

Development of SLD Capabilities in the RTA Icing Wind Tunnel

Hermann Ferschitz, Michael Wannemacher, Otto Bucek, Florian Knöbel, and Wolfgang Breitfuß
RTA

ABSTRACT

RTA Rail Tec Arsenal Fahrzeugversuchsanlage GmbH has focused on the simulation of in-flight icing conditions since 2012. Following the successful implementation of the icing conditions specified in EASA CS-25 Appendix C, it was expected that the facility could also be used to simulate the SLD conditions required by EASA CS-25 Appendix O. This paper sets forth theoretical considerations concerning the selection of suitable nozzles and their operation in the existing facility. The transport of large droplets through the contraction nozzle was simulated using a CFD program. The results then served as a basis for deriving secondary droplet breakup. The validations carried out confirm the theoretical considerations and identify potential limits and open research questions.

CITATION: Ferschitz, H., Wannemacher, M., Bucek, O., Knöbel, F. et al., "Development of SLD Capabilities in the RTA Icing Wind Tunnel," *SAE Int. J. Aerosp.* 10(1):2017, doi:10.4271/2017-01-9001.

INTRODUCTION

Safety is naturally a top priority in the aviation industry. When an aircraft flies in upper cloud layers, supercooled water droplets suddenly freeze and, within minutes, can form a centimeter thick layer of ice on critical components such as the engines, rotors, wings and sensors. In order to obtain certification for these components and the whole aircraft, manufacturers must demonstrate that sufficient protective measures have been implemented and that the formation of ice will not endanger flight safety in any way.

In order to develop, test and certify products, the aviation industry therefore urgently requires high-performance facilities where suitable icing tests can be carried out. Rail Tec Arsenal (RTA), an internationally active independent research and test institute for rail and road vehicles, aircraft and technical equipment, has taken on this challenge and built up new icing capabilities with funding from the Austrian Ministry for Transport, Innovation and Technology (BMVIT) via the Austrian Research Promotion Agency (FFG)

The large Climatic Wind Tunnel (CWT) depicted in the [Appendix](#) can be upgraded to an Icing Wind Tunnel (IWT) using an additional icing rig mounted on the existing CWT contraction section (see [Figure 1](#)). The IWT speed can be increased by integrating an additional contraction nozzle (see [Figure 2](#)). This new equipment allows cloud simulations to be carried out according to EASA CS-25 [1, Appendix C] or FAA Title 14 CFR Part 25 [2, Appendix C].

According to the EURICE Final Summary Report [3], the current EASA CS-25 [1, Appendix C] does not include all possible conditions present in the real atmosphere. Freezing rain in particular has long been underestimated as a potential hazard condition (see [4, p. 1]). The simulation of Supercooled Large Droplet (SLD) icing conditions such as freezing rain and freezing drizzle in IWTs has thus

become more important in recent years. Since these facilities offer the possibility to test components under reproducible conditions, RTA started to develop a method to simulate SLDs as freezing rain and freezing drizzle according to EASA CS-25 [1, Appendix O] or FAA Title 14 CFR Part 25 [2, Appendix O] in 2015.

