# General Information and Guide for Customers

## CLIMATIC / ICING WIND TUNNEL VIENNA

Version 5.3
July, 2023

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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 and IWT performance
- RTA services
- Description of test setup for engine inlets, wing sections and rotors
- Summary of icing cloud calibration

# 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 ARP5905 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 completely impartially and independently and grants all its customers the same terms and conditions.

The official accreditation requires strict compliance with stringent quality guidelines in terms of the correctness and reliability of the tests performed. RTA meets these high requirements by constantly improving the quality management system and by continuously upgrading the testing and measuring facilities in line with the latest developments in 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 us to recognize the latest trends and tap new market potentials in order to be able to provide tailored solutions. We intend to further extend our core business in the rail vehicle sector to include road vehicle manufacturers as well as the aviation and construction industries.

Each customer receives a general safety and access information briefing before entering the facilities of RTA.

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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.

# 5. Facility

RTA operates two modern Climatic Wind Tunnels (CWT) designed to optimize thermal comfort in public transport vehicles and to investigate and improve the availability and safety of systems in sensitive industrial areas.

Figure 1 shows the overview of the facility, which consists of a control room, the large and the small CWT arranged in parallel, the corresponding measurement rooms, a soak room, two preparation halls and other rooms with technical equipment, such as power supply units or the refrigeration unit. Figure 2 shows a rendering of both CWTs. Both wind tunnels can be modified to act as an Icing Wind Tunnel (IWT), for further information refer to Chapter 6.

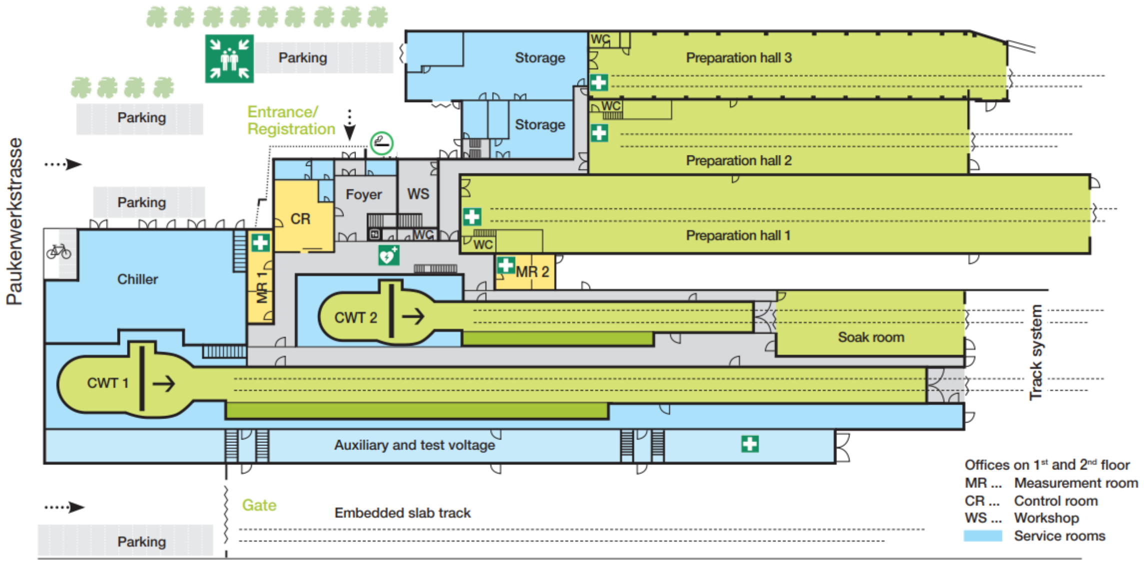

**Figure 1:** Facility overview

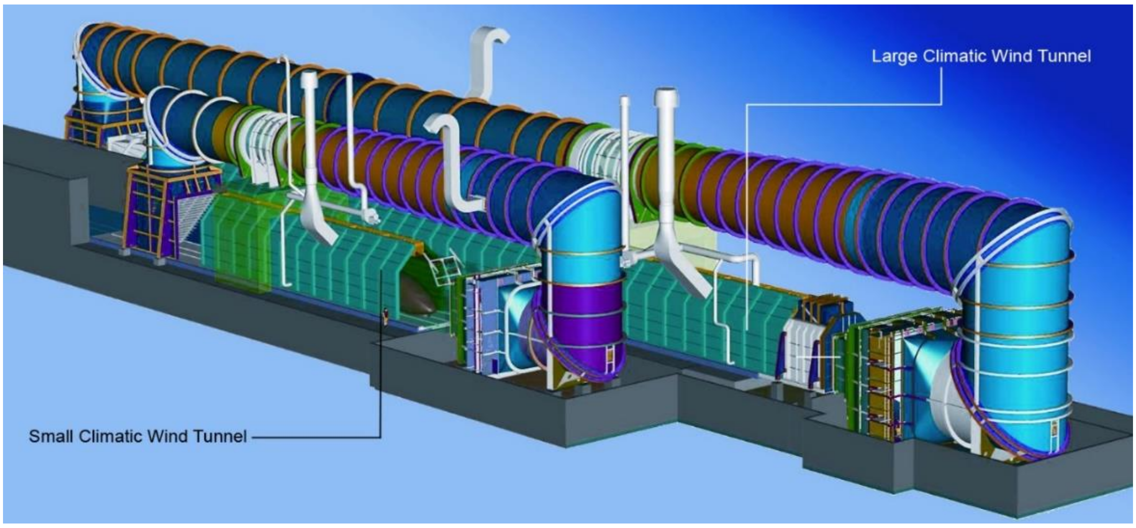

**Figure 2:** Large and Small Climatic Wind Tunnel

## 5.1 Climatic Wind Tunnels

The small Climatic Wind Tunnel (small CWT) as shown in Figure 3 can be used for rail vehicles, road vehicles, technical systems, aircraft engine cold start tests (e.g. complete helicopters), air conditioning of cockpits as well as for component testing under extreme temperatures, solar radiation and snow impact.

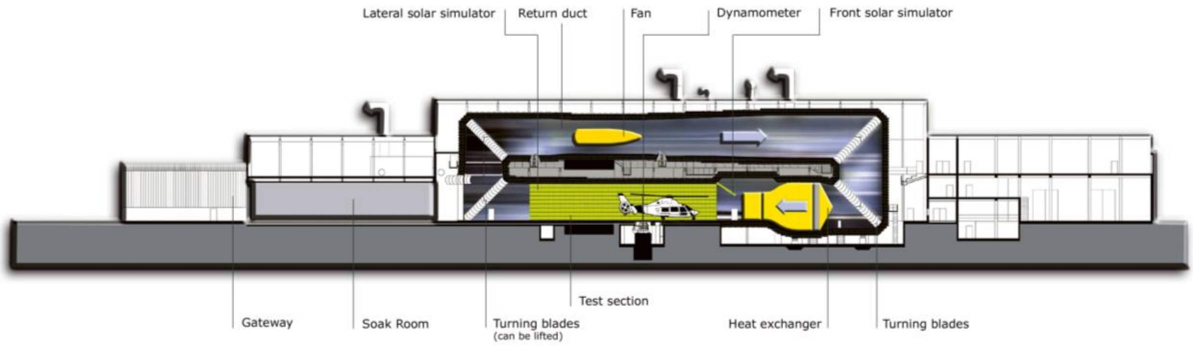

**Figure 3:** Small Climatic Wind Tunnel / Icing Wind Tunnel Vienna (IWT)

The large Climatic Wind Tunnel (large CWT) as shown in Figure 4 has the same scope as the small CWT. Both tunnels can be modified to be used as an Icing Wind Tunnel (IWT) (see Chapter 6).

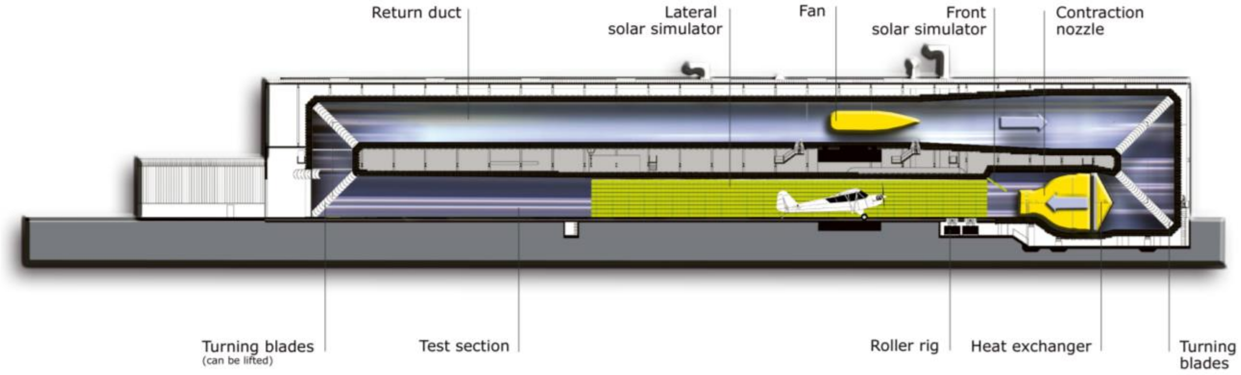

**Figure 4:** Large Climatic Wind Tunnel / Icing Wind Tunnel Vienna (IWT)

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<br>width / height / area | 3.5 m / 4.6 m / 16.1 m² | |
| Contraction ratio of main nozzle | 3.98 | 5.72 |
| Test section<br>width<br>height<br>cross-sectional area | <br>4.9 m to 5.1 m<br>5.9 m to 6.0 m<br>27.2 m² to 28.7 m² | <br>4.9 m to 5.6 m<br>5.9 m to 6.2 m<br>27.2 m² to 32.2 m² |
| Test section length | 33.8 m | 100.0 m |
| Dimensions of lateral solar simulator<br>length / height | 30.0 m / 4.3 m | 60.0 m / 4.3 m |
| Maximum airspeed[2]<br>restrictions at low temperatures<br>-15 °C<br>-30 °C | 45 m/s<br><br>40 m/s<br>30 m/s | 80 m/s<br><br>70 m/s<br>60 m/s |
| Maximum temperature range | -45 °C to +60 °C | |
| Maximum temperature gradient<br>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<br>at fixed 30° angle of incidence<br>operating temperature > -10 °C | 200 W/m² to 1,000 W/m² | |
| Solar intensity of front solar simulator<br>maximum airspeed:<br>at incidence angles < 45 ° up to 120 km/h<br>at incidence angles >= 45 ° up to 50 km/h<br>operating temperature > -10 °C | 200 W/m² to 1,000 W/m² | |
| General rain, snow and ground icing systems | stationary ceiling-mounted rain and icing system, mobile (snow) nozzles | |

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

**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 also 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<br>at temperatures > +10 °C | 10% to 98% |

## 5.4 Measurement Rooms

A measuring station with a separate meeting room is available close to the entrance at each of the two CWTs. In addition to office workplaces, filing cabinets, wardrobes, PC with internet access and telephone, these facilities also accommodate the PCs for online monitoring of the tests. The measuring stations provide 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 zoom cameras 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 modified 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 16.1m² contraction nozzle (as shown in Figure 5) is especially suitable for low-speed tests up to 20 m/s.

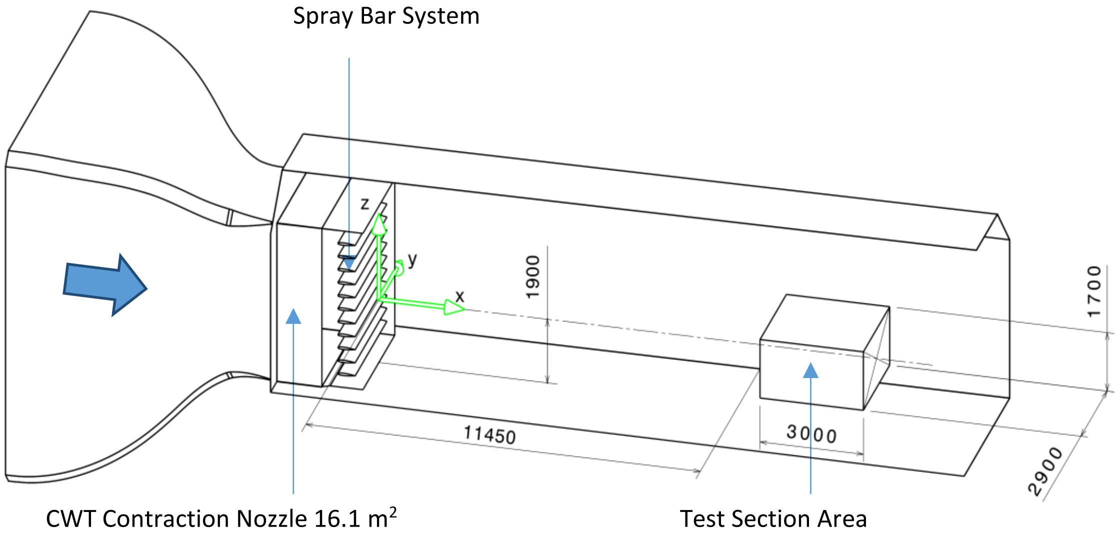

**Figure 5:** Test setup 1 with 16.1 $m^2$ cross-sectional area

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.

