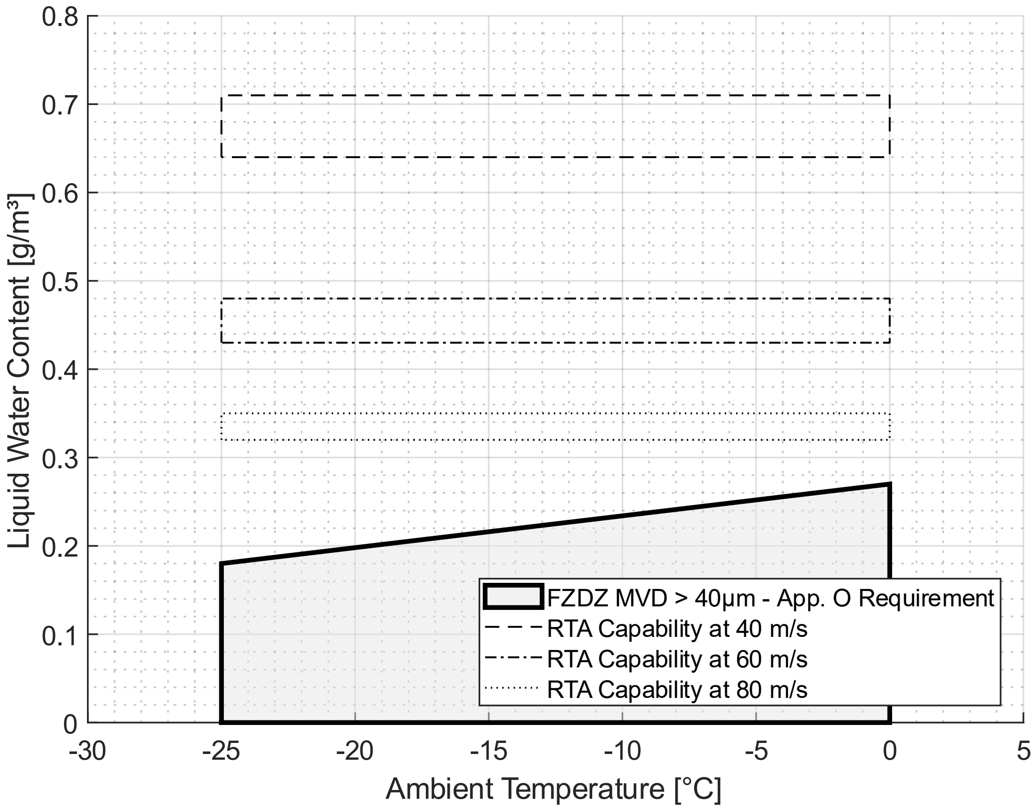


Figure 14: LWC capabilities for Freezing Drizzle MVD > 40 µm.

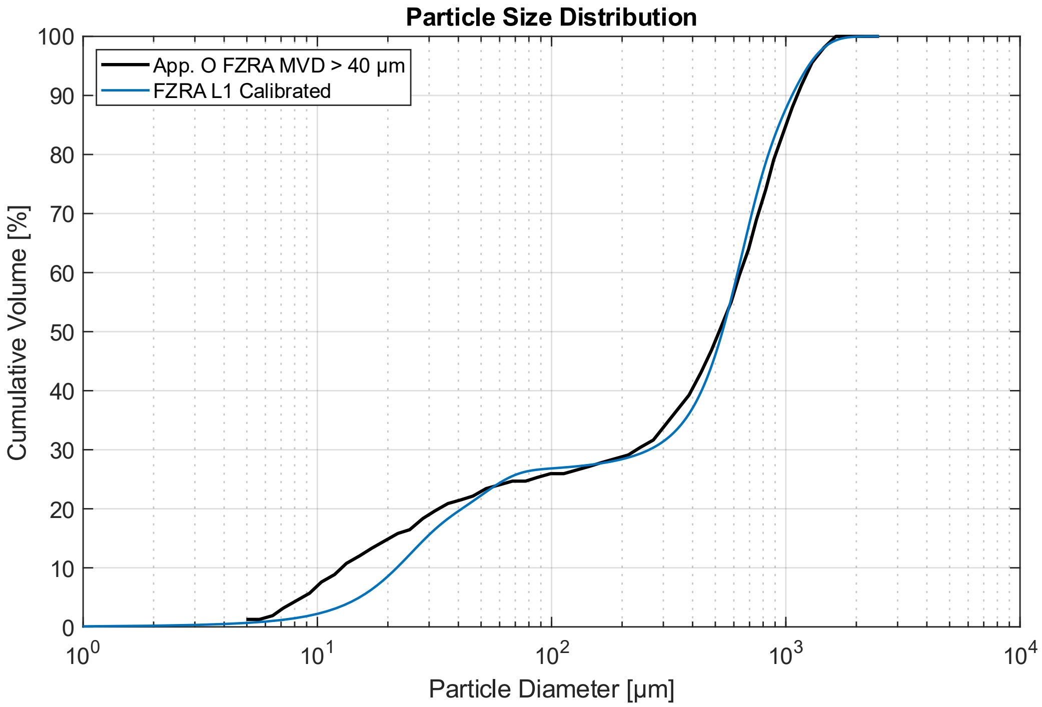


Figure 15: Cumulative volume distribution of drops for Freezing Rain MVD > 40 µm and the average distribution from the Appendix O regulations for Freezing Rain MVD > 40 µm (black).

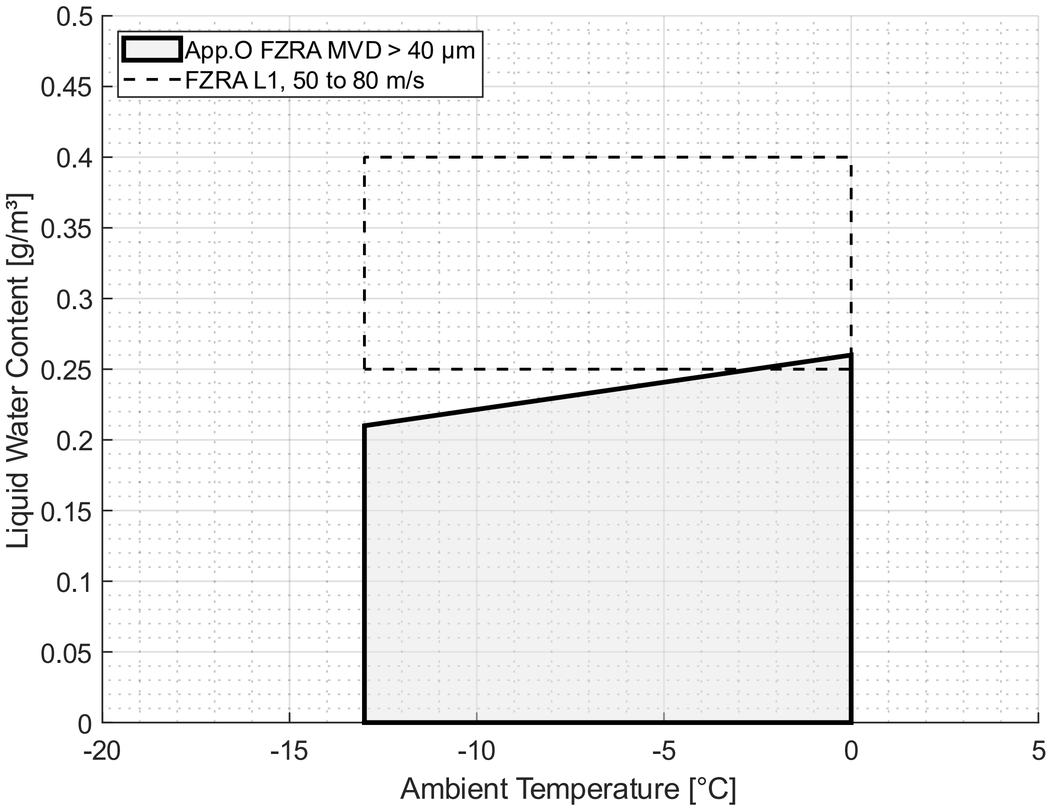
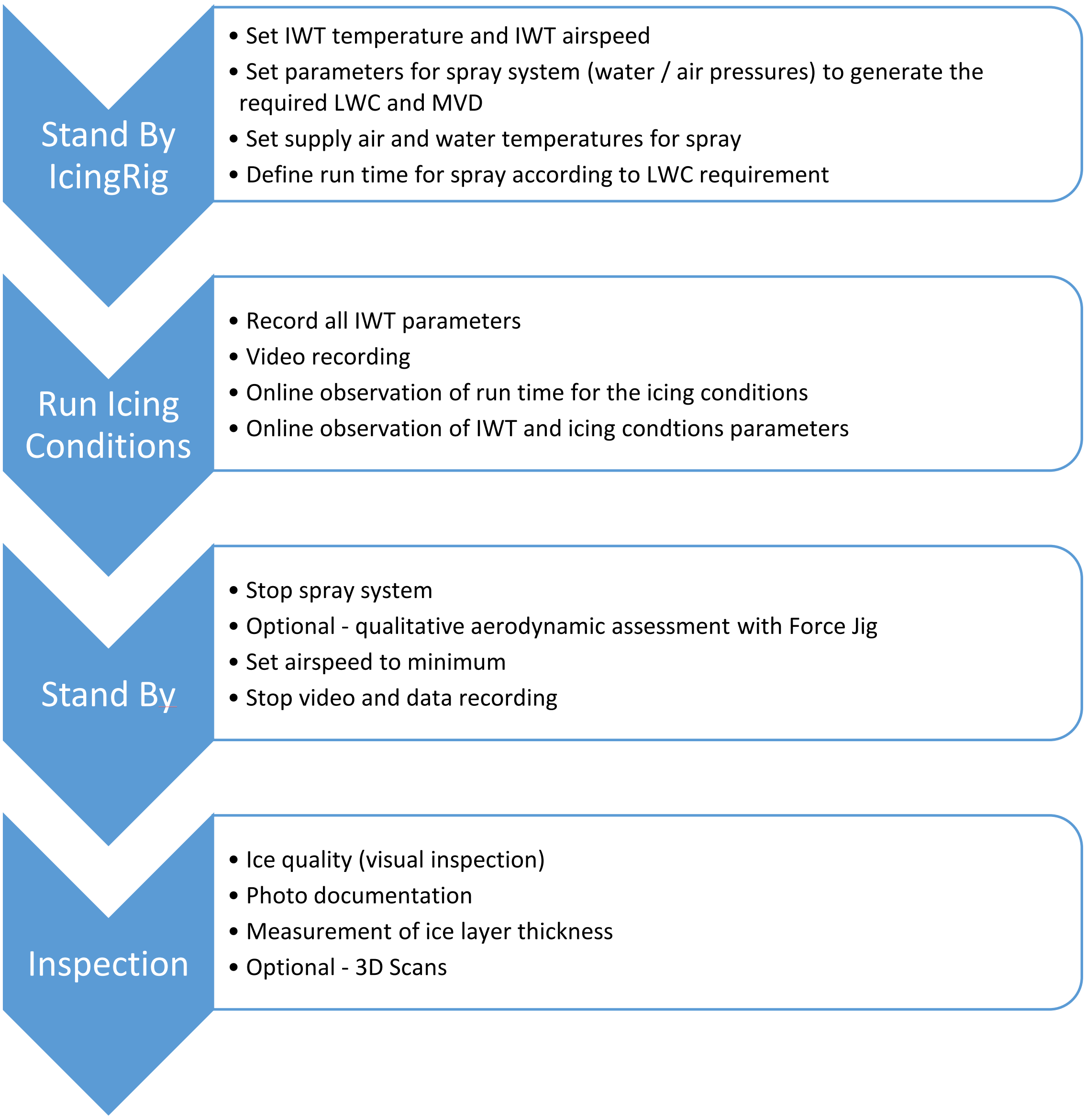


Figure 16: LWC capabilities for Freezing Rain MVD > 40 µm.

6.4 Test Run / Documentation

RTA ensures continuous data acquisition and records the tests on photo and video to document the proper functioning of the test facility. All measurement data and records are archived for at least ten years for later retrieval and verification. All relevant calibration documents are available on request.

The flowchart presented in Figure 17 describes an example for an icing test run with continuous spray.



Stand By IcingRig

- Set IWT temperature and IWT airspeed
- Set parameters for spray system (water / air pressures) to generate the required LWC and MVD
- Set supply air and water temperatures for spray
- Define run time for spray according to LWC requirement

Run Icing Conditions

- Record all IWT parameters
- Video recording
- Online observation of run time for the icing conditions
- Online observation of IWT and icing condtions parameters

Stand By

- Stop spray system
- Optional - qualitative aerodynamic assessment with Force Jig
- Set airspeed to minimum
- Stop video and data recording

Inspection

- Ice quality (visual inspection)
- Photo documentation
- Measurement of ice layer thickness
- Optional - 3D Scans

Figure 17: Procedure for icing conditions inside the IWT

The design of the RTA Icing Rig control system also allows cloud conditions to be changed (e.g. from intermittent to continuous) within a period of about 45-60 s (see Figure 18). The upper figure shows the water and air pressures for several different spray bars, whereas in the lower plots the LWC and the MVD in the test section are shown.

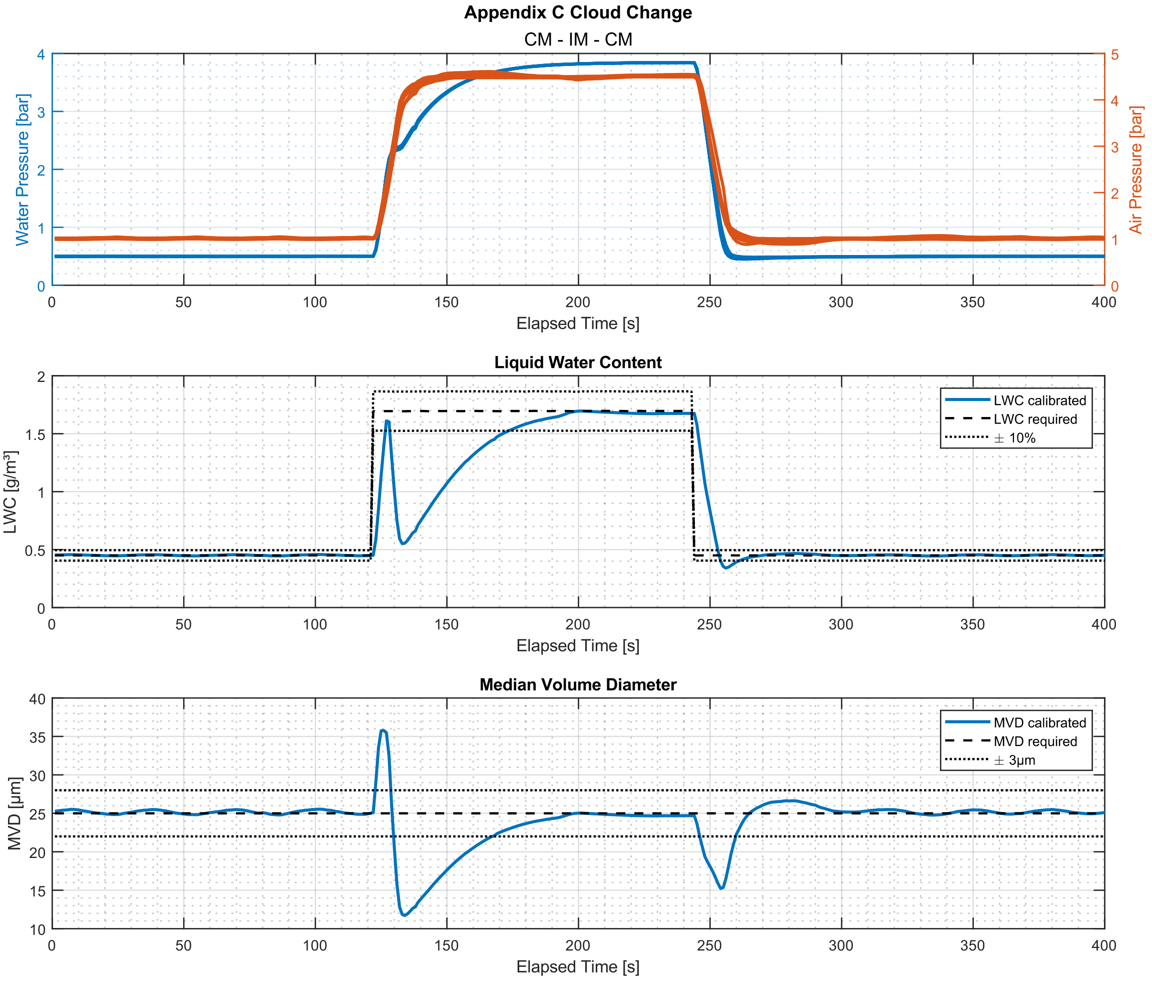


Figure 18: Icing test parameters during change of cloud conditions in the IWT.

6.5 Icing Tests

The icing wind tunnel of RTA provides ideal conditions for a wide range of tests ranging from full-scale test-objects like complete helicopters and small aircraft to wing sections, engines and propellers.

RTA has developed a large amount of machinery and test stands that are required for specific kinds of icing tests. These tests are described in this section.

6.5.1 Air Intake and Inlet Barrier Filter Tests

Air intake and inlet barrier filter tests can be carried out using a fan system to simulate the air flow of the engine. It is capable of flow rates up to 21.6 kg/s at a total pressure difference of 6 kPa. At lower flow rates, a higher total pressure difference is possible.

Alternatively, an engine can be operated inside of the wind tunnel using an exhaust gas system and a kerosine supply system. A water supply is provided to feed a water brake system if required. Specifications of the systems are shown in Table 7 and a test setup scheme is shown in Figure 19.

The engine and related equipment, e.g., the water brake and the control units, are within the customers responsibility. Electrical cabinets and special equipment can be set up in front of the IWT main entrance door or in the measurement room. The exhaust gas system and the kerosene and water supply are prepared and controlled by RTA.

Table 7: Engine equipment specification

Kerosine flow rate	8 l/min
Kerosine pressure	0 to 3 bar
Water flow rate	60 m^3/h
Water supply pressure	0 to 5 bar
Exhaust flow rate (Including secondary air flow)	60000 m^3/h

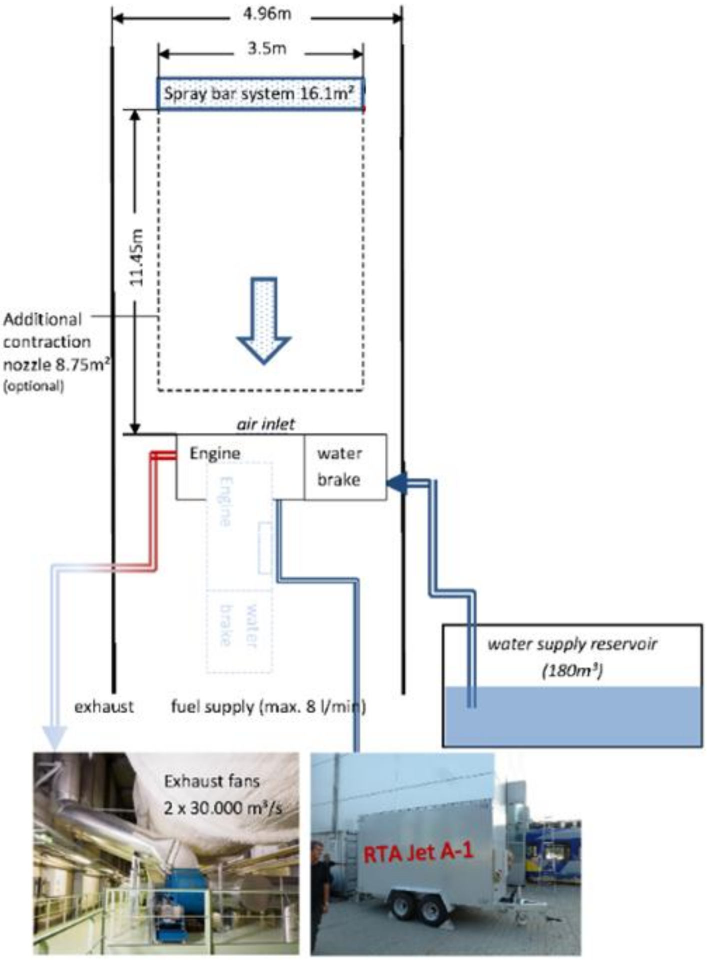


Figure 19: Setup for an air intake test with a running engine, including the supply systems inside the IWT.

6.5.2 Wing Tests

Tests on full-scale wing sections can be carried out with the RTA Force Jig (Figure 20). The Force Jig is a trailed wing mounting device with two side walls supporting the force measurement and the wing. The distance between the side walls can be adjusted to match the size of the wing. Wing tips can also be mounted on one side wall using a special adapter plate as shown in Figure 20. The results of the force measurement can be used for a qualitative comparison of the aerodynamic coefficients of the dry reference wing and different ice shapes (an example can be seen in Figure 21 and Figure 22). It has to be considered that the RTA IWT does not fulfil the flow requirements of an aerodynamic wind tunnel. The force measurement can be used to compare the aerodynamic situation of the dry wing section and the iced or de-iced section. Technical data of the force jig are listed in Table 8.

Table 8: Technical data of the Force Jig

Wing span	1 m up to 3 m (manually adjustable)
Chord length	Up to ~1.5 m
Temperature range	-30 °C to +20 °C
Angle of Attack (AoA) range	-20° to +20° (accuracy ±0.1°)
Force measurements	Lift (C_L), max. load of 20 kN – accuracy: ±20 N Drag (C_D), max. load of 20 kN – accuracy: ±20 N Moment (C_M), max. load of 1.5 kNm – accuracy: ±1.5 Nm
Customer Interface	Mounting plate / heated splitter blades

Figure 20: Test setup for a wing section test inside the IWT.

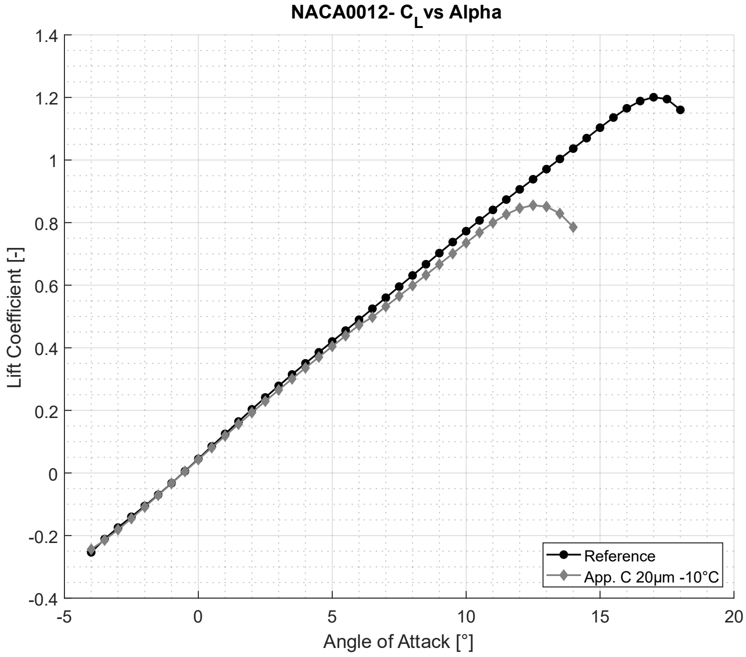


Figure 21: Lift coefficient versus angle of attack comparison for a dry and an iced NACA0012 wing.