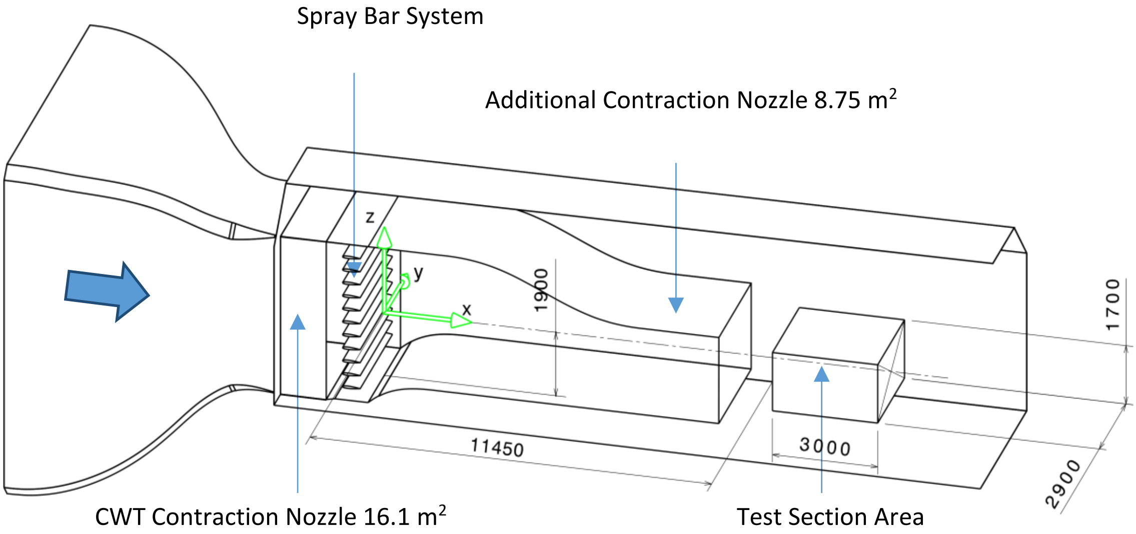

**Figure 6:** Test setup 2 with 8.75 $m^2$ cross-sectional area

The dimensioned cross-sectional area for the test setup 2 in the view of the wind direction is shown in Figure 7 below. The calibrated test section area (according to SAE ARP5905) is marked in cyan.

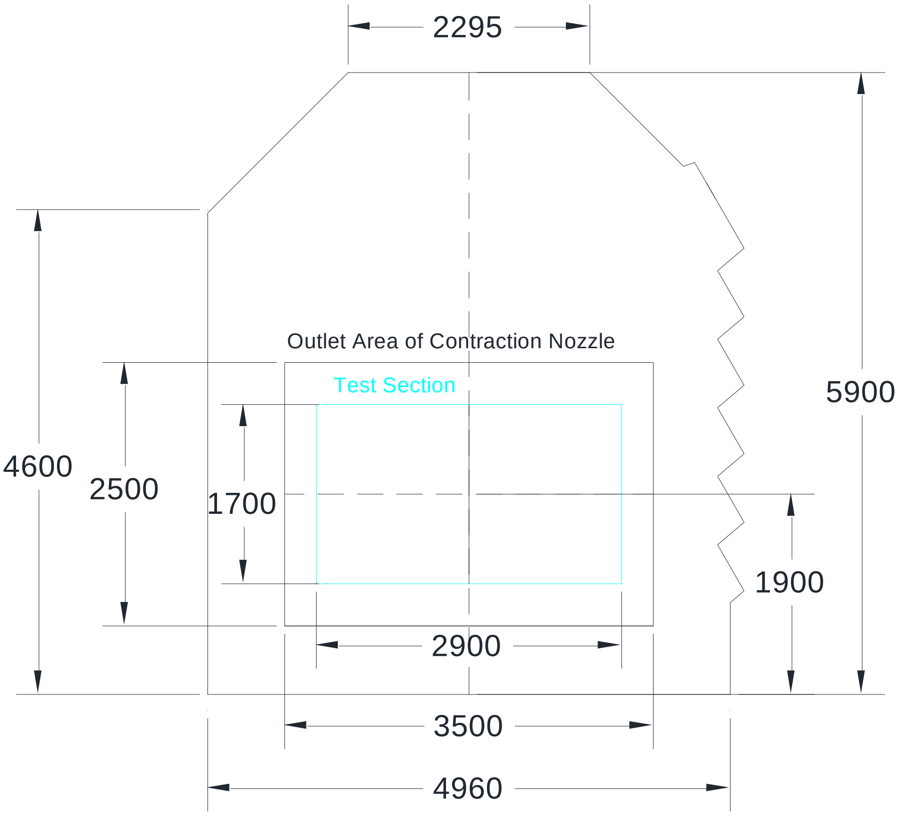

**Figure 7:** Cross-sectional area and test section area in the CWT for test setup 2 with 8.75 $m^2$

**Table 5:** Technical data of IWT

| **Description** | **IWT cross-section 16.1 m$^2$** | **IWT cross-section 8.75 m$^2$ (LWT)** |
|---|---|---|
| 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 | 10 m/s | 20 m/s |
| Maximum airspeed | 20 m/s | 80 m/s |
| Restrictions at low temperatures | | |
| at -15 °C and load approx. of 1,5 MW[3] inside CWT | 20 m/s | 60 m/s |
| at -30 °C and load approx. of 1,5 MW[3] inside CWT | 20 m/s | 40 m/s |
| Maximum temperature range for icing cloud simulation | -2 °C to -30 °C | |
| LWC at 20 µm MVD at min. airspeed | 0.22 – 1.12 g/m$^3$ | 0.21 – 3.11 g/m$^3$ |
| LWC at 40 µm MVD at min. airspeed | 0.42 – 2.64 g/m$^3$ | 0.36 – 2.66 g/m$^3$ |
| LWC at 20 µm MVD at max. airspeed | 0.11 – 0.56 g/m$^3$ | 0.05 – 0.78 g/m$^3$ |
| LWC at 40 µm MVD at max. airspeed | 0.21 – 1.32 g/m$^3$ | 0.09 – 0.83 g/m$^3$ |
| LWC FZDZ MVD < 40 µm at max. airspeed | - | 0.05 – 0.17 g/m$^3$ |
| LWC FZDZ MVD > 40 µm[4] at max. airspeed | - | 0.32 – 0.36 g/m$^3$ |
| LWC FZRA MVD > 40 µm[4] at max. airspeed | - | 0.25 g/m$^3$ |
| 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 | |
| Mass flow simulation (fan system) | from 5.5 kg/s to 25 kg/s at -30 °C with a total pressure difference up to 5 kPa | |
| Exhaust systems | max. 9 kg/s | |
| Bleed air simulation | 250 g/sec, 2 kPa, 250 °C | |
| Water supply for water brake system | max. 5.5 bar 700 l/min | |
| Kerosene (Jet A-1 F35) tank for permanent supply | 4500 l / max. 550 l/h at max. 3 bar | |

The IWT allows to test the performance of ice protection systems in an efficient laboratory environment. The large dimensions and high cooling capacity enable both the investigation of full-scale test objects such as wings and engine inlets with simulated mass flow as well as tests with running engines up to a load of about 1.5 MW. This makes the IWT installation feasible e.g. for investigating air intake systems and the effects on engine operation in simulated icing conditions.

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[3] max. running engine power and additional cooling power from the small CWT, depending on exhaust gas temperature (the static air temperature of the IWT may increase slightly)

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

## 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. Each of the spray bars features two independent supply circuits for water and air. The separate control for every second spray nozzle enables the operation of only half of the nozzles for very low LWC (Liquid water content) requirements or settings with bimodal droplet size distributions as necessary for the simulation of SLDs (Super Cooled Large Droplets). Furthermore, it allows a separate control of the water and air supply temperatures of each circuit, in order to ensure a 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 geodetic 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 if all nozzles are working during test runs.

The spray nozzles used (Spraying Systems Co®) are air atomizing nozzles which mix gas and liquid prior to the nozzle exit and use the kinetic energy of the gas to atomize the liquid.

## 6.3 Icing Conditions

### 6.3.1 Continuous maximum and Intermittent maximum icing conditions

The intermittent maximum intensity of atmospheric icing conditions (intermittent maximum icing) is defined by the liquid water content and the mean effective diameter of the droplets. Figure 8 and Figure 9 show the design icing characteristics envelope according to EASA CS-25 and CS-29 Appendix C (respectively FAR Part 25 Appendix C) in terms of LWC (g/m³) 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.

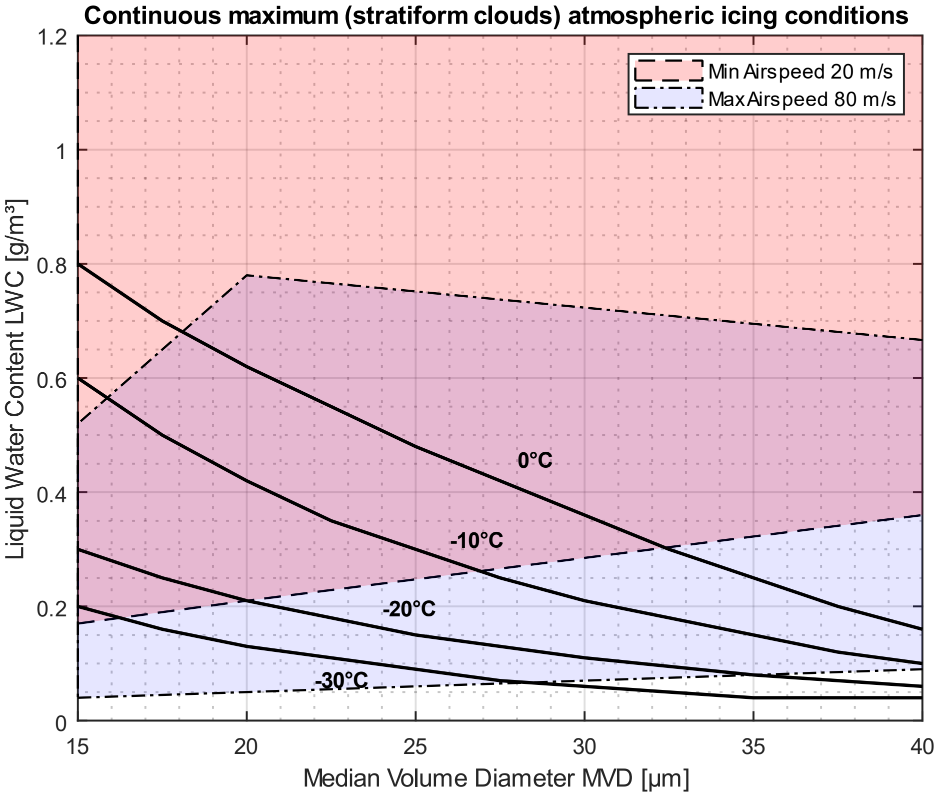


**Figure 8:** IWT capabilities continuous maximum (stratiform clouds) atmospheric icing conditions

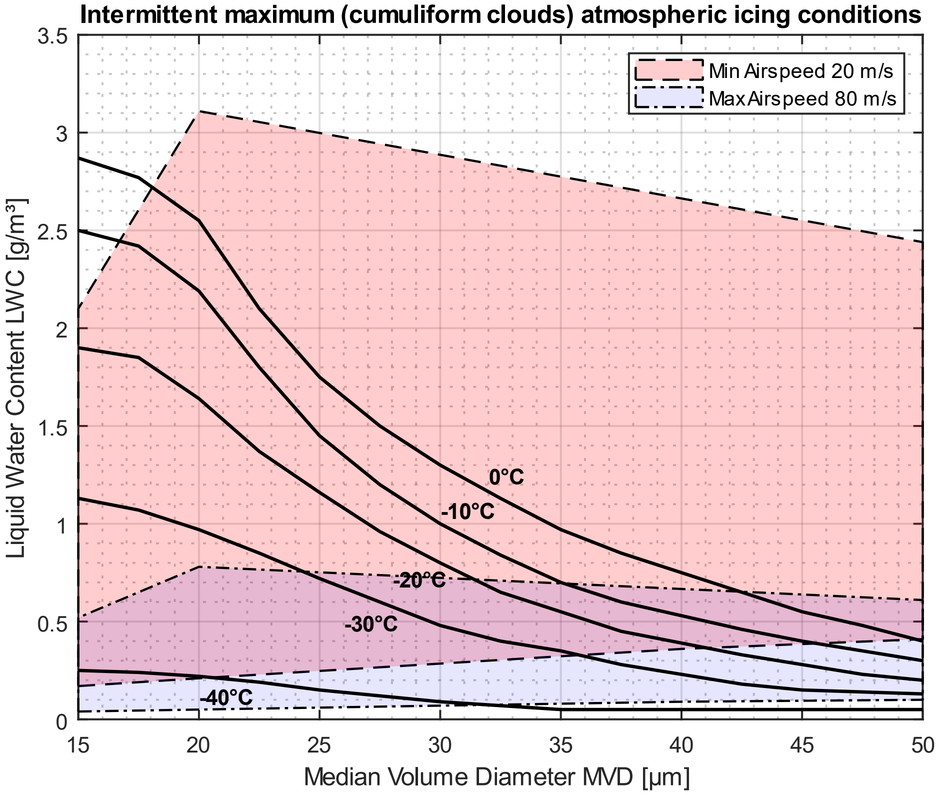


**Figure 9:** IWT capabilities intermittent maximum (cumuliform clouds) atmospheric icing conditions

### 6.3.2 Super Cooled Large Droplets (SLDs)

The super cooled large droplets icing conditions are defined by the liquid water content and the mean effective diameter of the cloud droplets. SLD icing conditions consist of freezing drizzle (conditions with spectra maximum drop diameters from 100 µm to 500 µm) and freezing rain (conditions with spectra maximum drop diameters greater than 500 µm) occurring in and/or below stratiform clouds.

Figure 10 shows the validated droplet distribution compared to EASA CS25 Appendix O (respectively FAR Part 25 Appendix O) requirements for Freezing Drizzle (FZDZ) MVD < 40µm. Figure 11 shows the validated LWC accordingly.

In Figure 12, the validated droplet diameter distribution compared to EASA CS25 Appendix O (respectively FAR Part 25 Appendix O) for Freezing Drizzle MVD > 40 µm can be seen. The achievable LWCs in the IWT as shown in Figure 13, differ from the requirements depending on airspeed and temperature. 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 in order to simulate Freezing Rain (FZRA) MVD > 40 µm conditions, with some limitations concerning the uniform cloud size, droplet temperature and droplet velocity. Figure 14 and Figure 15 show the measured droplet size distribution and liquid water content capabilities for FZRA respectively.