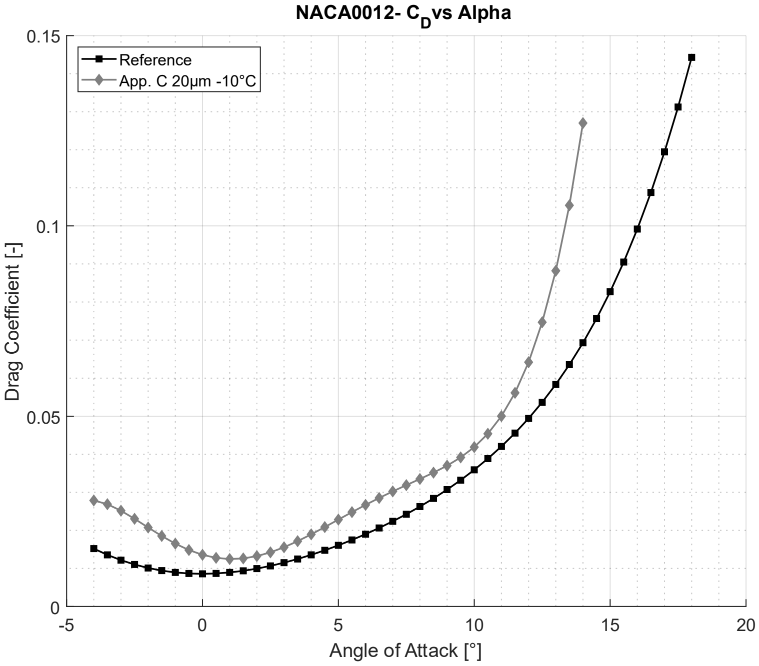


Figure 22: Drag coefficient versus angle of attack comparison for a dry and an iced NACA0012 wing.

For additional evaluation RTA offers the use of a high speed camera system (up to 1000 frames per second), a high-resolution 3-D scan with ice accretion density evaluation (see Figure 24 and Figure 25) as well as a high speed pressure acquisition unit with up to 32 channels (range: ± 7kPa).

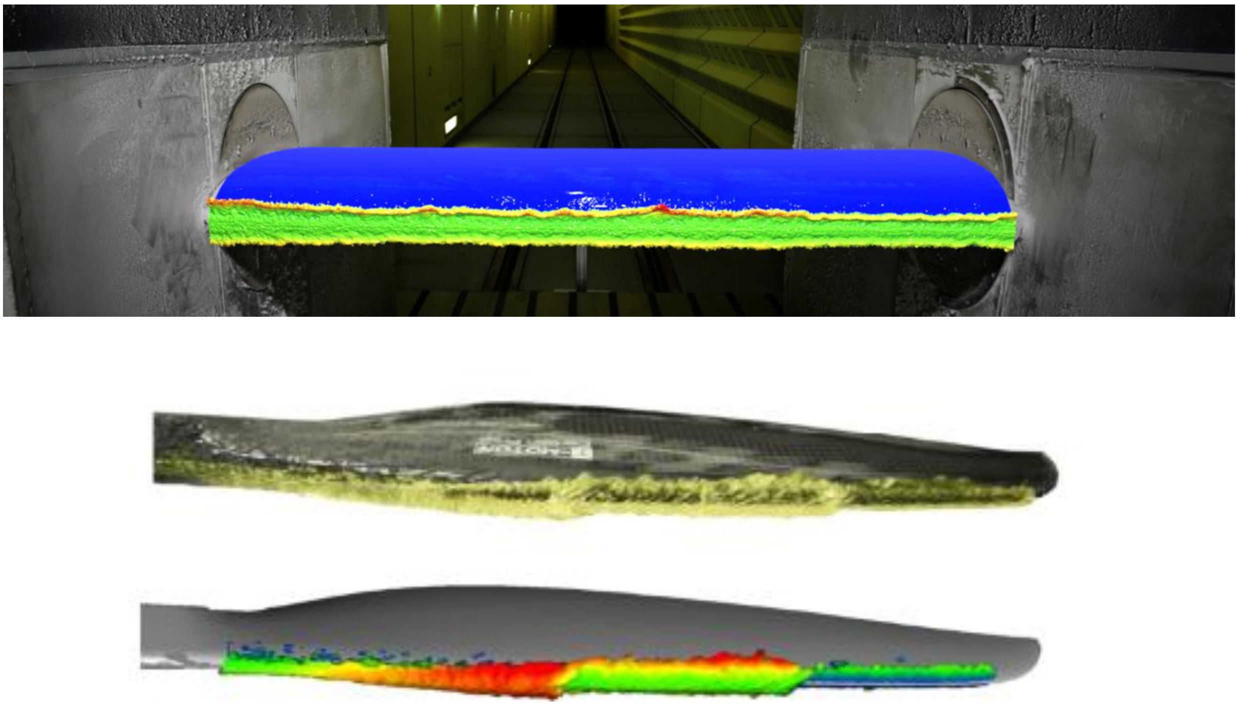


Figure 23: 3-D scan of ice shapes on a wing section and a UAV propeller in the RTA IWT created by AIIS.

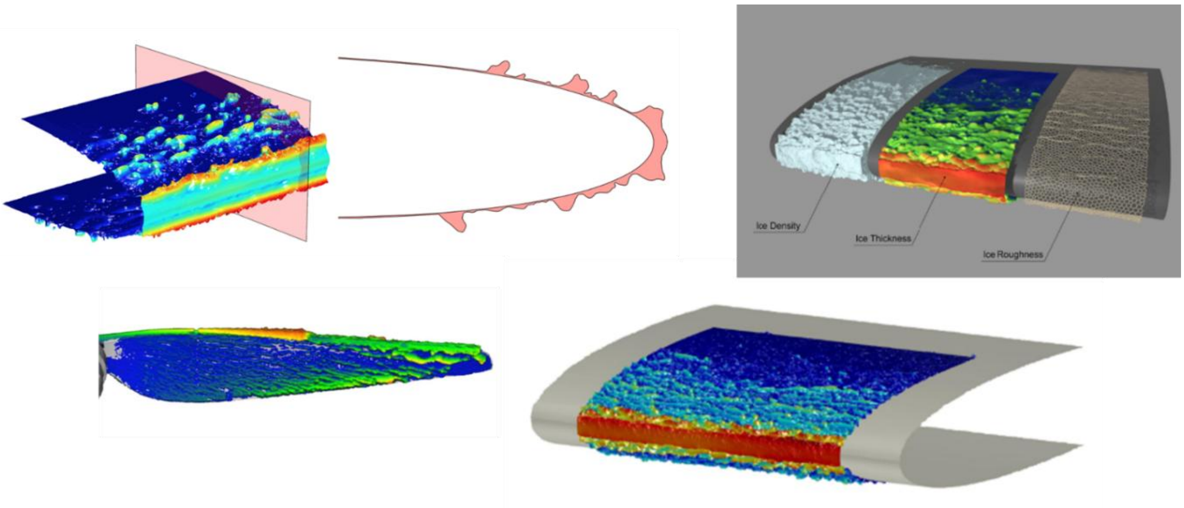


Figure 24: 3-D scan result of ice shapes generated in the RTA IWT incl. ice density, ice thickness and ice roughness, created by AIIS.

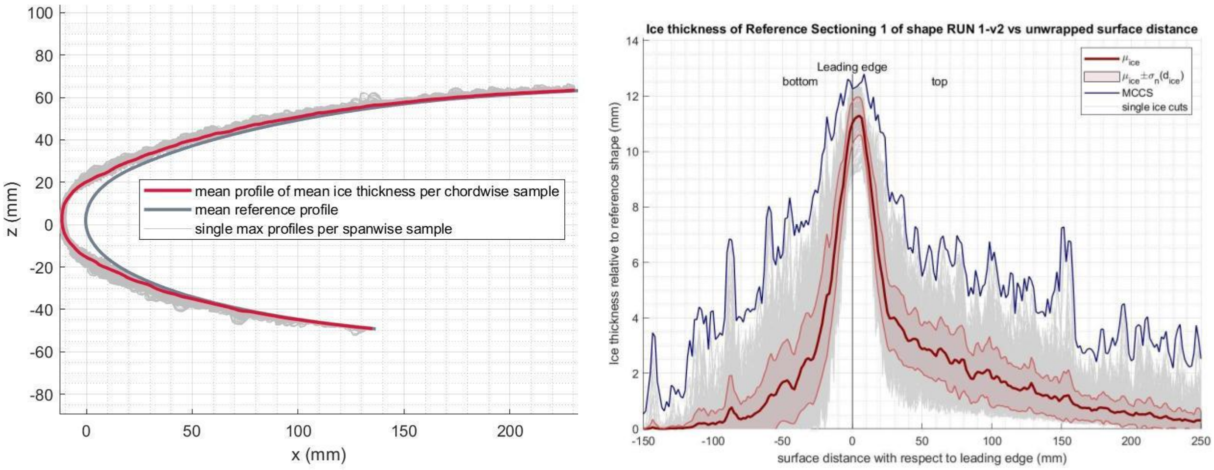


Figure 25: Detailed evaluation of an Appendix O ice shape generated in the RTA IWT, created by AIIS.

6.5.3 Propeller and Rotor Tests

RTA provides the test rigs “PropRig” and “AGIROS” to conduct propeller and rotor tests in icing conditions. The PropRig is suitable for general aviation - type propellers and tail rotors. The AGIROS test bench is designed for open rotor development and can also be used for general aviation type propellers. On both test benches, electrical power can be transmitted to the specimen to operate an IPS. The preparation of the specimen and test runs can be conducted in a separate safety room (the Soakroom, see Section 5.3).

Three different setup configurations in the wind tunnel are available. Figure 26 shows the PropRig and the AGIROS test bench in the standard configuration. Figure 27 shows the PropRig in pusher configuration including a dummy fuselage cover. In the third configuration, the axis of rotation is orthogonal to the airflow as for a helicopter tail rotor shown in Figure 28. In Table 9 the main specifications are summarized.

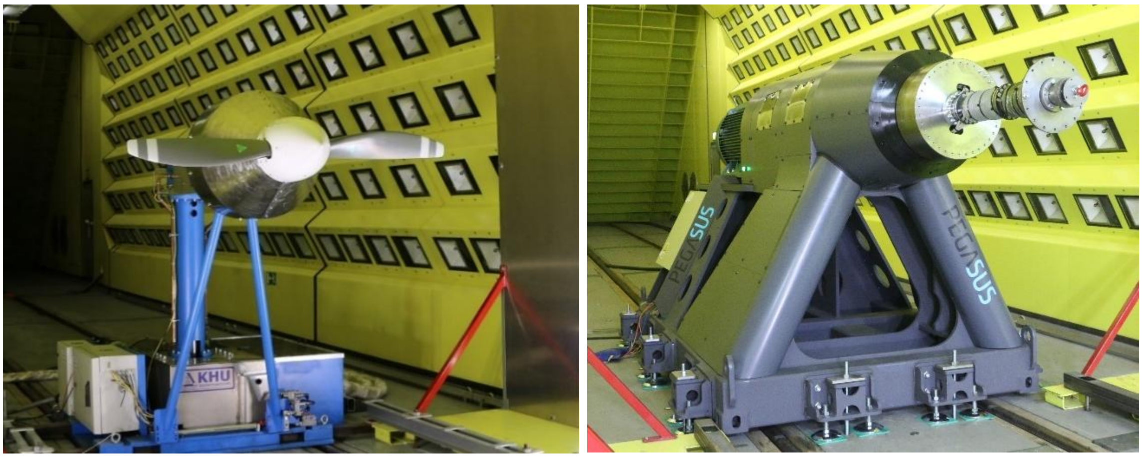


Figure 26: Standard configuration of the Prop Rig shown in the left image. Agiros test bench shown in the right image.

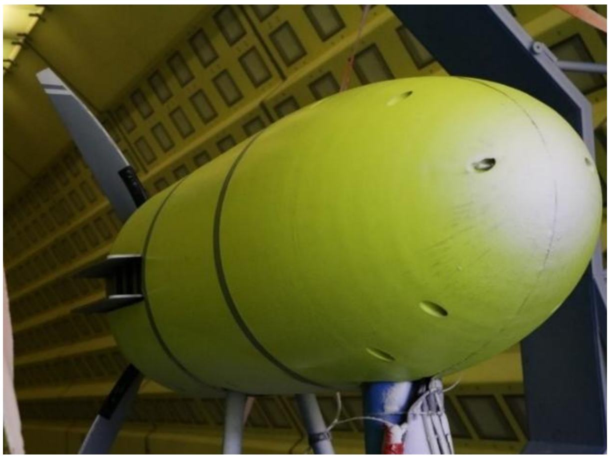


Figure 27: Prop Rig in pusher configuration including a dummy fuselage cover.

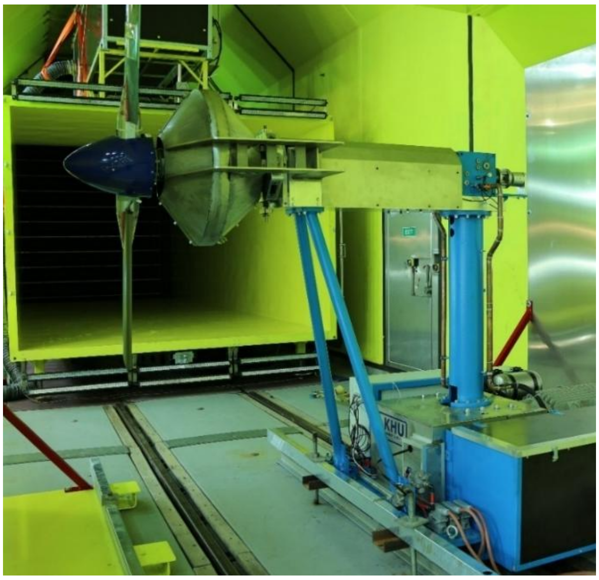


Figure 28: Prop Rig in tail rotor configuration.

Table 9: Technical data of the propeller test benches.

	PropRig	**AGIROS**
Shaft power	180 kW	315 kW
shaft speed	2500 rpm	1900 rpm
Torque	700 Nm	3000 Nm
Max specimen weight	30 kg	450 kg
Max imbalance	75 g*m	500 g*m
IPS power supply	8 x 400V / 35 A (16 sliprings)	7 x 800 VDC / 20 A (18 sliprings)
Strain measurement	8 x quarter bridge 1000 Ohm	Quarter and full bridge
Temperature measurement	-	PT100 & Thermocouple type K
Pressure measurement	-	via quarter bridge port

6.6 Snow Tests

The following sections describe RTA's snow capabilities and include the operating envelopes in terms of Median Volume Diameter (MVD) or Median Mass Diameter (MMD) and Total Water Content (TWC) respectively.

6.6.1 Blowing Snow

Blowing snow is generated by means of the RTA IcingRig with a dedicated set of air atomizing spray nozzles (see Figure 29). Depending on the customer requirements, specific snow conditions with a TWC up to 1 g/m³ at 80 m/s and a MVD in the range of 10 µm to 40 µm can be provided based on an individual calibration. The snow density is approximately 300 kg/m³.

Figure 29: Nozzle setup for blowing snow tests in the RTA IWT and snow piled up.

6.6.2 Nature-like Falling and Blowing Snow

Within the Horizon 2020 project ICE GENESIS[7], a new technology has been developed that recreates natural snowflakes (see Figure 30) in the temperature range from -10°C to +3°C.

The nature-like snow is produced by a snow machine that can be mounted either in the contraction nozzle (prototype solution) or on the ceiling of the IWT. Blowing and falling snow can be produced by running these systems with and without wind, respectively.

Calibration results of the new snow generation system in a blowing snow setup as well as snow accretion data on a NACA0012 test article with a chord length of 0.377 m are shown in [1]. Three different snow density "recipes" from wet to dry snow conditions were investigated enabling snow tests at a TWC up to 0.6 g/m³ at 40 m/s and a MMD in the range of 500 µm to 700 µm with particles up to 5 mm.

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[7] Natural-Like Snow Conditions in the Rail Tec Arsenal (RTA) Icing Wind Tunnel", 2023-01–140 Breitfuß, W., Ferschitz, H., Schwarzenboeck, A., Heller, R., Pervier, H., Dupuy, R., Jaffeux, L., Berne, A. „Experimental Simulation of Natural-Like Snow Conditions in the Rail Tec Arsenal (RTA) Icing Wind Tunnel, SAE International Journal of Advances and Current Practices in Mobility 2023-01-1407: https://doi.org/10.4271/2023-01-1407

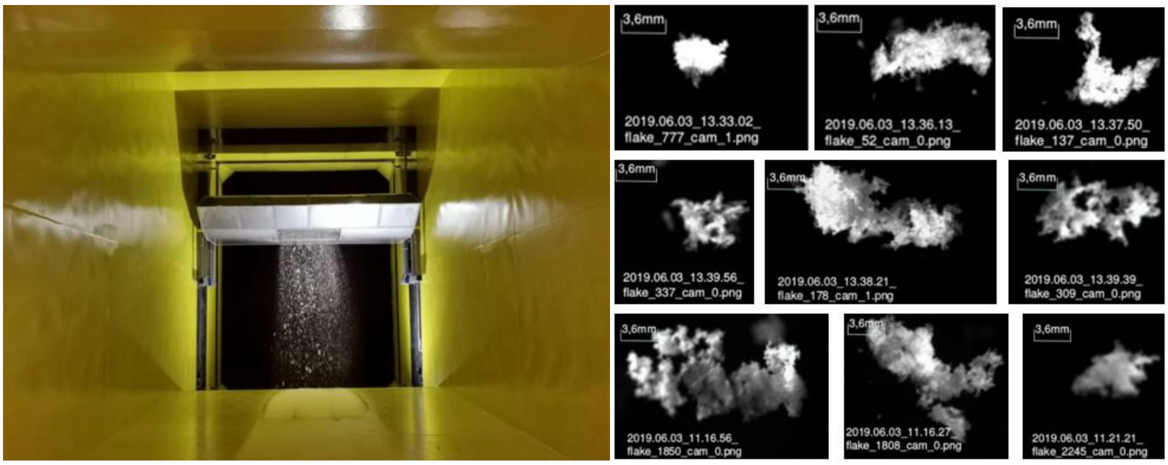

Figure 30: Snow fall technology in the RTA IWT and snow particle morphology results.

For a falling snow setup (i.e. minimal wind), the MMDs are larger, typically between 7 and 9 mm, with individual snow particle sizes ranging from 500 µm to 4 cm. A snow production between 20 – 120 kg/h is possible, which allows to perform tests that meet the requirements of 1 g/m³ that is stated in CS-25.1093, Point 1[8,9]. The snow density varies between 150 and 300 g/m³. It is possible to produce also wet falling snow through humidification nozzles in the snow generation system.

7. Summary of Icing Wind Tunnel Calibration

This section of the report describes the IWT calibration and validation procedures that are performed in accordance with the recommended practices for calibration and acceptance of IWTs (SAE ARP5905A [1]). The following aerodynamic parameters are regularly validated:

- True airspeed and airspeed uniformity
- Air temperature and air temperature uniformity
- Flow angularity
- Flow turbulence

Furthermore, the following icing cloud parameters are regularly validated:

- Liquid water content and liquid water content uniformity
- Median volume diameter

Validation and calibration reports of the above-mentioned parameters can be made available upon request.

7.1 Airspeed and airspeed uniformity

RTA uses a cup anemometer for the validation of low windspeeds (typically 20 m/s or lower), and a Prandtl tube for measurements of windspeeds up to the tunnel maximum of 80 m/s. For the measurement of the airspeed uniformity, the instrument is traversed through the tunnel cross section. An example of an airspeed uniformity distribution for an airspeed of 40 m/s at RTA is shown in Figure 31. The airspeed uniformity depends on the tunnel configuration, the

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[8] (https://www.easa.europa.eu/en/document-library/easy-access-rules/online-publications/easy-access-rules-large-aeroplanes-cs-25?page=37)

[9] AC29-2C Advisory Circular ‘Certification of transport category rotorcraft’. Available at: https://www.faa.gov/documentlibrary/media/advisory_circular/ac_29-2c.pdf

airspeed and the purge (standby) pressure of the nozzles of the Icing Rig. The uniformity typically increases if the additional contraction nozzle is installed and with increasing airspeed. Detailed validation reports are available on request.

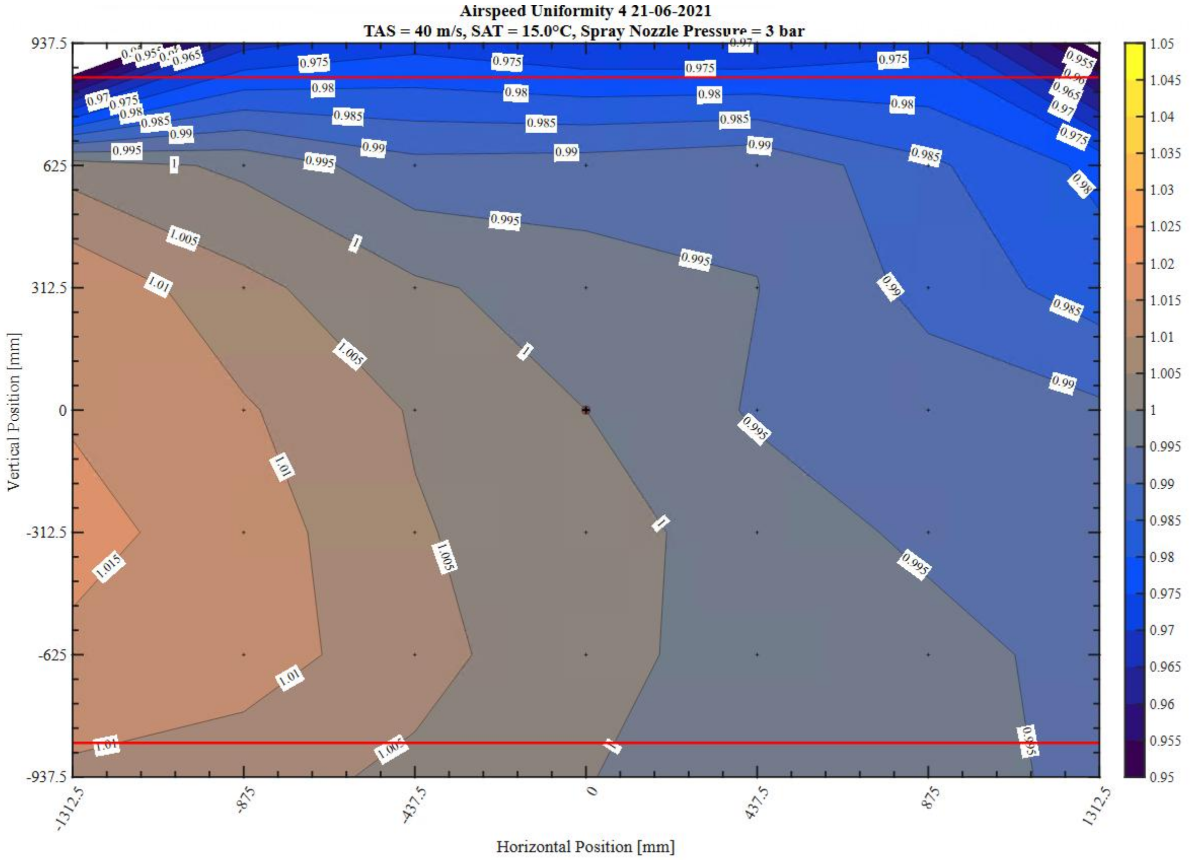

Figure 31: Airspeed distribution in the LWT at 40 m/s and 3 bar spray nozzle purge pressure. Red lines indicate the boundary of the test section. Vertical position zero corresponds to the center of the test section at a height of 1.9 m.