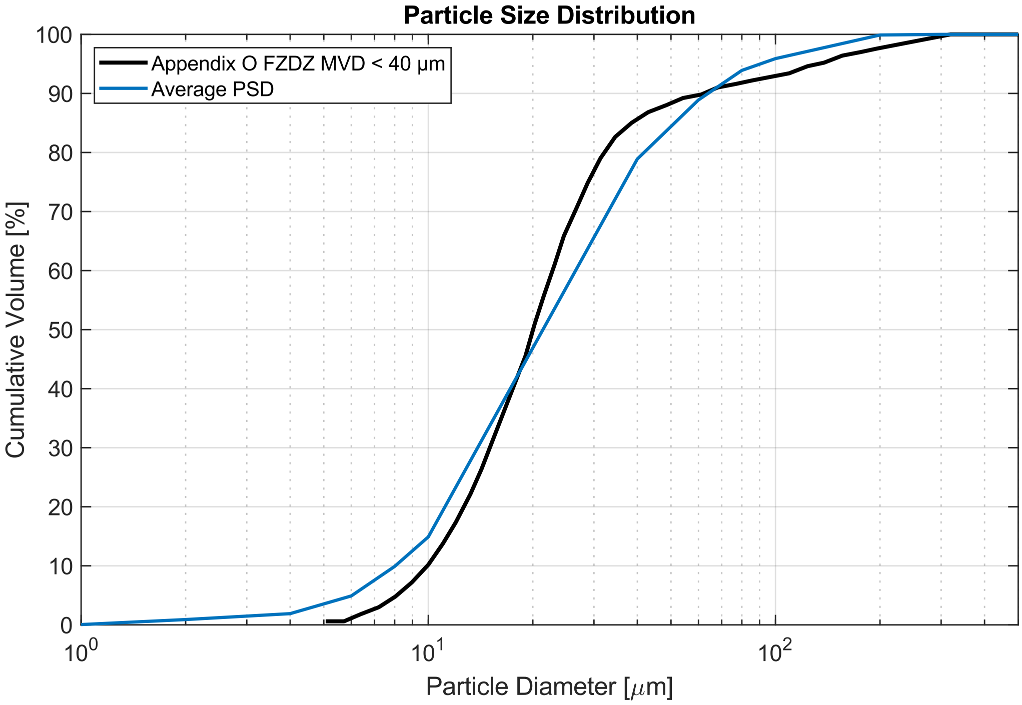


**Figure 10:** Particle size distribution of Freezing Drizzle MVD < 40 µm

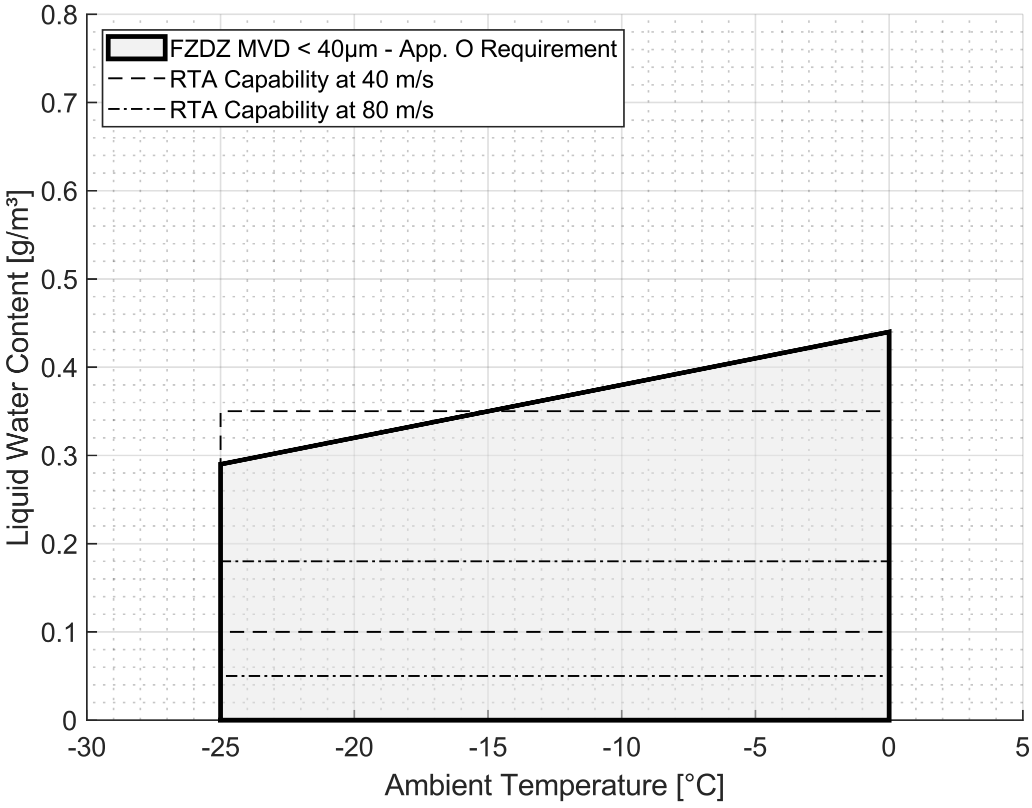


**Figure 11:** LWC capabilities of Freezing Drizzle MVD < 40 µm

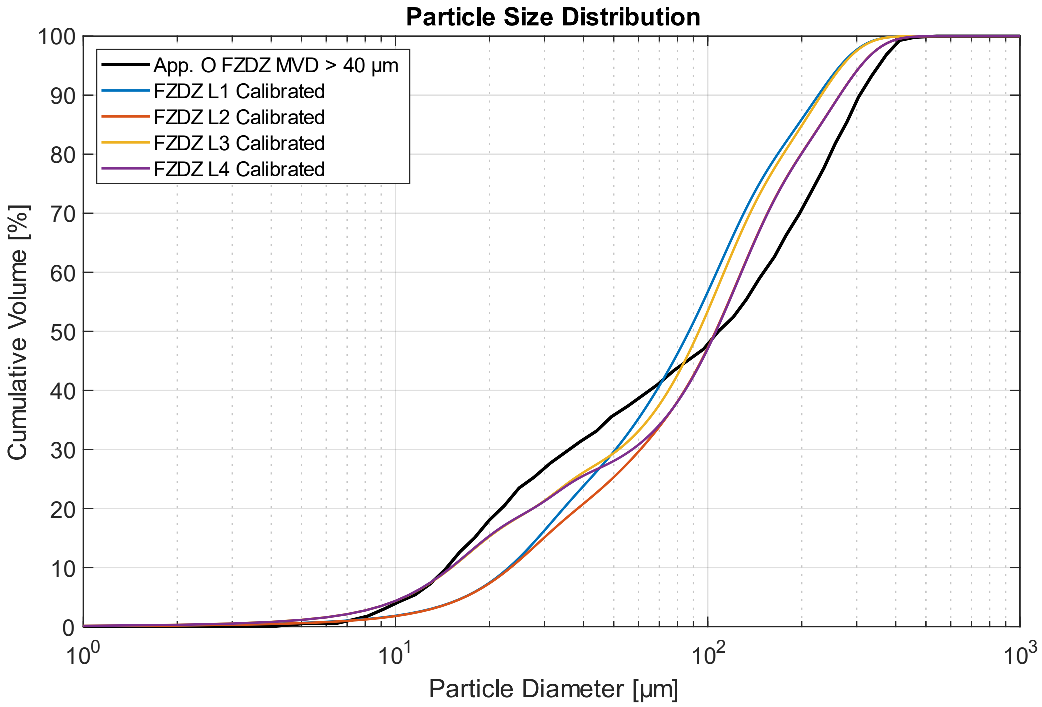


**Figure 12:** Particle size distribution of Freezing Drizzle MVD > 40 µm

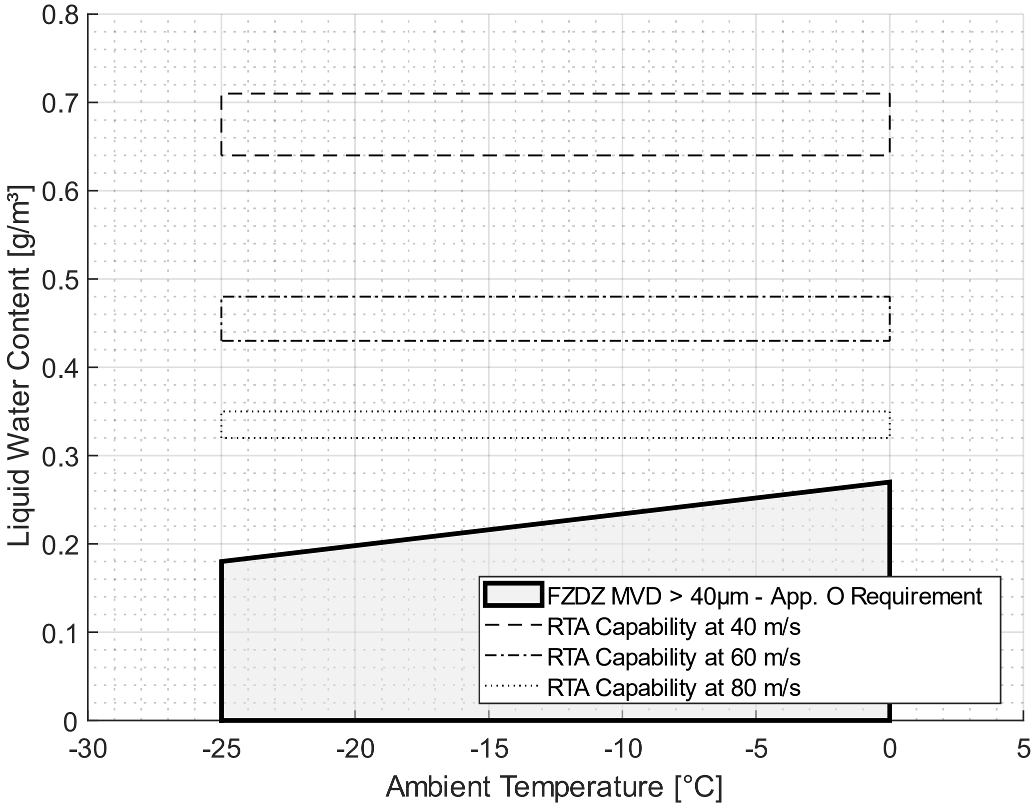


**Figure 13:** LWC capabilities of Freezing Drizzle MVD > 40 µm

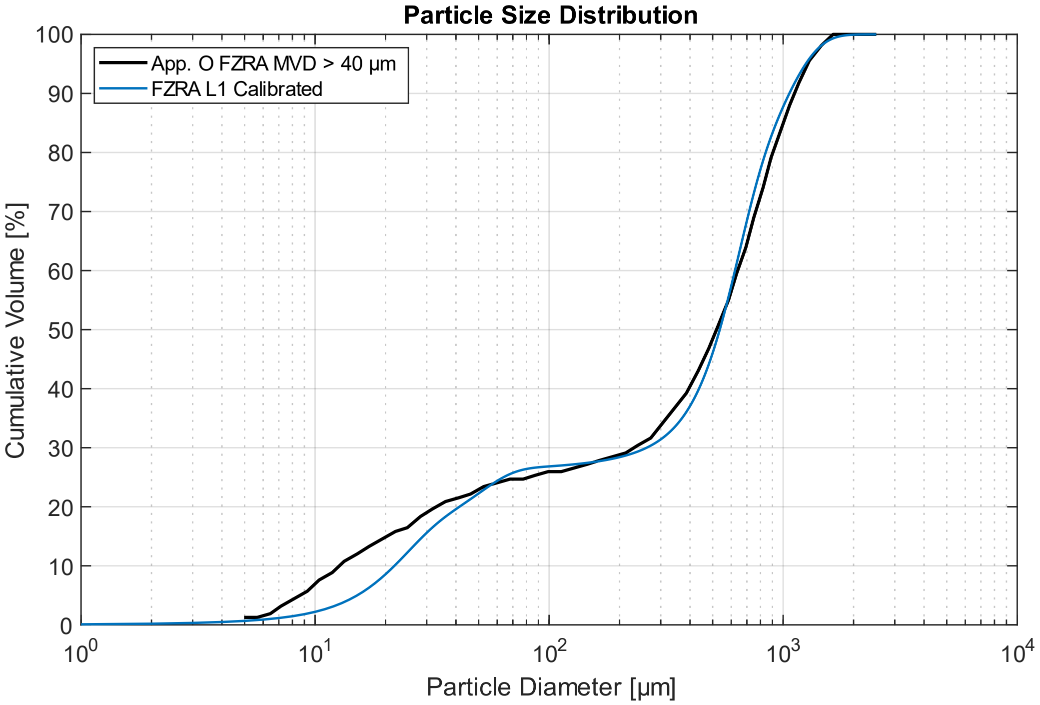


**Figure 14:** Particle size distribution of Freezing Rain MVD > 40 µm

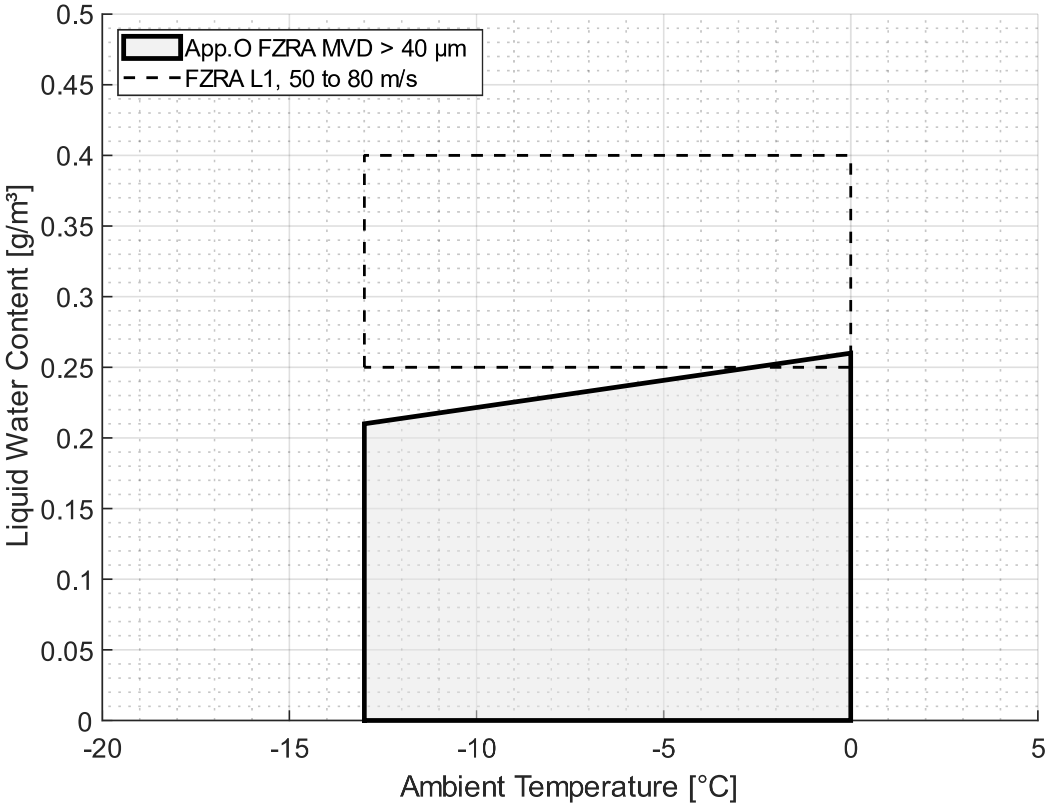
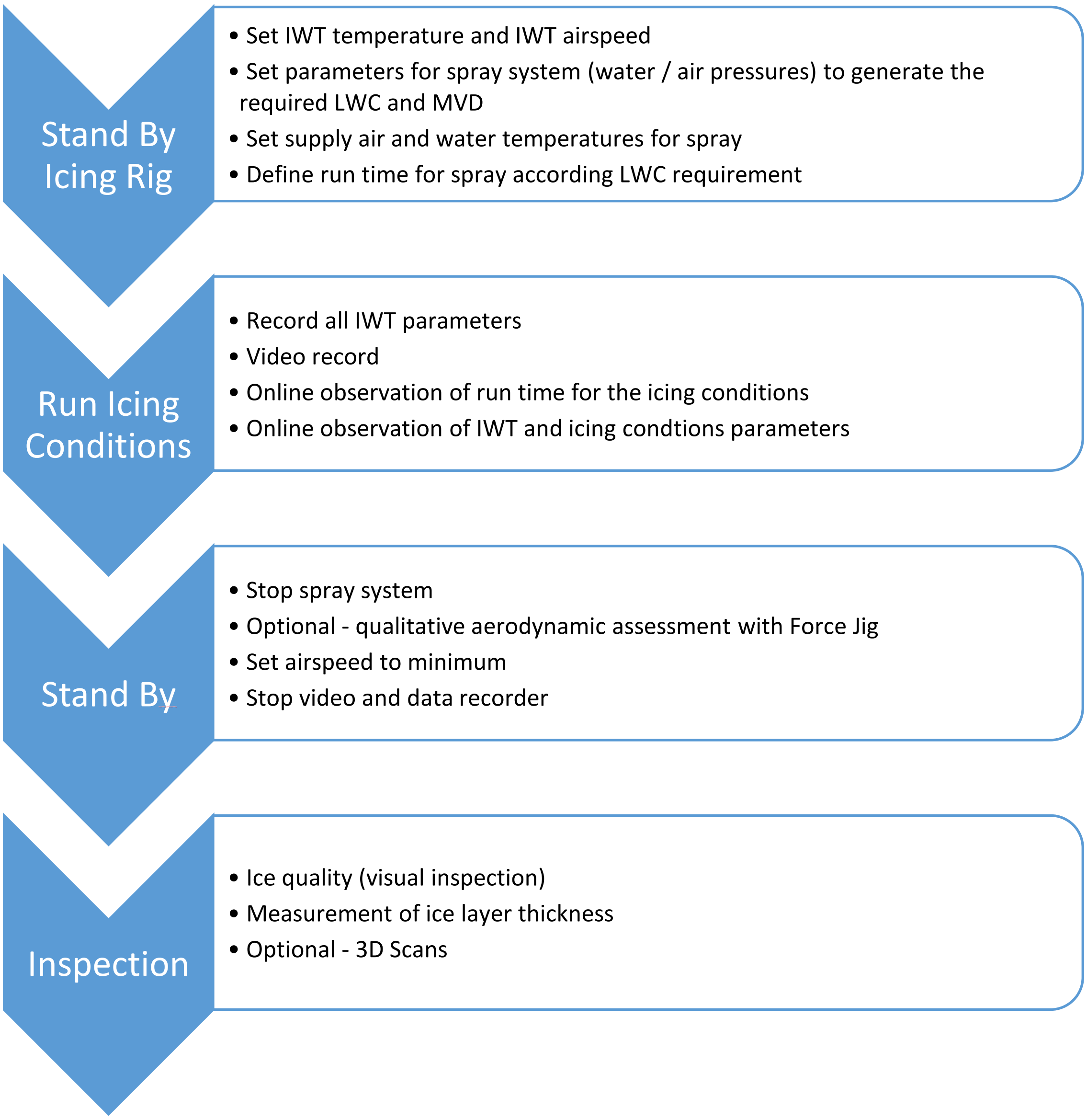


**Figure 15:** LWC capabilities of Freezing Rain MVD > 40 µm

## 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 16 describes an example for an icing test run with a continued cloud.



**Stand By Icing Rig**

- 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 LWC requirement

**Run Icing Conditions**

- Record all IWT parameters
- Video record
- 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 recorder

**Inspection**

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

**Figure 16:** 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 17). 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.

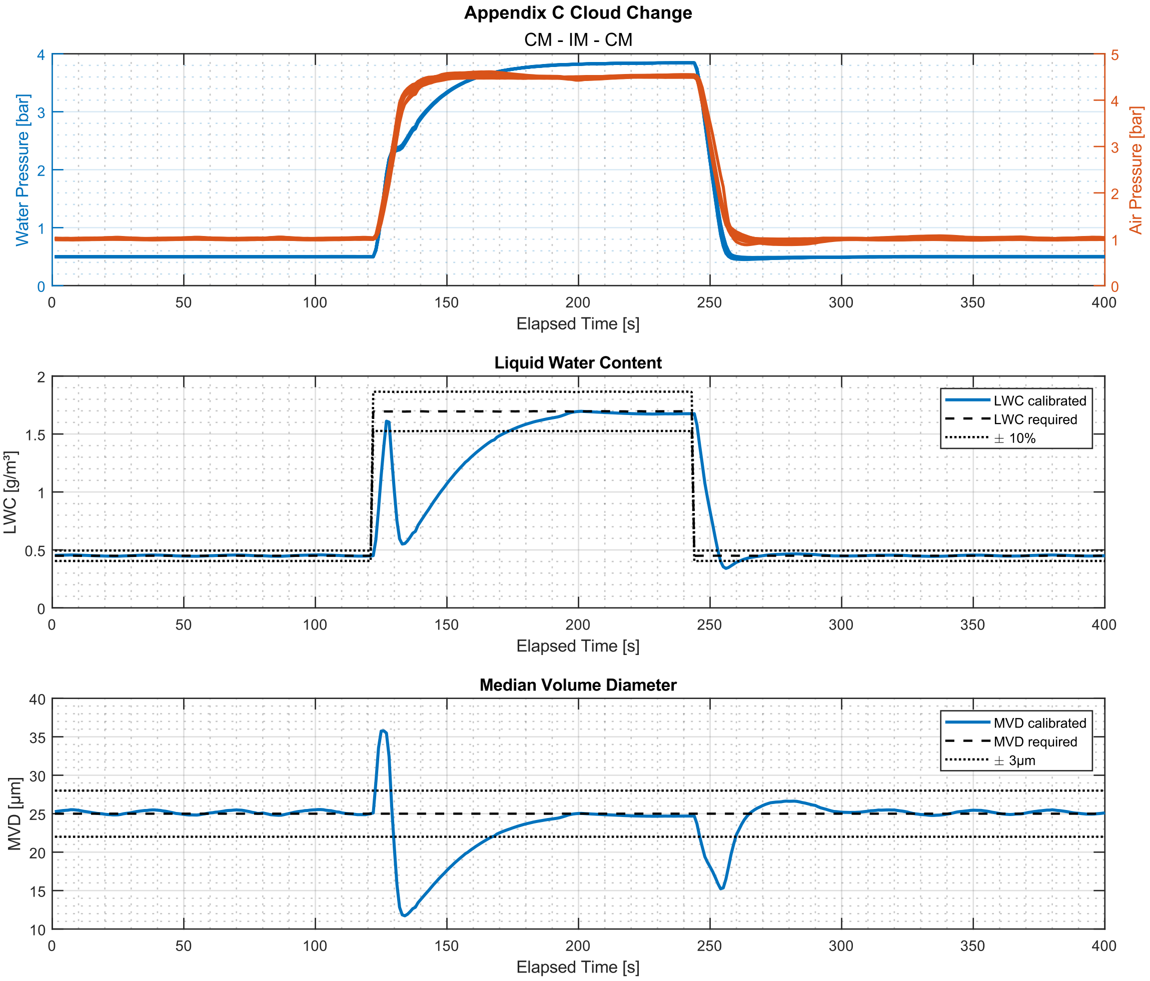


**Figure 17:** Icing test parameters during change of cloud conditions in the IWT

## 6.5 Icing Tests

The Icing Wind tunnel of RTA is one of the largest worldwide and provides ideal conditions for 1:1 scaled test-objects as well as complete helicopters or small aircraft. The wide range of available measurement instruments as e.g. wattmeter, temperature sensors and