7.2 Air temperature and air temperature uniformity

The air temperature is measured with a specially shielded and calibrated PT-100 sensor. Similar as for the airspeed measurement, the PT-100 sensor can be traversed across the tunnel cross-section to obtain measurements of the temperature uniformity. An example of the temperature uniformity can be seen in Figure 32. Detailed calibration reports are available on request.

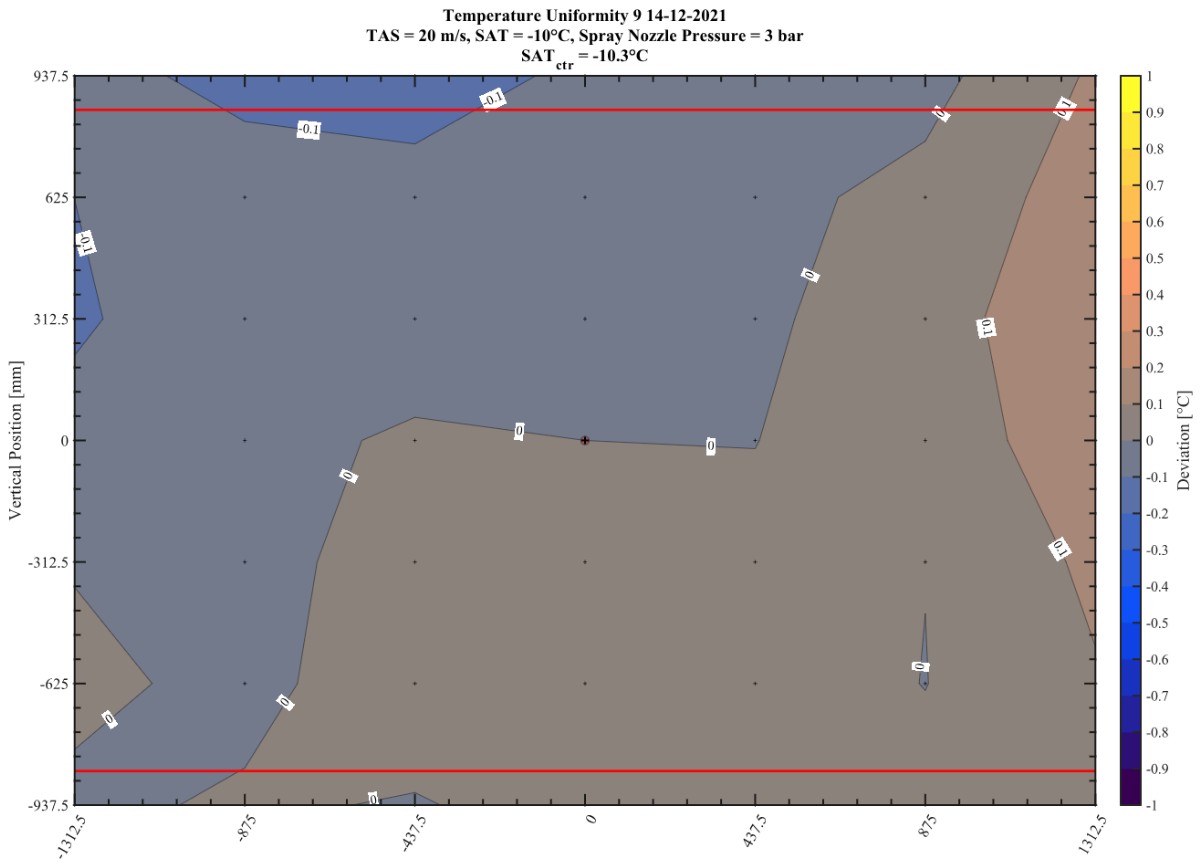

Figure 32: Air temperature distribution in the SWT without additional contraction nozzle for a static air temperature of -10°C and an airspeed of 20 m/s. The color code indicates deviations from the temperature at the center of the test section, which is -10.3°C. Red lines indicate the boundary of the test section. Vertical position zero corresponds to the center of the test section at a height of 1.9 m.

7.3 Flow angularity

The flow angularity in pitch and in yaw direction at RTA can be measured with a five-hole probe, whose pressure values are recorded with a Scanivalve of RTA. The flow angularity has been established for the empty tunnel cross section. The installation of test articles typically changes the flow angularity. Aerodynamic measurements can be performed ahead of the testing to assess how the installation and the test article affect the flow angularity.

7.4 Flow turbulence

The flow turbulence intensity is measured with a hotwire anemometer, which can be traversed through the test section. The flow turbulence intensity depends on the IWT setup, it is smaller when the contraction nozzle is installed. It is furthermore also affected by the purge pressure of the Icing Rig, high purge pressures increase the turbulence intensity. An example image of the turbulence intensity is shown in Figure 33.

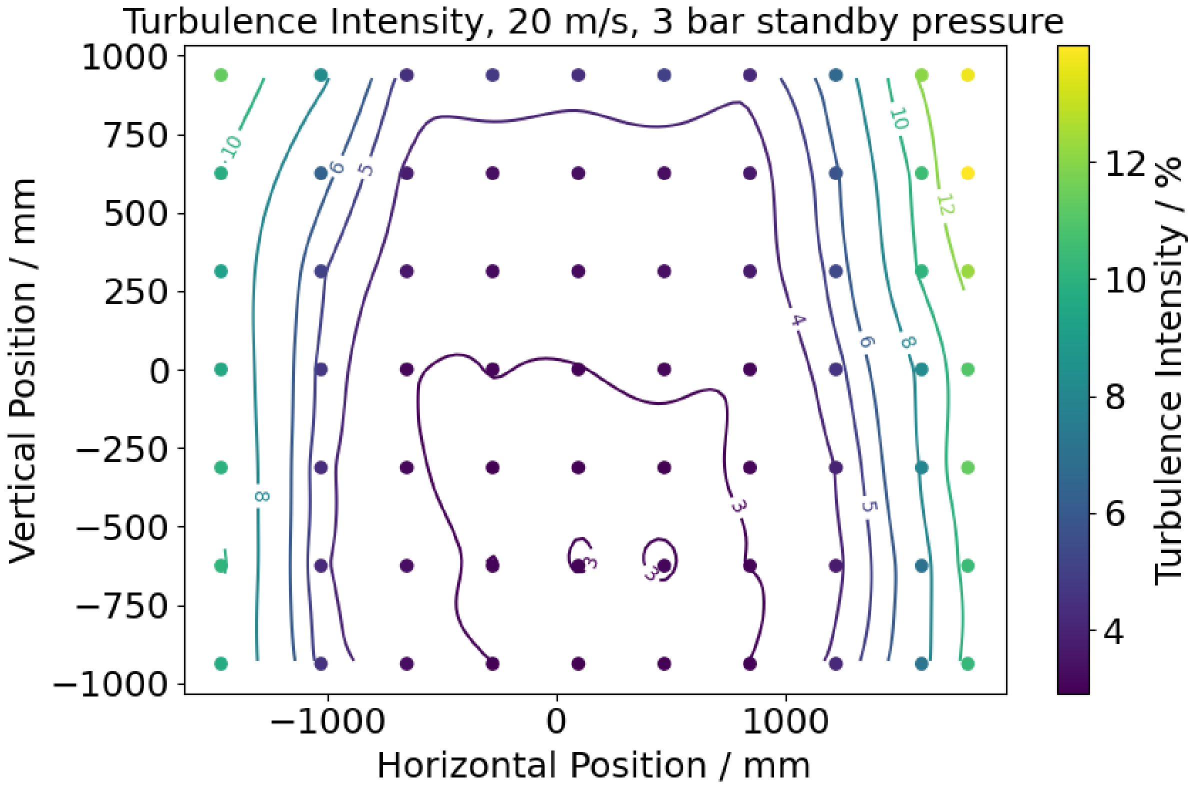

Figure 33: Turbulence intensity in the SWT without the additional contraction nozzle and with 3 bar standby purge pressure active at the Icing Rig.

7.5 Icing Cloud Size and Uniformity

The icing cloud size relative to the cross-sectional area and its uniformity are validated using an ice accretion grid. The grid is exposed to rime ice conditions for a certain amount of time to achieve a target ice thickness of about 6.4 mm. Afterwards, it is manually measured at specific positions (see Figure 34) using a caliper, as seen in Figure 35. All the measurements are converted to relative LWC normalized to the center of the test section.

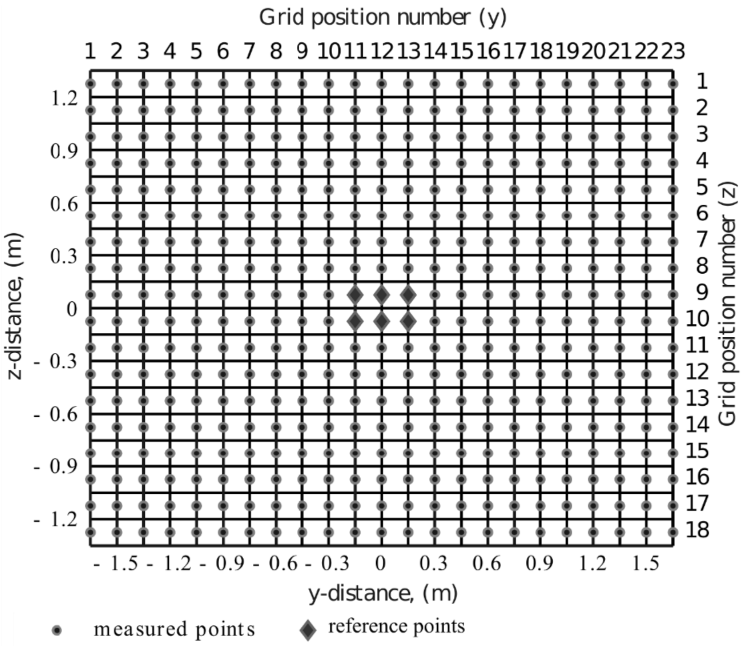

Figure 34: Measurement locations for icing cloud uniformity. The reference points are indicated with black diamonds.

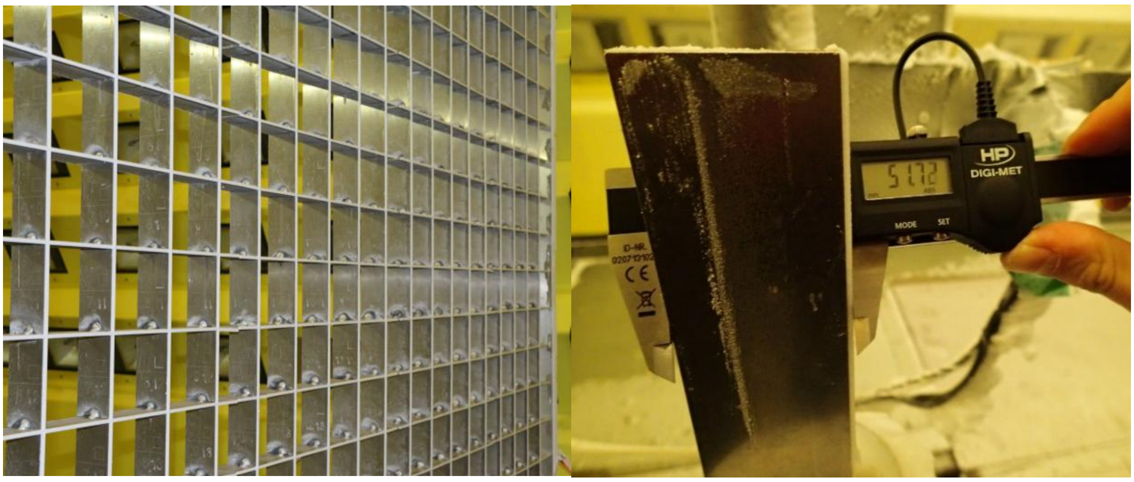

Figure 35: Icing grid with ice accretion (left) and measurement of the ice thickness with a computerised sliding calliper (right).

Two examples are provided for the reduced cross-sectional area, one at a higher airspeed and an MVD of 20 µm (Figure 36) and one at a lower airspeed with an MVD of 40 µm (Figure 37). The results show that the area of interest is uniform in accordance with the requirements of the SAE ARP5905A.

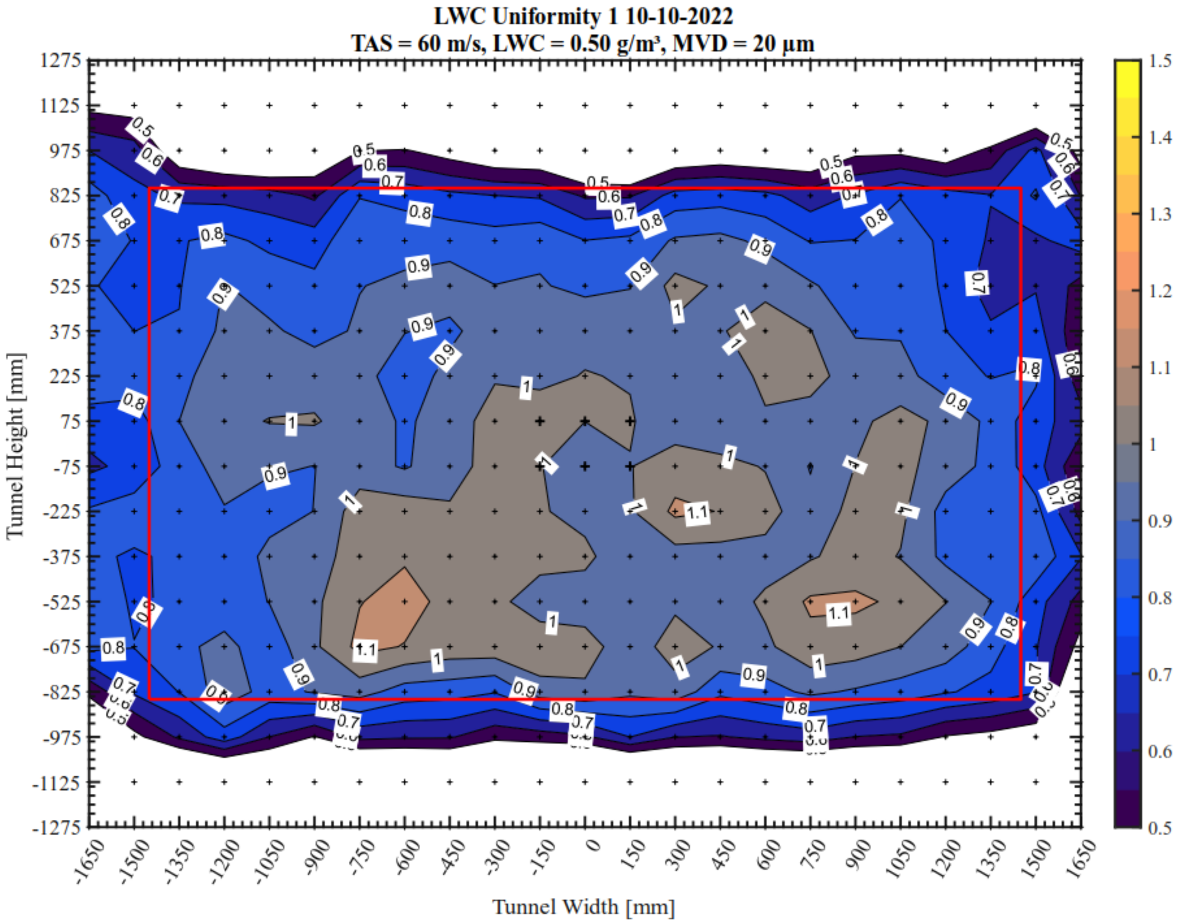

Figure 36: LWC uniformity at 60 m/s and LWC 0.5 g/m³; droplet MVD 20 µm. Red lines indicate the boundary of the test section.

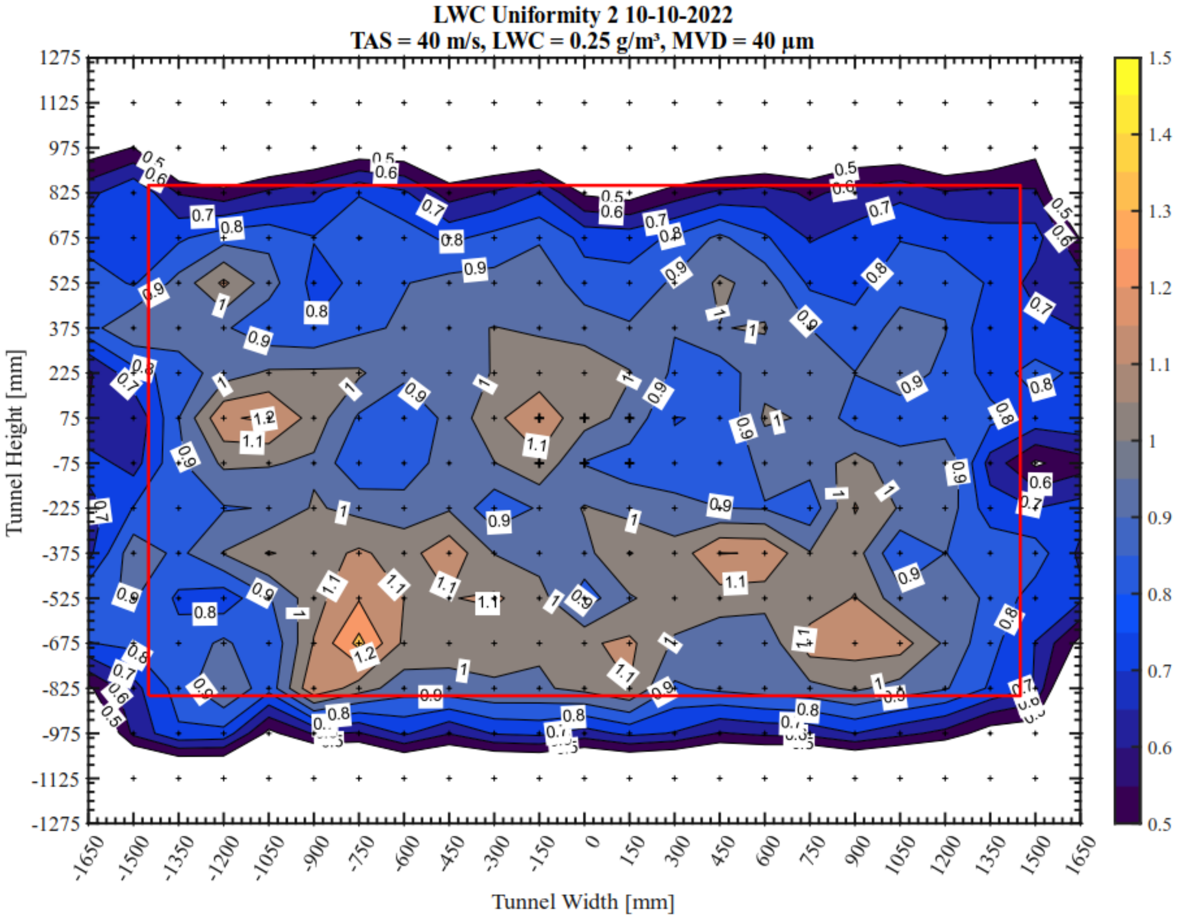

Figure 37: LWC uniformity at 40 m/s and 0.25 g/m³; droplet MVD 40 µm. Red lines indicate the boundary of the test section.

Figure 38 shows the measured LWC uniformity for the Freezing Drizzle MVD > 40 µm condition. In Figure 39 the current LWC uniformity capability for the experimental Freezing Rain MVD > 40 µm configuration is shown.

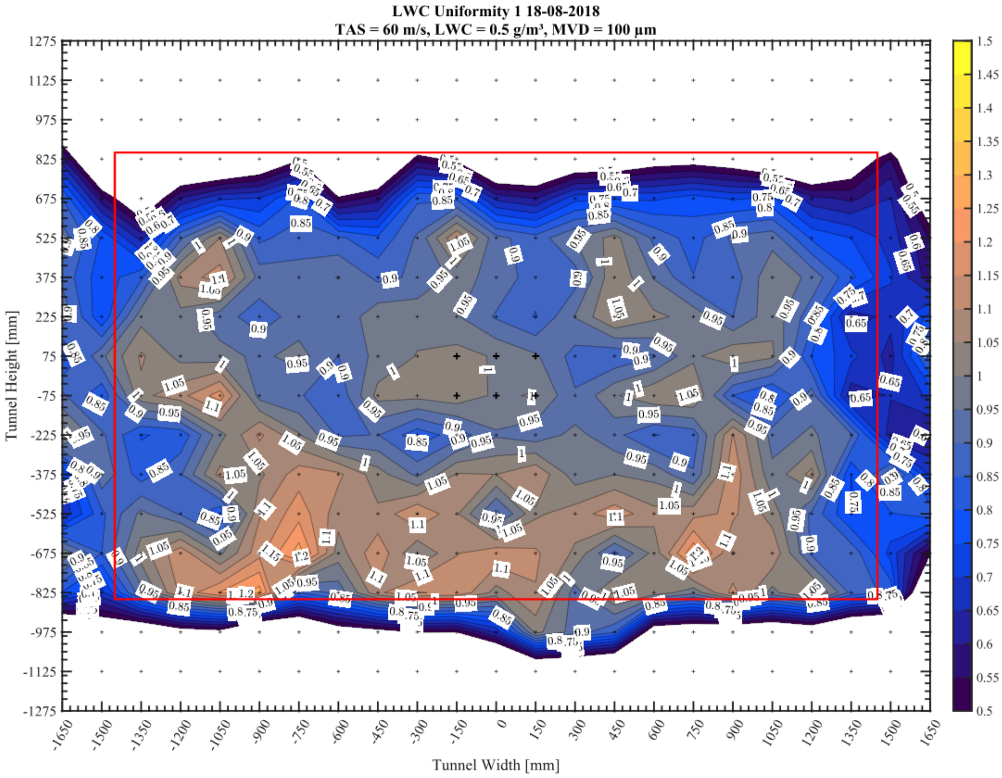

Figure 38: LWC uniformity at 60 m/s and 0.5 g/m³; Freezing Drizzle MVD > 40 µm. Red lines indicate the boundary of the test section.

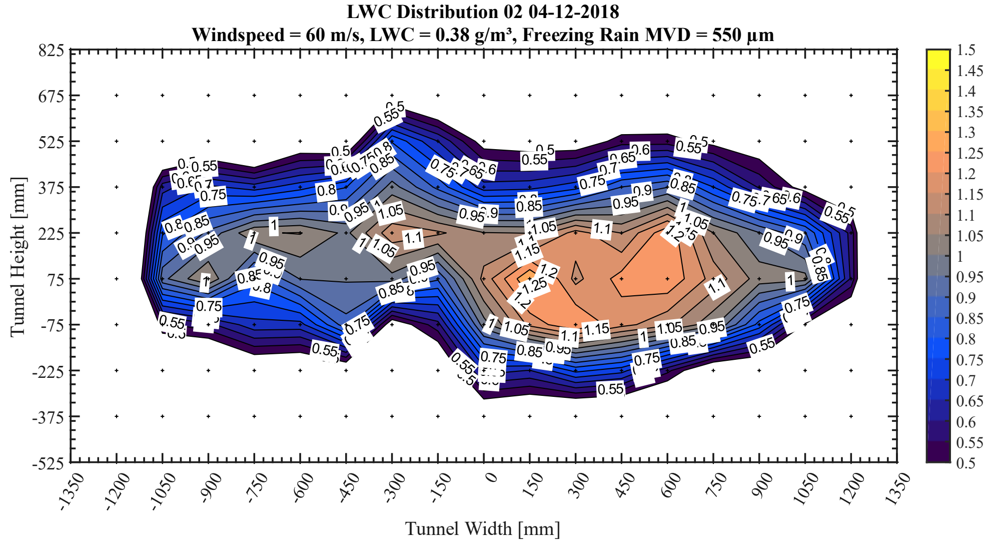

Figure 39: LWC uniformity at 60 m/s and 0.38 g/m³; Freezing Rain MVD > 40 µm [10].