differential pressure transmitters ensures a high flexibility in measuring the necessary boundary conditions. Moreover, evaluation tools such as high-speed cameras, stroboscope camera systems, high speed channel pressure scanners, 3-D scans and aerodynamic force investigations can additionally be provided on request. RTA provides advice and support during product development process and even performs certification tests.

RTA is open to all research projects that make a major contribution to the industry or help to extend and improve RTA's service portfolio. RTA has been involved in numerous national and European projects.

### 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 and kerosine supply system. A water supply is provided to feed a water brake system if required. Specifications of the systems are shown in Table 6 and a test setup scheme is shown in Figure 18.

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 6: 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 |

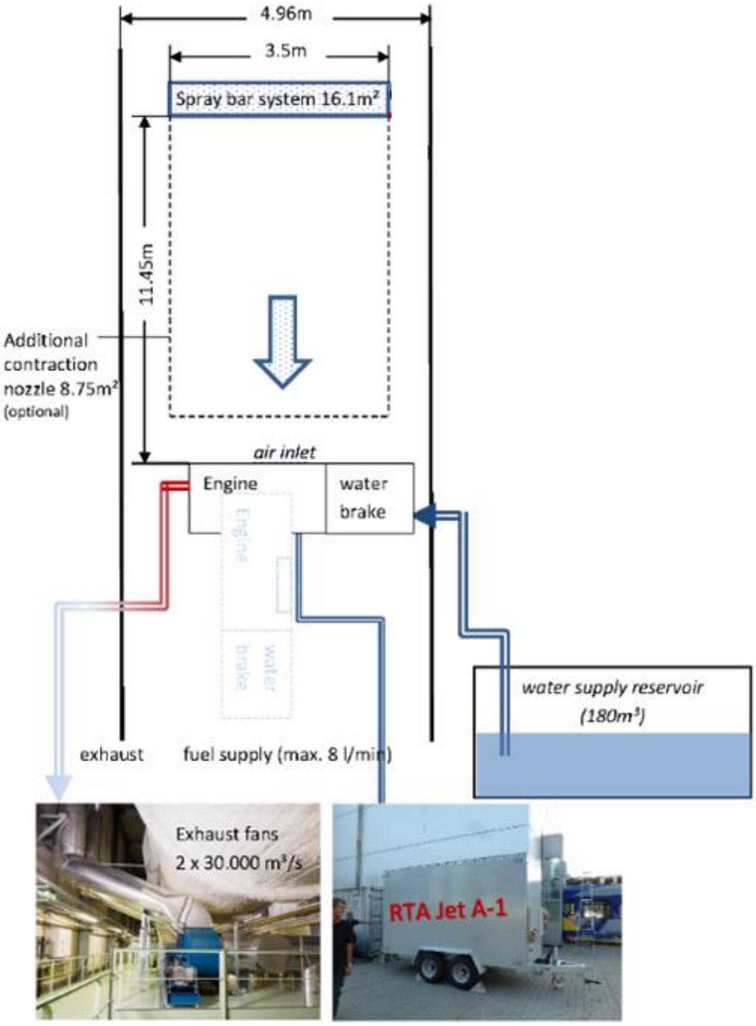


**Figure 18:** Test setup for an engine including supply systems inside the IWT

### 6.5.2 Wing Tests

Tests on 1:1 scaled wing sections can be carried out with the additional contraction nozzle in combination with the RTA Force Jig (Figure 19). The Force Jig is a trailed wing mounting device with two slide-able shields supporting the force measurement and the wing. Wing tips can also be mounted on one side wall using a special adapter plate as shown in Figure 19. 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 20 and Figure 21), it has to be considered that the RTA IWT does not fulfil the flow requirements of an aerodynamic wind tunnel.