7.6 Liquid Water Content (LWC)

For the LWC calibration the icing blade method as described in the SAE ARP5905A is used. The icing blade is shielded by a metal housing to protect it from ice contamination prior to spray stabilization (see Figure 40). As soon as the spray is stabilized, the blade is extended using a

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[10] the freezing rain simulation will be performed with a prototype setting, a permanent improvement is under development and will increase the stability of the spray system as well as the covered area.

double acting pneumatic cylinder. The exposure duration to the cloud depends on the LWC and should result in an ice thickness of 1.5 mm to 4.5 mm. After the exposure the blade is retracted again, the ice accretion is documented using a camera and automatically evaluated at multiple positions using a specially developed algorithm. Finally, the blade is cleaned from the ice and can be used again. As the blade method is only valid if all impinging water freezes on impact, the measurements are performed at an ambient temperature of -18 °C.

Figure 40: Icing blade installed in the test section.

The results of a LWC calibration are shown in the following figures. The specific liquid water content (lwc) is plotted, which is the liquid water content (LWC) normalized by a factor, which depends on the number of active nozzles and the airspeed. This makes test points with different airspeed and nozzle settings comparable. The lwc depends on the water supply pressure and the air supply pressure, as does the MVD. Thus, both the MVD and the lwc can be set to the test requirements by varying the water and air supply.

To visualize the correlation of the fitted model to the measured data, the values are placed on separate axes and plotted against each other in Figure 41 (without contraction nozzle) and in Figure 42 (with contraction nozzle). The grey area represents a ±10% deviation from the ideal value, the dash-dotted line limits a ±20% deviation area.

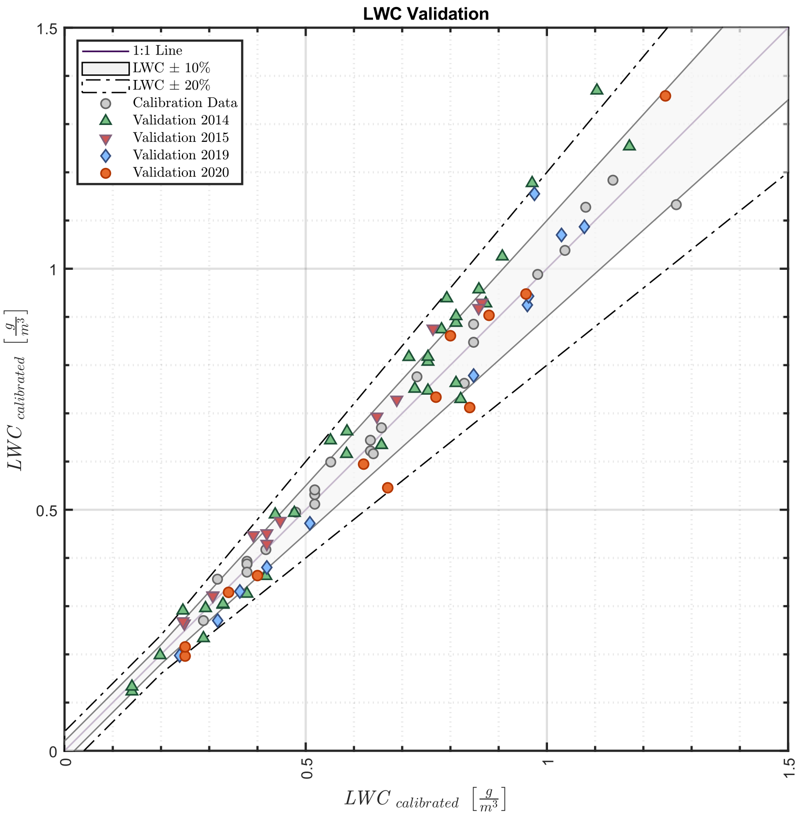

Figure 41: Comparison of measured versus calibrated LWC, Test Setup 1.

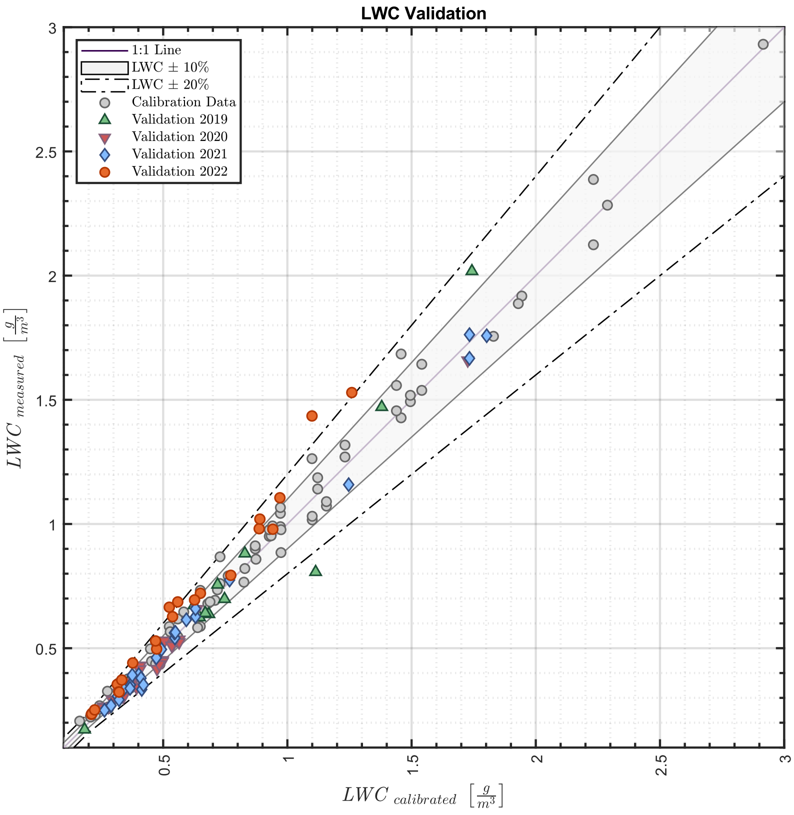

Figure 42: Comparison of measured versus calibrated LWC, Test Setup 2.

7.7 Water Droplet Size and Median Volume Diameter (MVD)

Measurements of the median volume diameter (MVD) are available as a function of water and air supply pressures for both the full and the reduced cross-sectional area. The MVD is measured using the laser diffraction system “Spraytec” from Malvern Instruments Ltd. The instrument is equipped with a 300 mm lens and is capable of measuring droplets in a range from 0.1 µm to 900 µm.

Particles produced by the spray nozzles are not all the exact same size. Example images of typical droplet size distributions are shown for MVDs of 20 µm (Figure 43) and 40 µm (Figure 44).

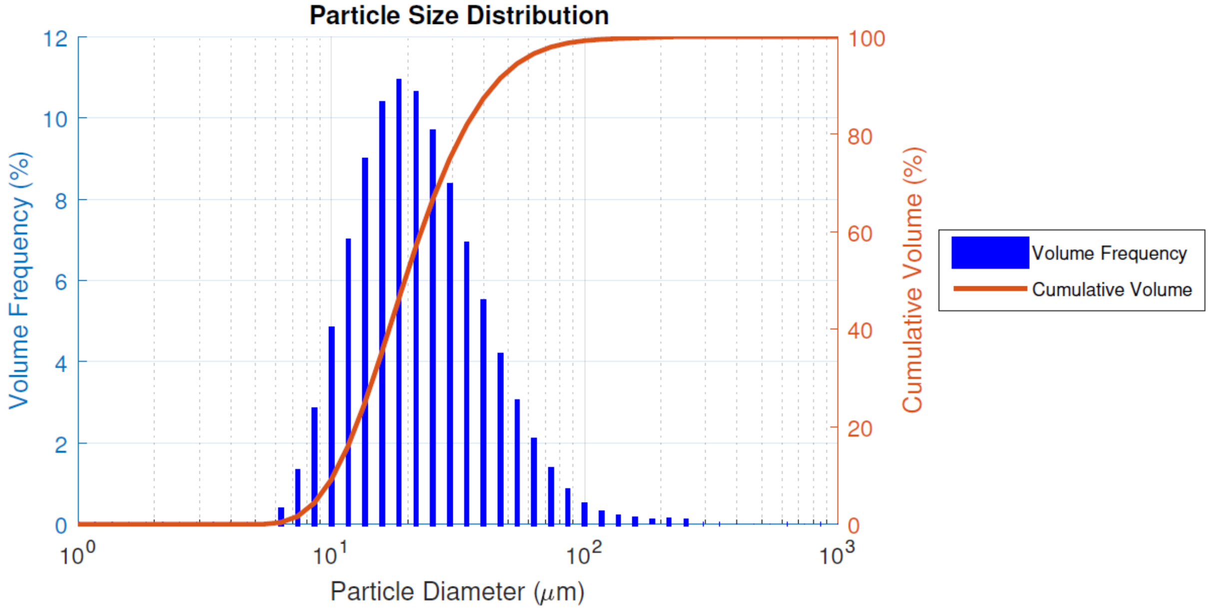

Figure 43: Droplet size distribution of an MVD = 20 µm cloud.

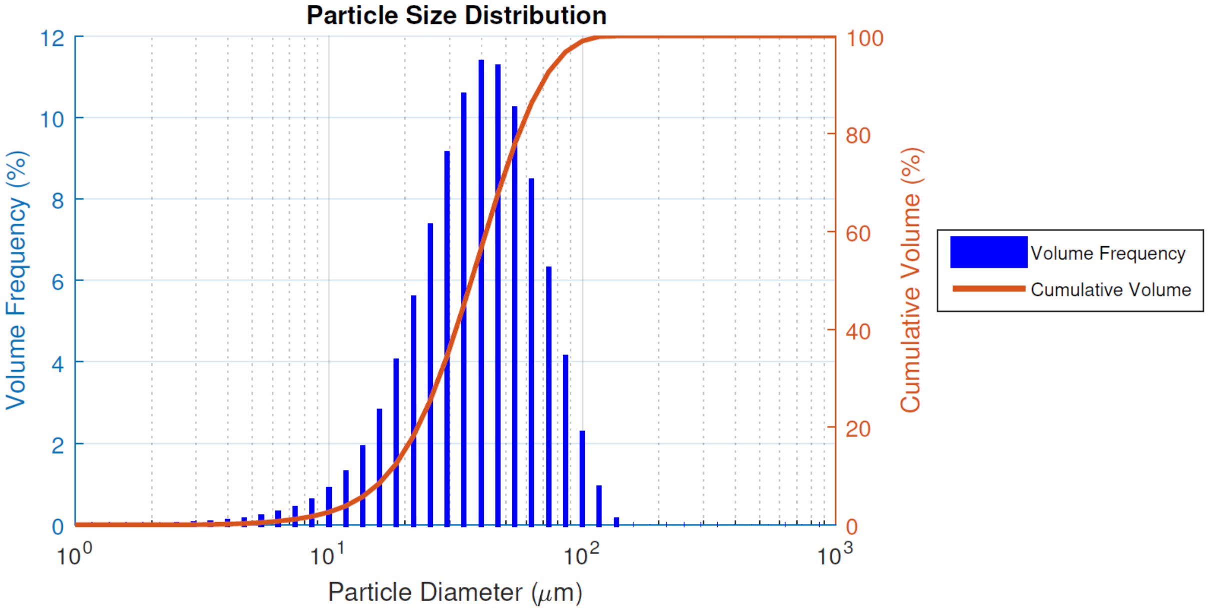

Figure 44: Droplet size distribution of an MVD = 40 µm cloud.