**Table 7:** Technical data 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<br>Drag ($C_D$), max. load of 20 kN – accuracy: ±20 N<br>Moment ($C_M$), max. load of 1.5 kNm – accuracy: ±1.5 Nm |
| Customer Interface | Mounting plate / heated splitter blades |

**Figure 19:** Test setup for a wing section test inside the IWT

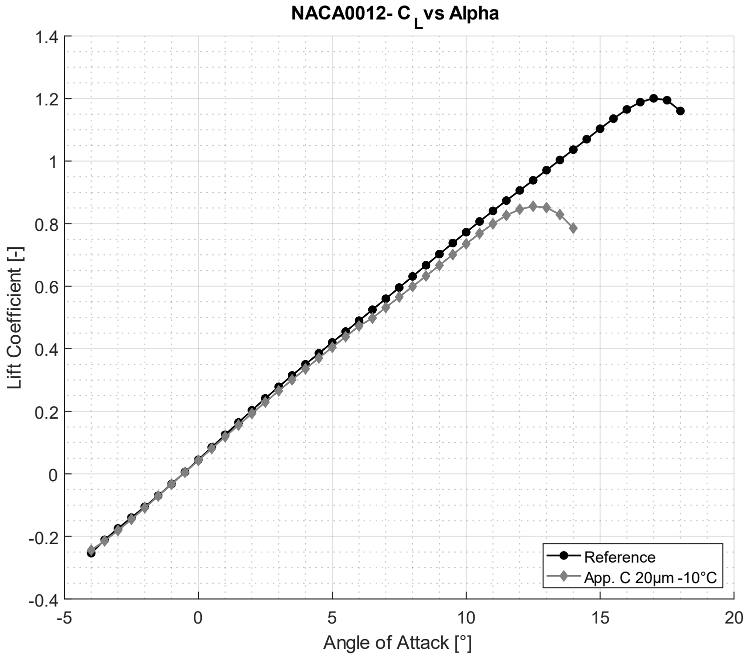


**Figure 20:** Lift coefficient versus angle of attack comparison for a dry and iced NACA0012 wing

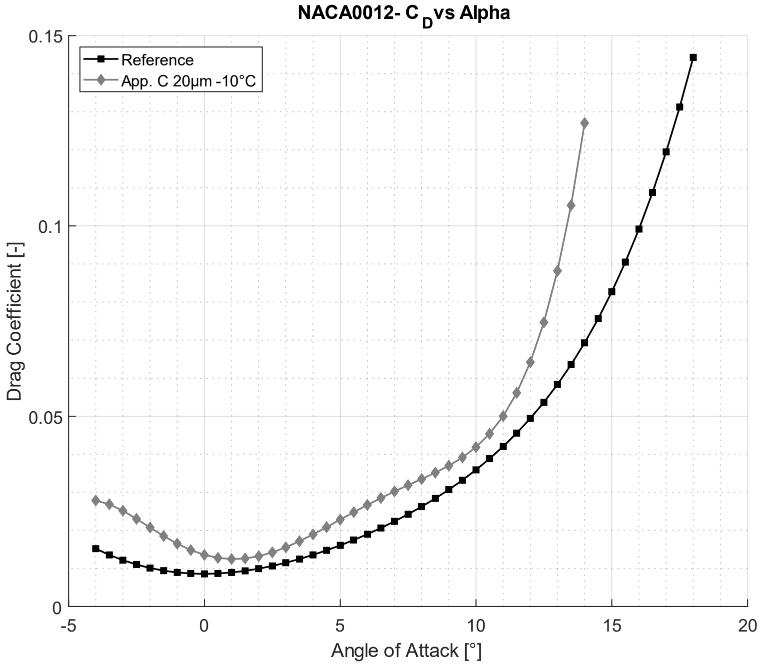


**Figure 21:** Drag coefficient versus angle of attack comparison for a dry and iced NACA0012 wing

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 23 and Figure 24) as well as a high speed pressure acquisition unit with up to 32 channels (range: ± 7kPa).

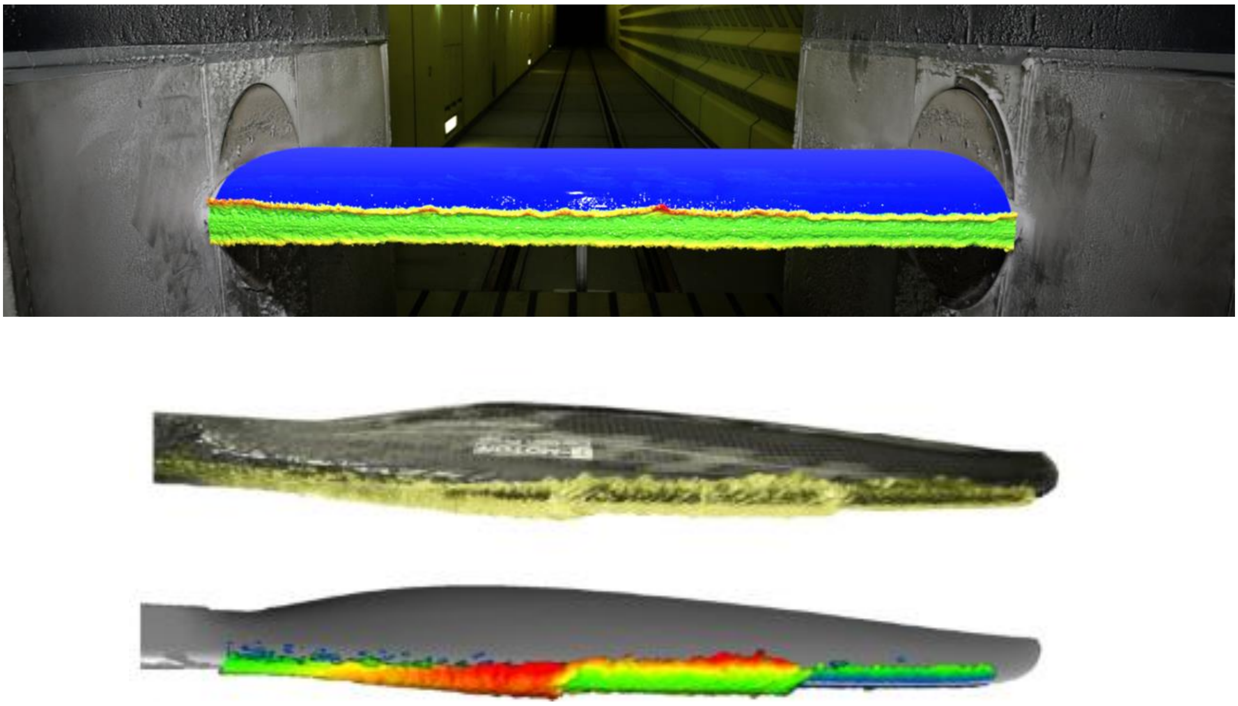


**Figure 22:** 3-D scan of ice shapes on a wing section and a UAV propeller in the RTA IWT created by AIIS

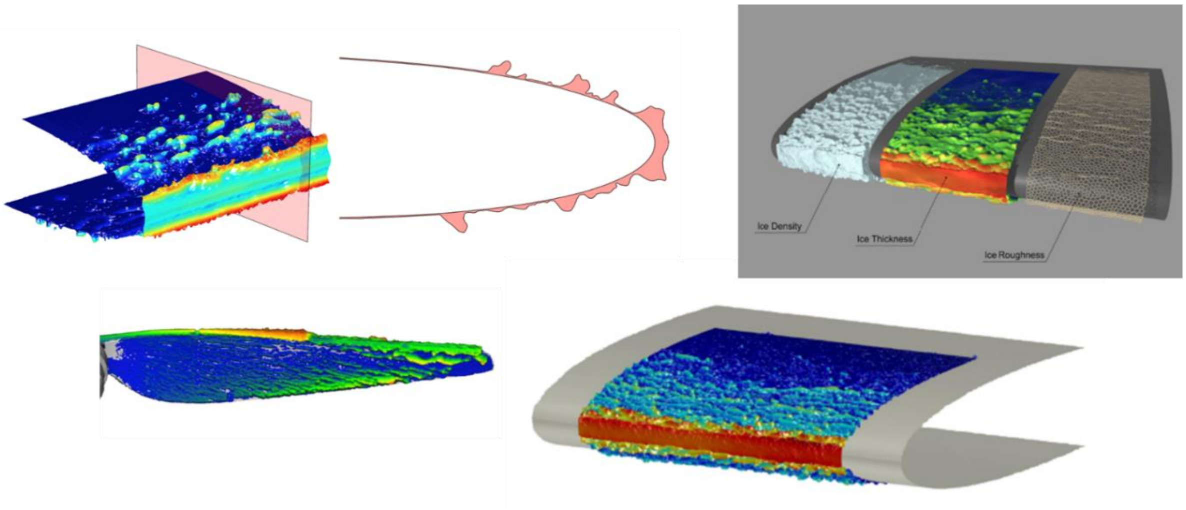


**Figure 23:** 3-D scan result of ice shapes generated in the RTA IWT incl. ice density, ice thickness and ice roughness created by AIIS

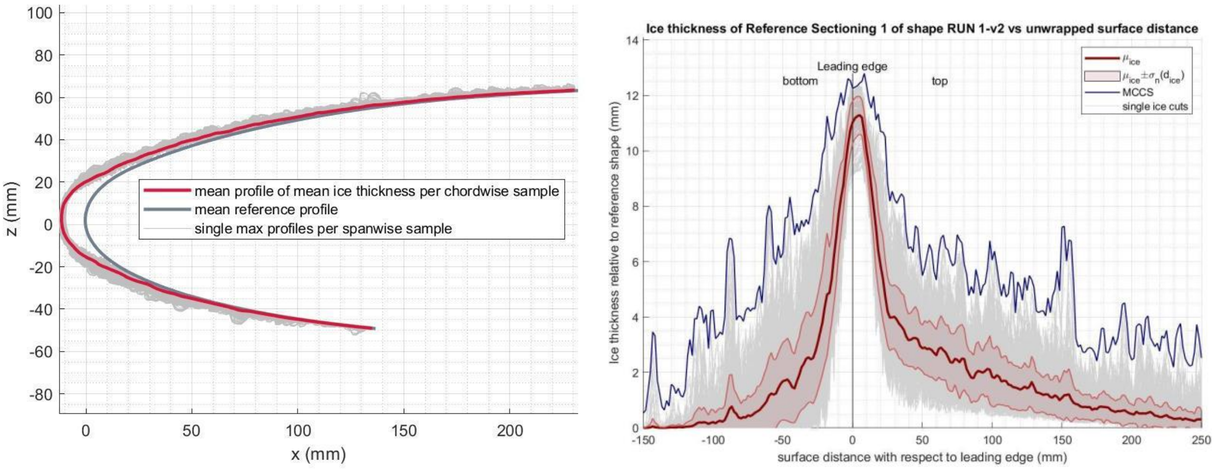


**Figure 24:** Detailed evaluation of an Appendix O ice shape generated in the RTA IWT created by AIIS

### 6.5.3 Propeller and Rotor Tests

RTA provides a test rig (“Prop Rig”) to conduct propeller and rotor tests in icing conditions. It has a shaft power of 90 kW at speeds up to 2500 rpm. Electrical power can be transmitted to the Specimen to operate an IPS, and it is capable of an unbalance up to 75 g*m on the propeller. For further information, a separate information document can be provided.

Three different setup configurations in the wind tunnel are available. Figure 25 shows the standard configuration in the left-, and the pusher configuration in the right image. For the pusher configuration, a cover is used to cover the rear part of the test bench. In the third configuration, the axis of rotation is orthogonal to the airflow as for a helicopter tail rotor sown in Figure 26. In Table 8 the main specifications are summarized.

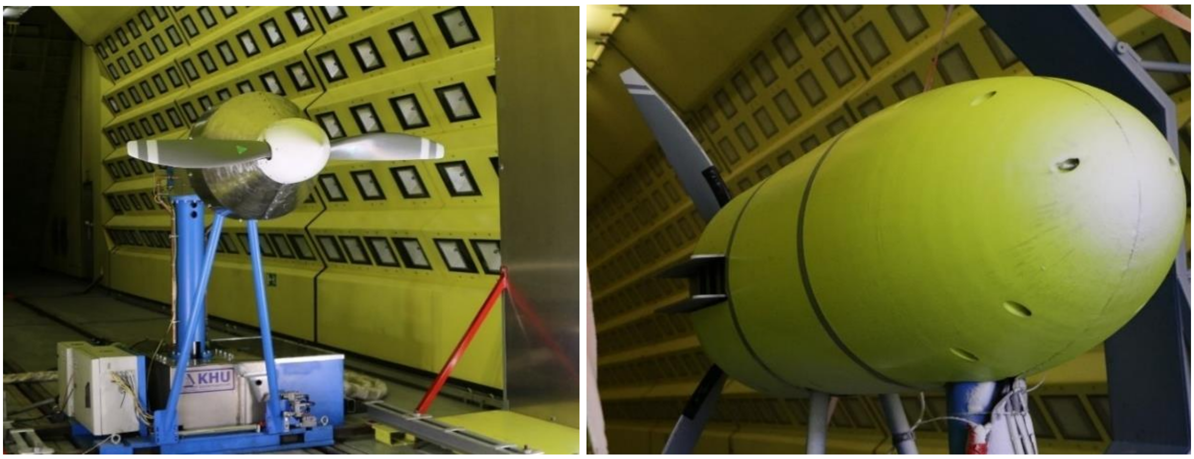


Figure 25: Standard configuration of the prop Rig shown in the left image. A cover can be used for the rear part of the test bench for the pusher configuration as shown in the right image.

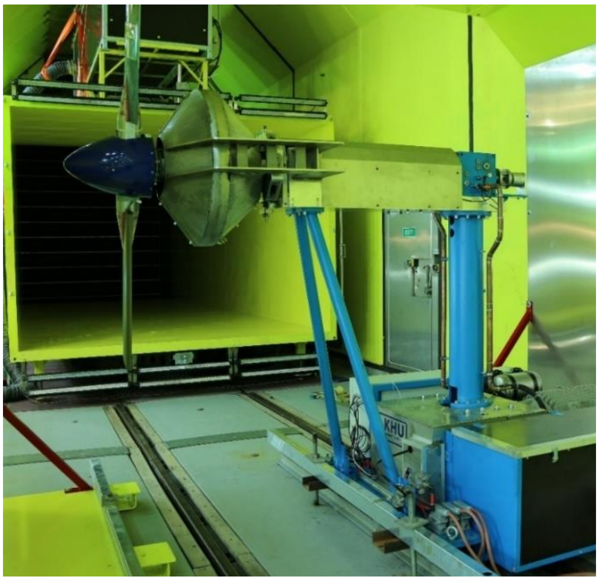


Figure 26: Prop Rig helicopter tail rotor configuration

Table 8: Technical data Prop Rig

| | |
|---|---|
| System power | 90 kW<br>(upgrade to 180 kW in progress) |
| Revolutions | Up to 2500 rpm |
| Admissible imbalance | Up to 75 gm |
| Thrust measurement | Up 10 kN |
| Torque measurement | Up 1 kNm |
| Electrical power supply | 8 x 400V / 35 A (16 sliprings) |

## 6.6 Snow Tests

RTA is continuously enhancing the portfolio for tests at adverse weather conditions. Recent development activities focused on the generation of snow conditions. In this context, detailed investigations including extensive calibration activities in the regime of blowing and falling snow conditions were conducted. 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 Icing Rig with a dedicated set of air atomizing spray nozzles (see Figure 27). Depending on the customer requirements, specific snow conditions with a TWC up to 1 g/$m^3$ at 80 m/s and a MVD in the range of 25 µm to 40 µm can be provided based on an individual calibration. Formerly conducted investigations indicated a density in the order of around 300 kg/$m^3$.

**Figure 27:** Nozzle setup for blowing snow tests in the RTA IWT and snow piled up

### 6.6.2 Falling Snow

Within the Horizon 2020 project ICE GENESIS[4], a new technology has been developed aiming to better recreate natural snowflakes (see Figure 28). The focus of the newly developed system was the generation of falling snow in a temperature range of +1 °C to -4 °C. The calibration results of the new snow generation system as well as snow accretion data on a NACA0012 test article with a chord length of 0.377 m are presented 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/$m^3$ at 40 m/s and a MMD in the range of 500 µm to 700 µm with particles up to 5 mm. The machine is designed to be upgraded in the future with a second snow generation unit in order to double the amount of producible snow.

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[4] Presentation of 2nd public workshop – RTA Snow Test Capability,” URL: https://www.ice-genesis.eu/media/articles/files/2nd_Public_Workshop/ICE_GENESIS_WP7_RTA_Public_Workshop_R1.1.pdf

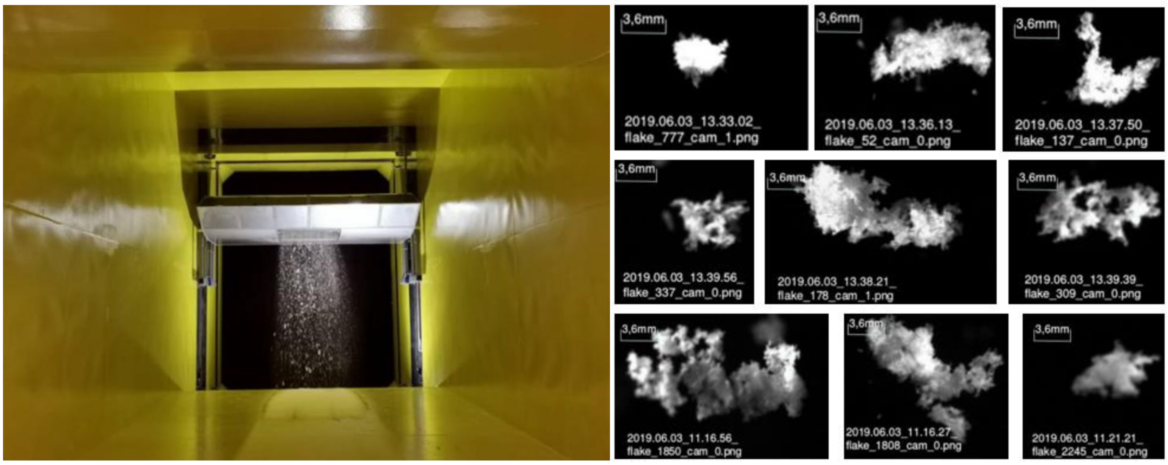

**Figure 28:** Snow fall technology in the RTA IWT and snow particle morphology results

# 7. Summary of Icing Wind Tunnel Calibration

This section of the report summarizes the IWT icing calibration and validation results. Validation reports have been prepared for all aerodynamic and cloud uniformity parameters. Each report describes the validation method used in detail and can be made available upon request. During each test all relevant parameters are recorded using a computerised data recording system. The stored data will be available for at least 10 years from the test date.

The evaluation of the IWT was carried out according to the recommended practice for calibration and acceptance of IWTs (SAE ARP5905). All tests were performed for both IWT configurations, i.e. with and without the contraction nozzle described in paragraph 6.1. The first baseline calibration was done in 2014, in 2021 an updated baseline calibration was performed. Check calibrations of the LWC, MVD and Cloud Homogeneity are conducted at least every two years in order to show that the baseline calibration is still valid.

## 7.1 Aero-Thermal Calibration

The tunnel was calibrated for aero-thermal effects in both the full and the reduced cross-sectional area. Only the flow angularity calibration for the reduced cross-sectional area will be done on request.

Temperature stability was validated for the full cross-sectional area and found to comply with the SAE ARP5905 requirements.

The turbulence intensity was validated for the reduced cross-sectional area and found to comply with the SAE ARP5905 requirements in the test section. An example turbulence intensity at the location of where a wing would be mounted is shown in see Figure 29.

Airspeed variations were validated for both cross-sectional area and were also found to comply with the requirements with the nozzle air supply on. The only exception was observed for the full cross-sectional area (16.1m²) at a low airspeed of 10 m/s and very high air pressure. In this case, compliance was not achieved for the entire cross-sectional area. The compliant area can be increased by raising the airspeed or reducing the nozzle air pressure. As an example, the airspeed distributions for the reduced cross-sectional area are provided in Figure 30 and Figure 31.

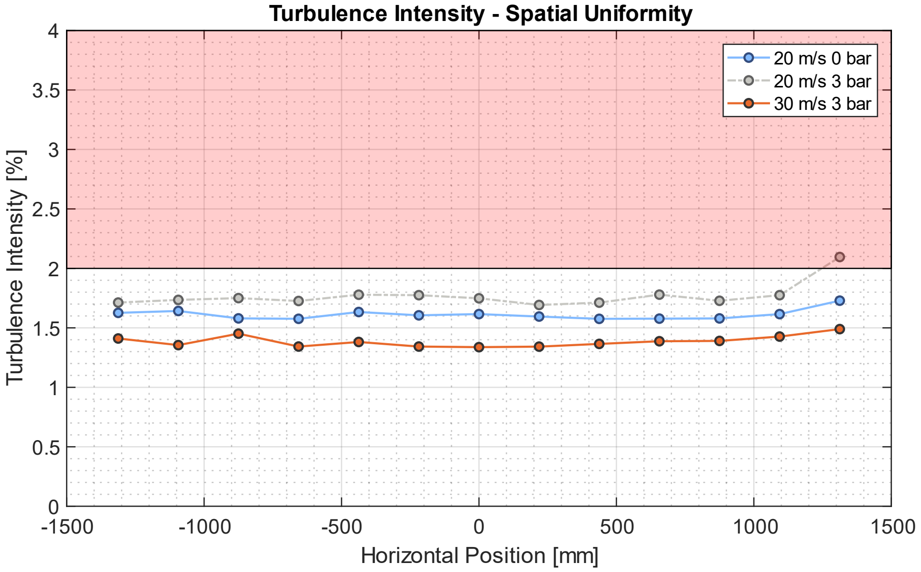

**Figure 29:** Turbulence intensity measurement results for the reduced cross-sectional area

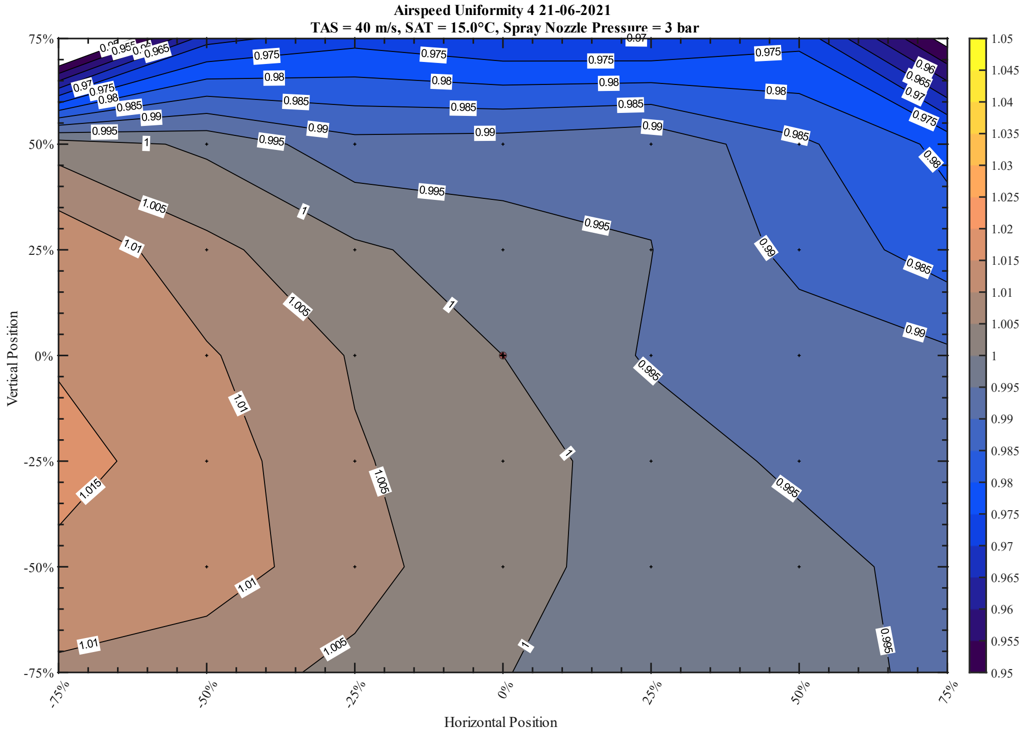

**Figure 30:** Test setup 2, airspeed distribution at 40 m/s and 3 bar spray nozzle air pressure

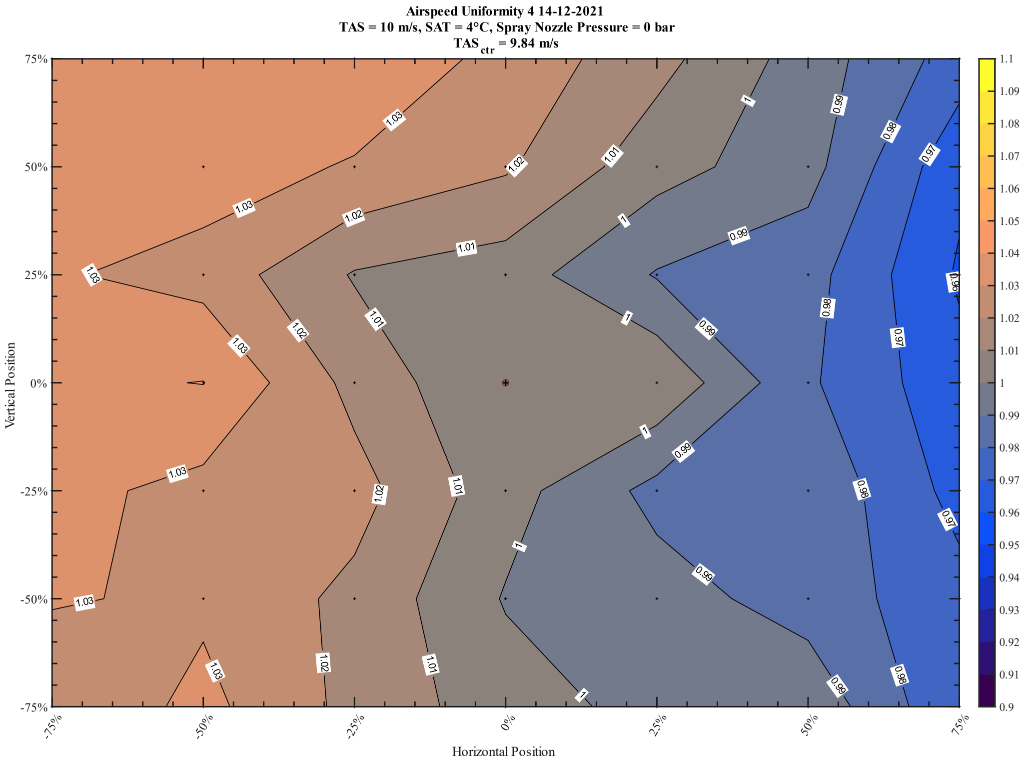

**Figure 31:** Test setup 1, airspeed distribution at 10 m/s and 0 bar spray nozzle air pressure

## 7.2 Icing Cloud Size and Uniformity

The icing cloud size relative to the cross-sectional area and its uniformity was also validated. This was done using an ice accretion grid. The grid is exposed to rime ice conditions for a certain amount of time in order to achieve a target ice thickness of about 6.4mm and then manually measured at specific positions (see Figure 32) using a caliper, as seen in Figure 33. In order to get a map of the LWC distribution in the cross-sectional area, all the measurements are converted to relative LWC normalized to the center of the test section.

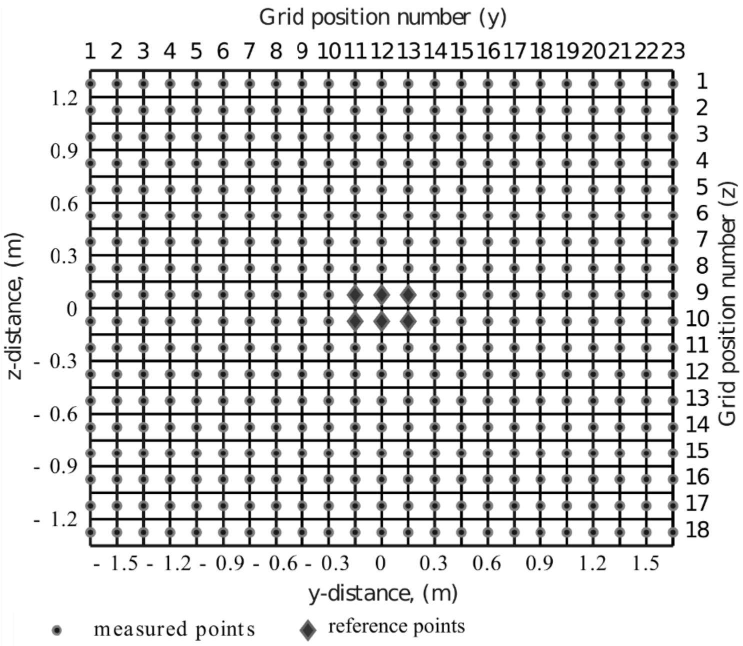

**Figure 32:** Measuring points for icing cloud uniformity. The reference points are indicated with black diamonds.

**Figure 33:** Computerised sliding calliper

Two examples are provided for the reduced cross-sectional area, one at a higher airspeed and an MVD of 20 µm (Figure 34) and one at a lower airspeed with an MVD of 40 µm (Figure 35). The results show that the area of interest is uniform in accordance with the requirements of the SAE ARP5905.