Droplet size calibrations are performed at the test section centre. All calibration points were put into a non-linear least squares analysis to provide a mathematical model for calculating the MVD based on the two input parameters (water and air pressure). A cross validation indicates temporal stability over the past years. To visualise the correlation of the fitted model to the measured data, the values are placed on separate axes and plotted against each other (Figure 45). The grey area represents the allowed deviation according to SAE ARP 5905A.

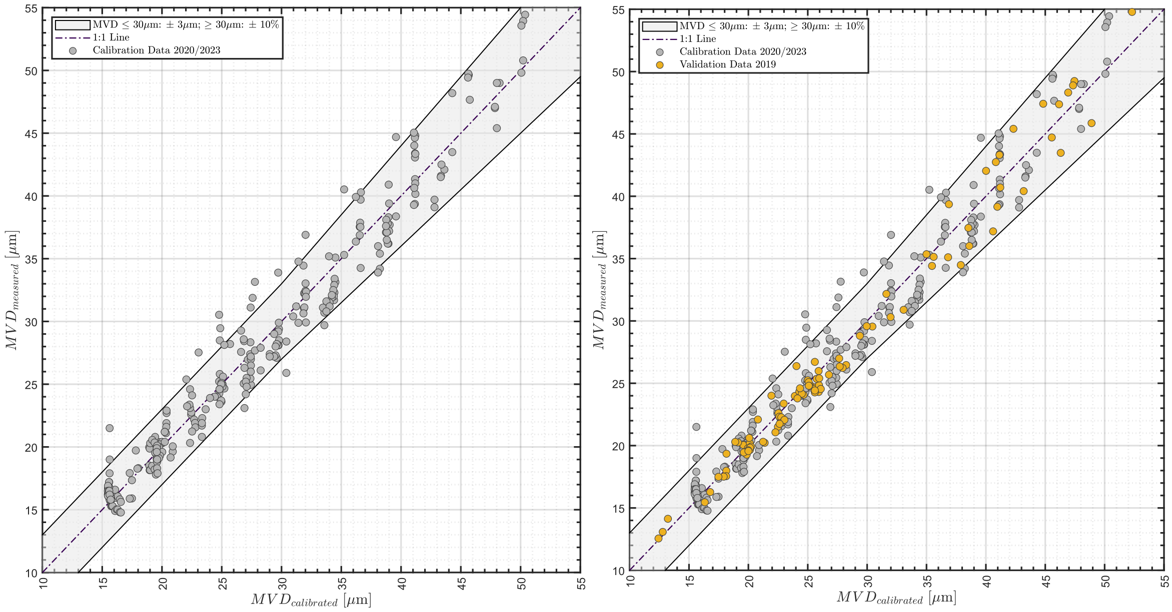

Figure 45: Comparison between measured data and the curve fit for the MVD, calibration points (left) and validation data (right).

The measured particle size distribution for Freezing Drizzle MVD > 40 μm is shown in Figure 46. The Malvern Spraytec can also be equipped with a 750mm lens in to measure droplets with a diameter range of 2.0 - 2000 microns. This configuration was used for the measurement of the particle size distribution of Freezing Rain MVD > 40 μm (see Figure 47).

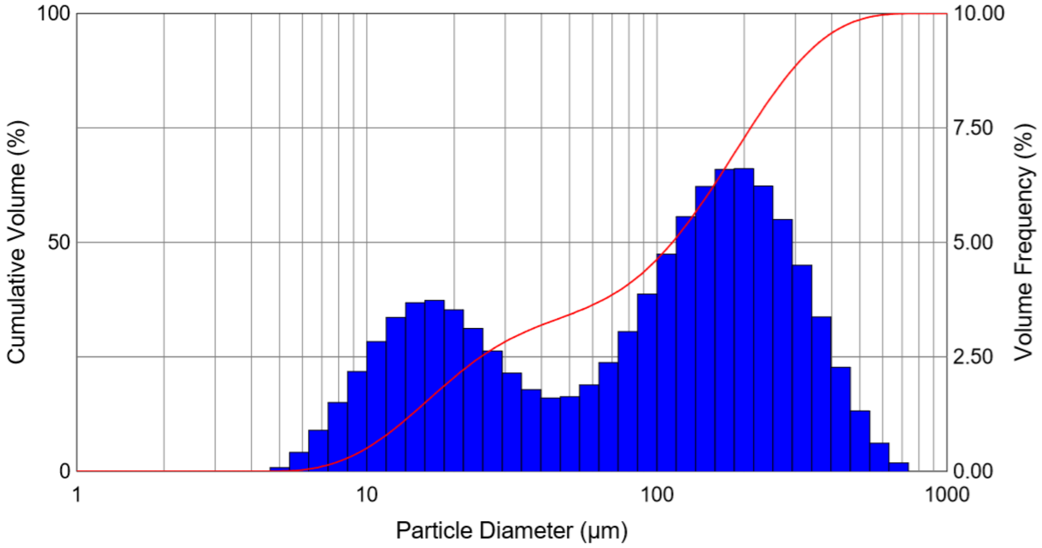

Figure 46: Measured particle size distribution for Freezing Drizzle MVD > 40 μm using the Malvern Spraytec.

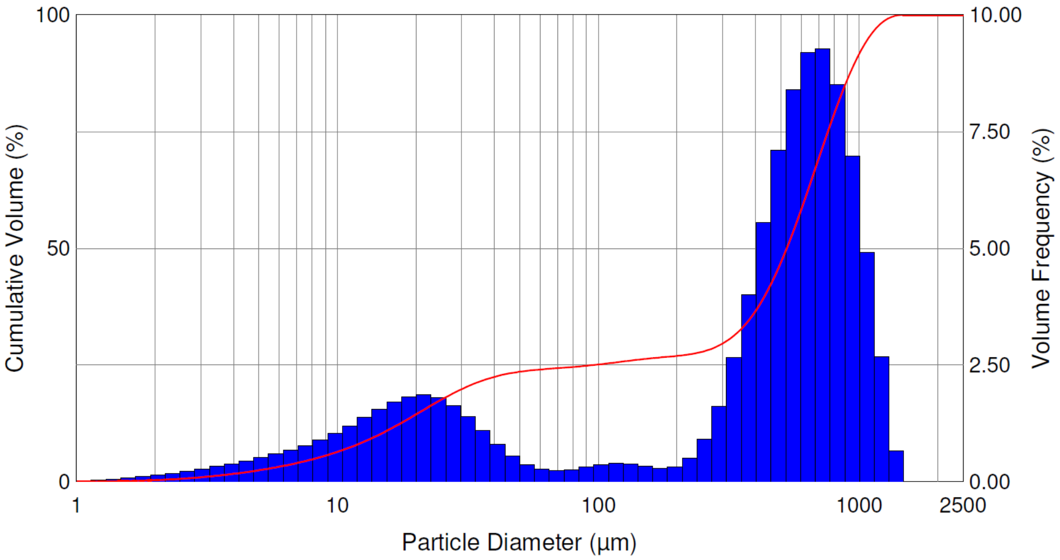

Figure 47: Measured particle size distribution for Freezing Rain MVD > 40 µm using the Malvern Spraytec.

8. Summary

In the two IWTs of Rail Tec Arsenal a large range of environmental conditions can be replicated. Slow flying aircraft such as helicopters, unmanned aerial vehicles and small aircraft can be tested in the speed-range they operate in. Components of faster flying aircraft have also been tested numerous times at RTA, if necessary, scaling laws are applied to compensate for the slower speed during the test. Please contact RTA for details.

Water treatment allows heating of the water for low icing temperatures as well as pre-cooling for icing tests close to an ambient temperature of -2 °C. The distance of 11.5 m between the spray nozzle exit and the test section provides sufficient time to supercool small and large droplets, this makes it possible to test also Appendix O conditions at RTA. The design of the spray bar system (2 separately controllable circuits per spray bar) provides the opportunity to produce bimodal spray conditions as well.

The additional integration of the small CWT for pre-conditioning of the needed fresh air provides the unique opportunity to carry out icing tests also on running engines at temperatures down to -30 °C and loads up to 1.5 MW.

To further support the test needs of our customers, a wide range of voltage sources and dried compressed air as well as bleed air and mass flow simulation systems are available for icing tests. Detailed calibration documents for both IWTs are available on request. Please contact us with your test requirements and we will find a suitable solution for you.

Contact: aviation@rta.eu

9. Relevant Publications

[1] Breitfuß, W., Ferschitz, H., Schwarzenboeck, A., Heller, R. et al., "Experimental Simulation of Natural-Like Snow Conditions in the Rail Tec Arsenal (RTA) Icing Wind Tunnel," SAE Technical Paper 2023-01-1407, 2023, https://doi.org/10.4271/2023-01-1407.

[2] Breitfuß, W., Moser, R., Hassler, W., Ferschitz, H. et al., "Comparison of Numerical Simulations with Experimental Data for an Electrothermal Ice Protection System in Appendix O Conditions," SAE Technical Paper 2023-01-1396, 2023, https://doi.org/10.4271/2023-01-1396.

[3] Breitfuß, W., Wannemacher, M., Knöbl, F., and Ferschitz, H., "Aerodynamic Comparison of Freezing Rain and Freezing Drizzle Conditions at the RTA Icing Wind Tunnel," *SAE Int. J. Adv. & Curr. Prac. in Mobility* 2(1):245-255, 2020, https://doi.org/10.4271/2019-01-2023.

[4] Fallast, A., Rapf, A., Tramposch, A., Hassler, W., "Kinetic and thermal simulation of water droplets in icing wind tunnels," CEAS Aeronautical Journal, https://doi.org/10.1007/s13272-021-00558-y.

[5] Ferschitz, H., Wannemacher, M., Bucek, O., Knöbl, F. et al., "Development of SLD Capabilities in the RTA Icing Wind Tunnel," *SAE Int. J. Aerosp.* 10(1):12-21, 2017, https://doi.org/10.4271/2017-01-9001.

[6] Hassler, W., Breitfuß, W., Rapf, A., Fallast, A. et al., "Numerical Simulation of In-flight Icing by Water Droplets with Elevated Temperature," SAE Technical Paper 2023-01-1477, 2023, https://doi.org/10.4271/2023-01-1477.

[7] Kozomara, D., Amon, J., Puffing, R., Neubauer, T. et al., "Experimental Investigation of UAS Rotors and Ice Protection Systems in Appendix C Icing Conditions," SAE Technical Paper 2023-01-1380, 2023, https://doi.org/10.4271/2023-01-1380.

[8] Puffing, R., Hassler, W., Neubauer, T., Kozomara, D. et al., "Aerodynamic Assessment of Complex 3D Ice Shape Replications," *SAE Int. J. Adv. & Curr. Prac. in Mobility* 2(1):15-27, 2020, https://doi.org/10.4271/2019-01-1936.

[9] Puffing, R., Neubauer, T., Moser, R., Hassler, W. et al., "Experimental Investigation of a CRM65 Wingtip Mockup under Appendix C and Appendix O Icing Conditions," SAE Technical Paper 2023-01-1386, 2023, https://doi.org/10.4271/2023-01-1386.

[10] Tramposch A. (FH Joanneum), Thomann M. (FH Joanneum), Kozomara D. (AIIS), “Determination of Droplet Impingement on an Octocopter at different Flight and Icing Conditions with CFD Methods,” AIAA AVIATION 2021 FORUM, 2021, https://doi.org/10.2514/6.2021-2501

[11] van 't Hoff, S., Lammers, K., Jung, J., Kim, H. et al., "Icing Qualification Wind Tunnel Test of Helicopter Engine with Inlet Barrier Filter Air Intake," SAE Technical Paper 2023-01-1381, 2023, https://doi.org/10.4271/2023-01-1381.

Further information is available at https://www.rta.eu/en/expertise/professional-publication.