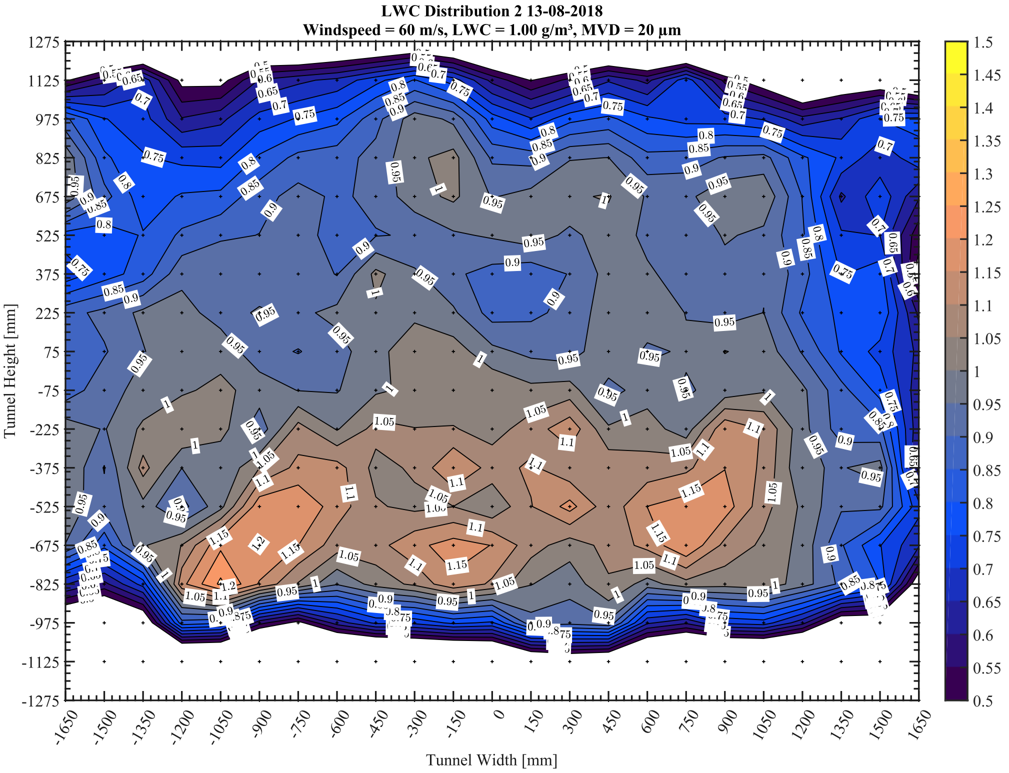

**Figure 34:** LWC uniformity at 60 m/s and LWC 1.0 g/m³; droplet MVD 20 µm

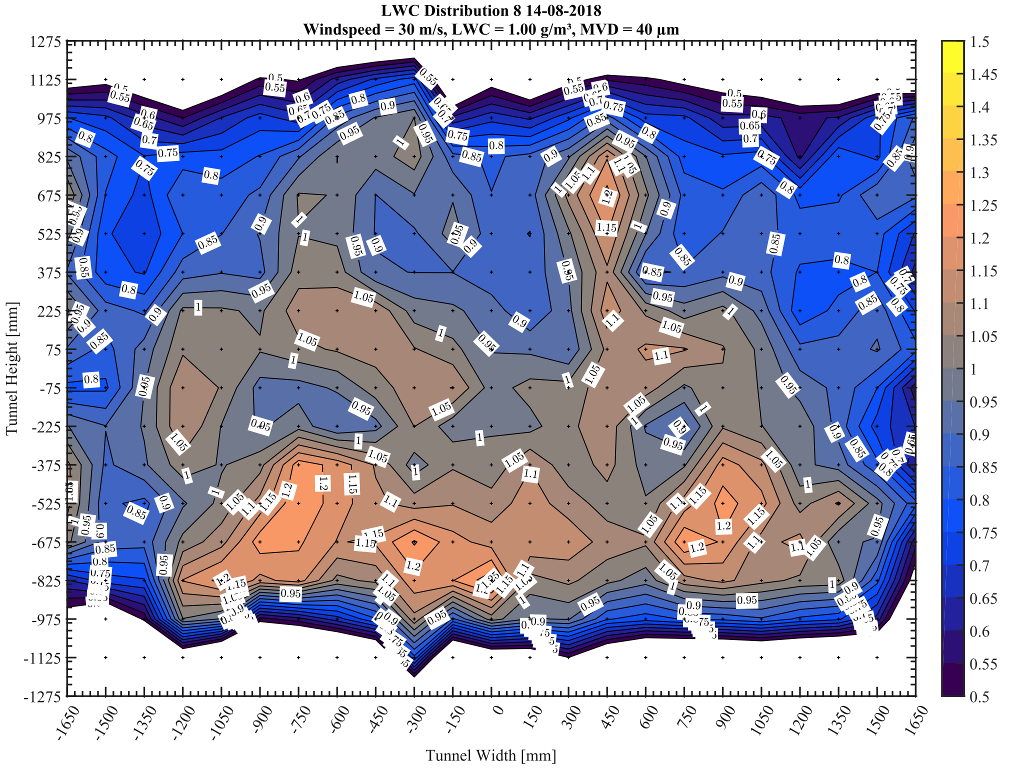

**Figure 35:** LWC uniformity at 30 m/s and 1.0 g/m³; droplet MVD 40 µm

Figure 36 shows the measured LWC uniformity for the Freezing Drizzle MVD > 40 µm condition. In Figure 37 the current LWC uniformity capability for the experimental Freezing Rain MVD > 40 µm configuration is shown.

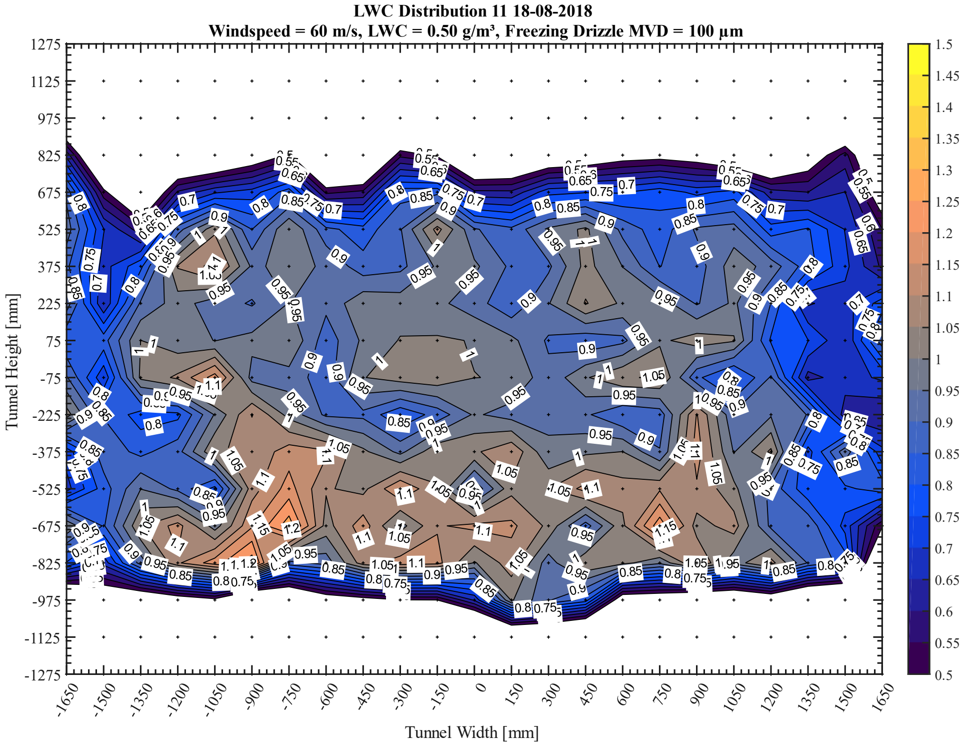

**Figure 36:** LWC uniformity at 60 m/s and 0.5 g/m³; Freezing Drizzle MVD > 40 µm

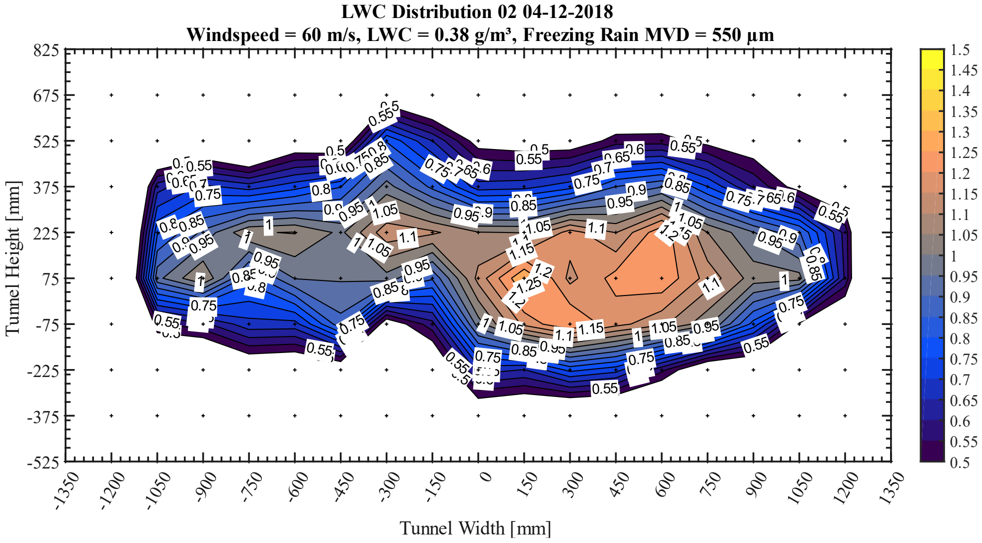

**Figure 37:** LWC uniformity at 60 m/s and 0.38 g/m³; Freezing Rain MVD > 40 µm [5)]

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[5] the freezing rain simulation will be performed with a prototype setting, a permanent improvement is in progress and will increase the stability of the spray system as well as the covered area

## 7.3 Water Droplet Size, Median Volume Diameter (MVD)

The droplet sizes were calibrated for both the full and the reduced cross-sectional area. The MVD was measured as a function of both water and air supply pressures 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 38) and 40 µm (Figure 39).

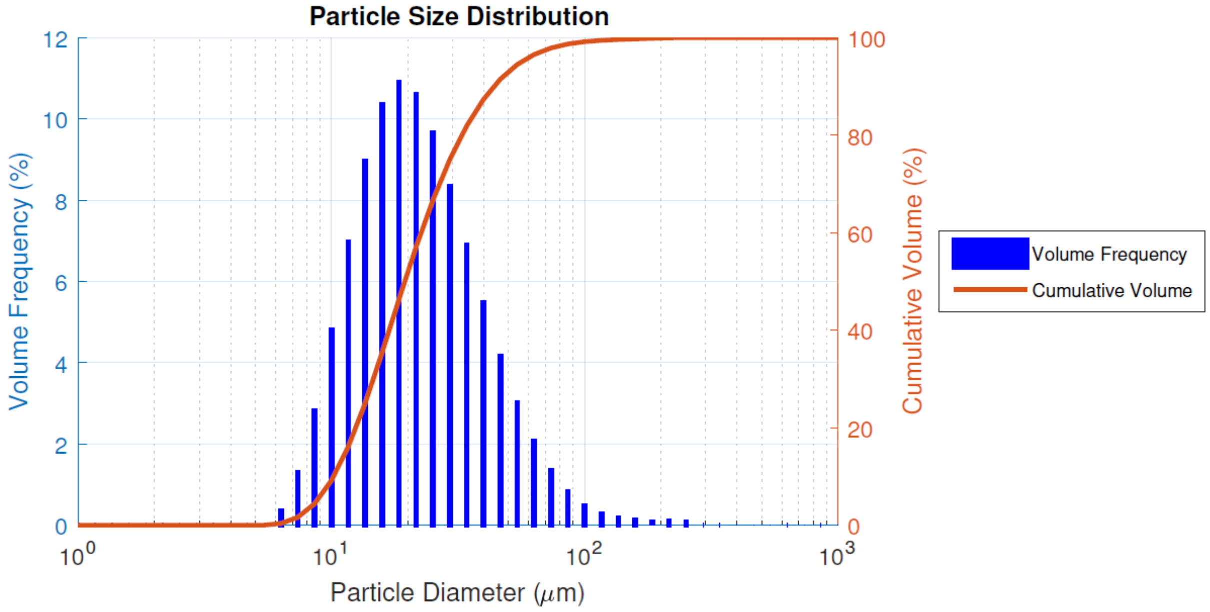

**Figure 38:** Droplet size distribution of an MVD = 20 µm cloud

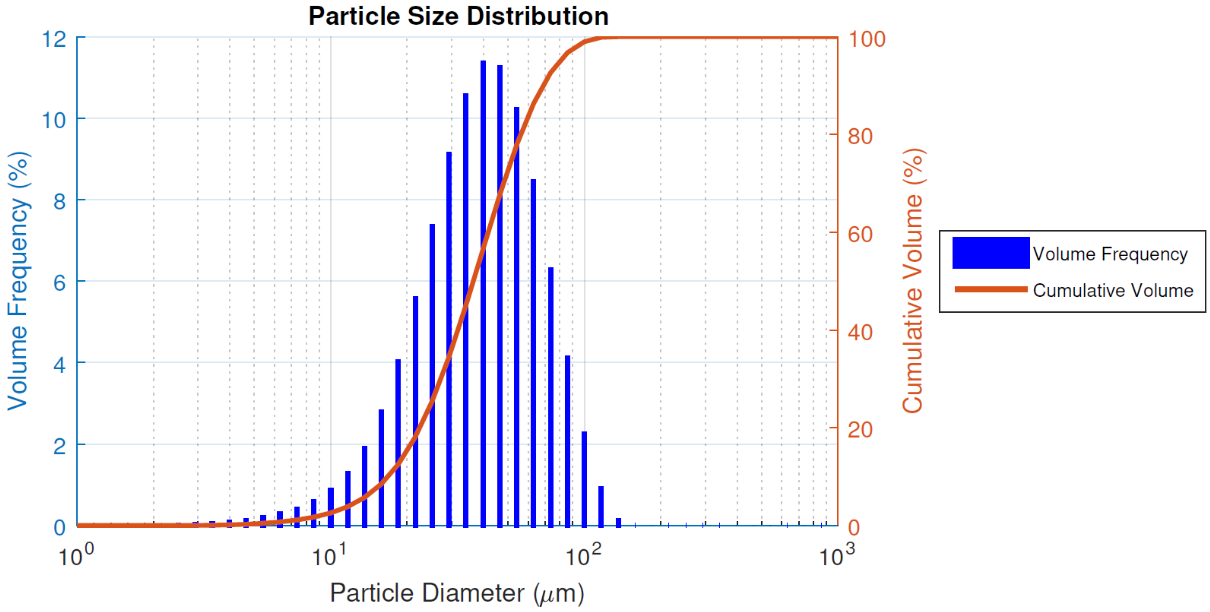

**Figure 39:** Droplet size distribution of an MVD = 40 µm cloud

Droplet size calibrations were 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 40). The grey area represents the allowed deviation according to SAE ARP 5905.

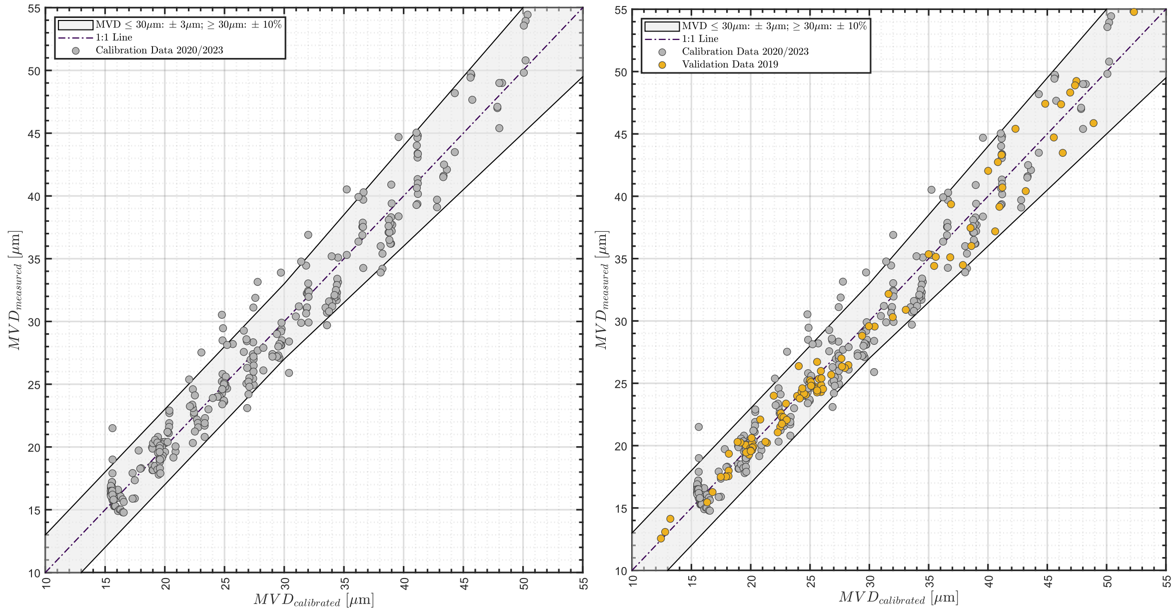

**Figure 40:** Comparison between measured data and the curve fit for the MVD, calibration points (left) and validation data (right)

The measured particle size distribution for Freezing Drizzle MVD > 40 µm is shown in Figure 41. The Malvern Spraytec can also be equipped with a 750mm lens in order 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 42).

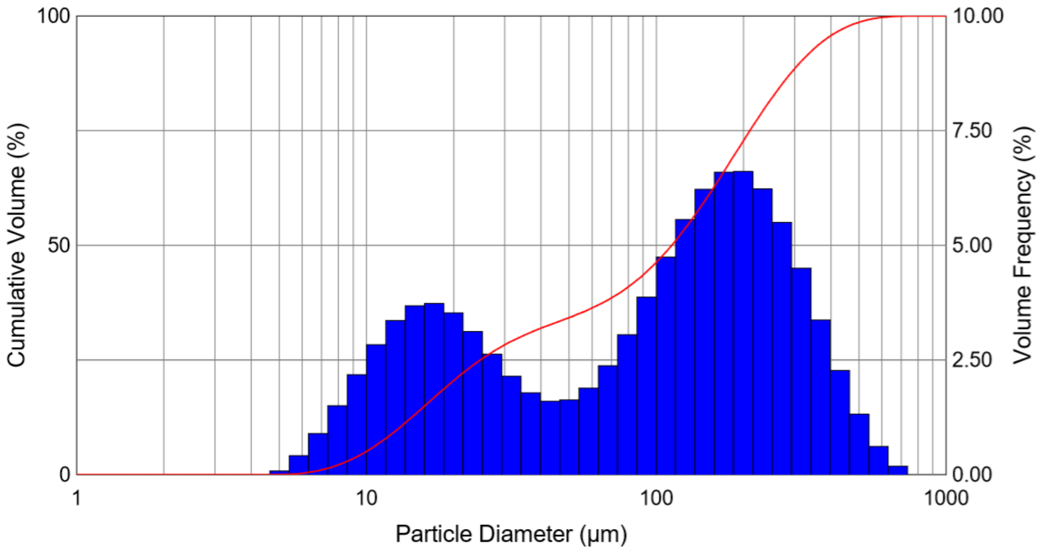

**Figure 41:** Measured particle size distribution for Freezing Drizzle MVD > 40µm using the Malvern Spraytec

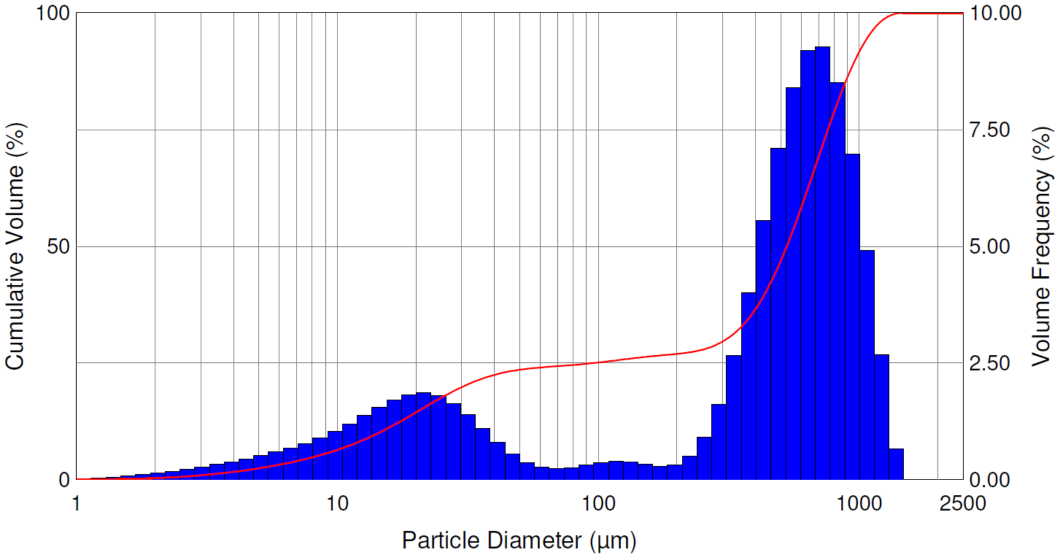

**Figure 42:** Measured particle size distribution for Freezing Rain MVD > 40µm using the Malvern Spraytec

## 7.4 Liquid Water Content (LWC)

For the LWC calibration the icing blade method as described in the SAE ARP5905 is used. The icing blade is shielded by a metal housing to protect it from ice contamination prior to spray stabilization (see Figure 43). As soon as the spray is stabilized, the blade is extended using a double acting pneumatic cylinder. The exposure duration to the cloud is depending on the LWC and should last long enough to achieve an ice thickness of 1.5 mm to 4.5 mm. After the exposure it 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 at impact, the ambient temperature is set to -18 °C.

**Figure 43:** Automatic icing blade installed in the test section

The results of the LWC calibration are shown in the following figures. Instead of the LWC, the specific liquid water content (lwc) is plotted. The lwc is the liquid water content (LWC) normalized by a factor, which depends on the number of active nozzles and the airspeed. This allows all conditions to be represented in a single figure. 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 45 (with contraction nozzle) and Figure 44 (without contraction nozzle). The grey area represents a ±10% deviation from the ideal value, the dash-dotted line limits a ±20% deviation area.

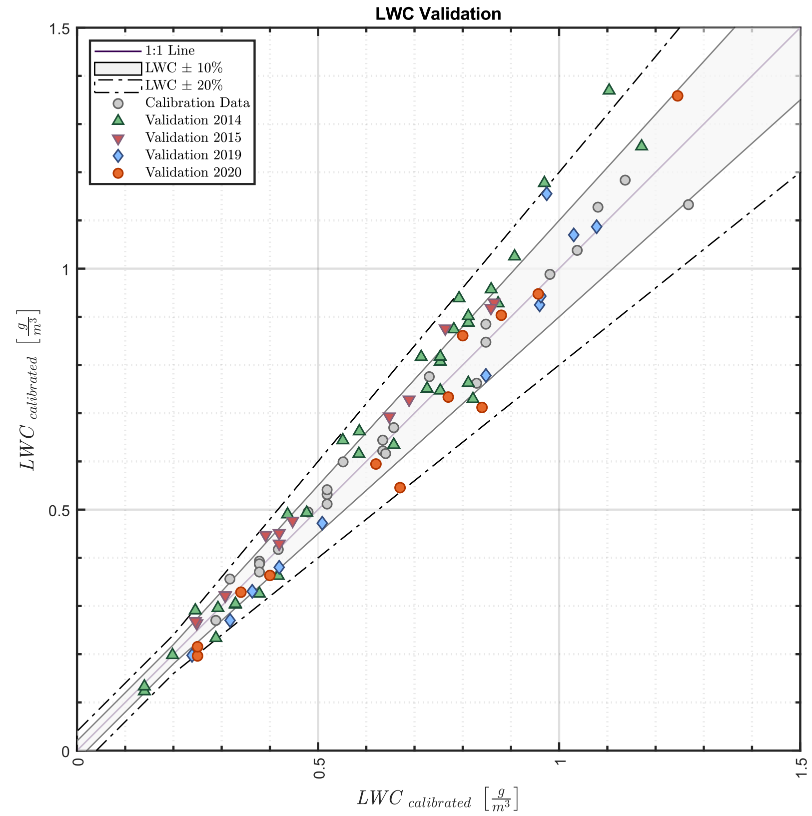

**Figure 44:** Comparison of measured versus calibrated LWC, Test Setup 1

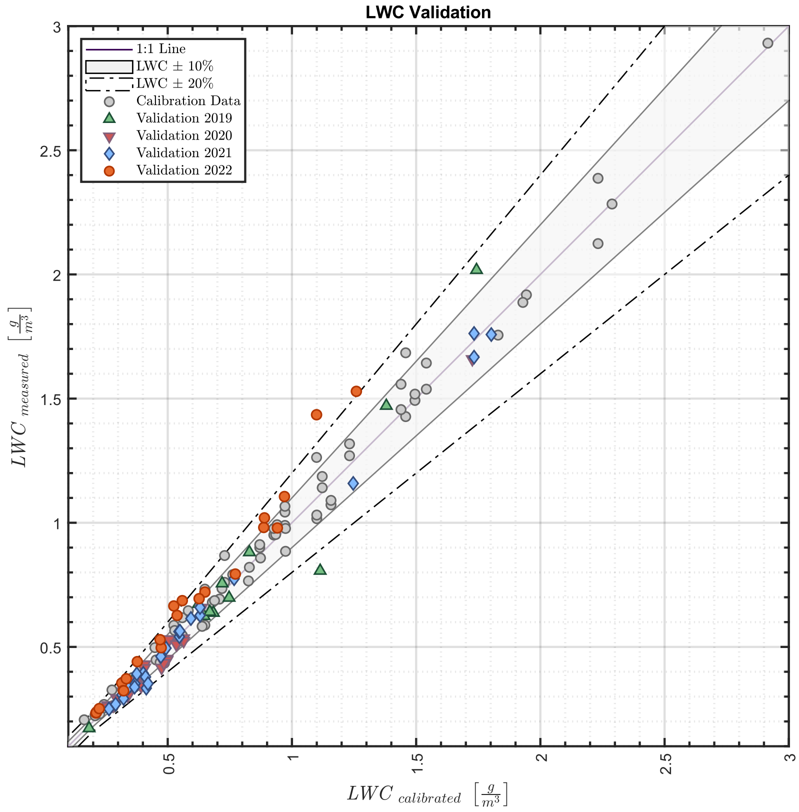

**Figure 45:** Comparison of measured versus calibrated LWC, Test Setup 2

## 8. Summary

The Icing Wind Tunnel Vienna is designed especially for low speed ranges, which makes it ideal for the testing of slow flying aircraft such as helicopters, unmanned aerial vehicles, small aircraft, etc. The long cooling section of approximately 11.5 m from the spray nozzle exit to the test section area ensures an ideal temperature adjustment of the droplets even for larger sizes (super cooled status). 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. Water treatment allows a heating of the water for low icing temperatures as well as pre-cooling for icing tests close to an ambient temperature of 0 °C.

Detailed calibration documents for the large IWT are available on request and will be handed over together with the test documentation after completion of the tests. For the small IWT only limited calibration data is available, as the calibration process is still ongoing.

The design of the spray bar system (2 separately controllable circuits per spray bar) allows the droplet range to be extended for SLD simulation. 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.

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.