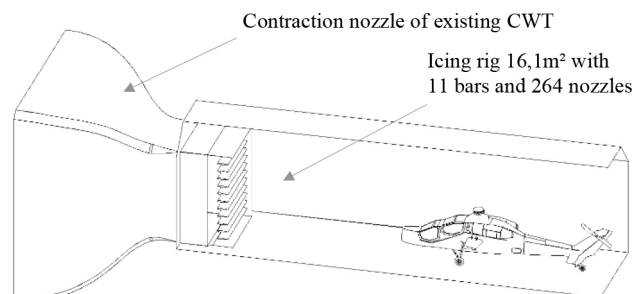


Figure 1. Icing rig connected to the CWT

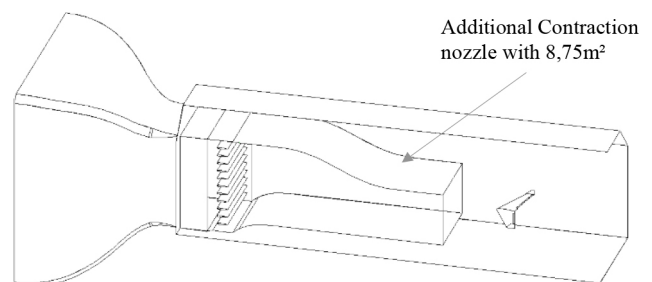


Figure 2. Icing rig with additional contraction nozzle

SLD ENVIRONMENT

The definition of SLD icing conditions in the form of freezing drizzle and freezing rain can be found in EASA CS-25 [1, Appendix O]. The droplet distribution and Liquid Water Content (LWC) for SLDs are defined as shown in [Figures 3, 4, 5, 6](#).

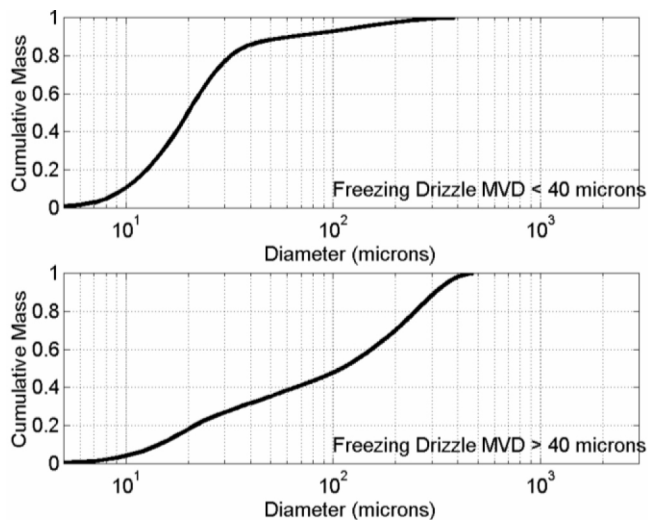


Figure 3. Freezing drizzle, droplet diameter distribution [1, Appendix O]

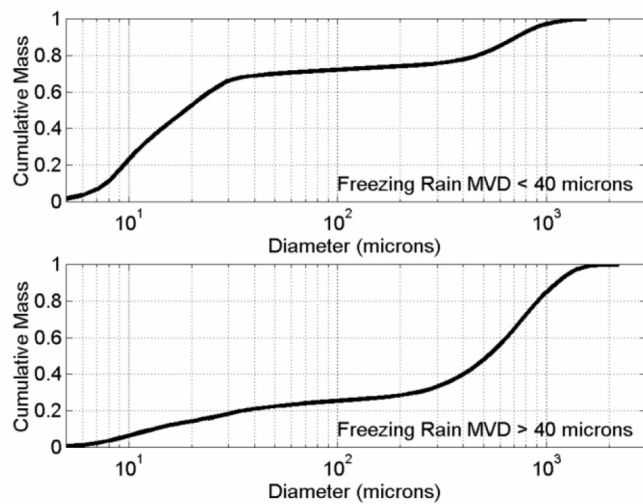


Figure 4. Freezing rain, droplet diameter distribution [1, Appendix O]

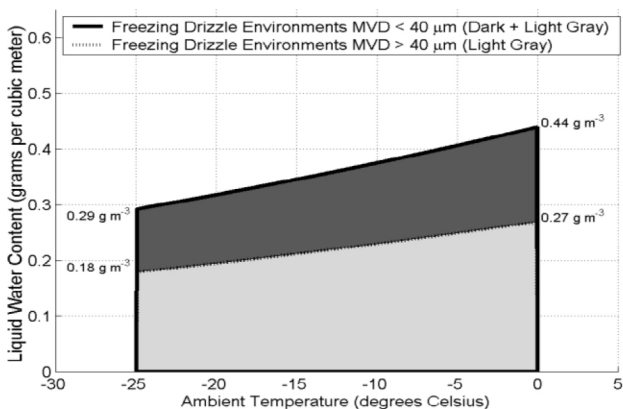


Figure 5. Freezing drizzle, LWC [1, Appendix O]

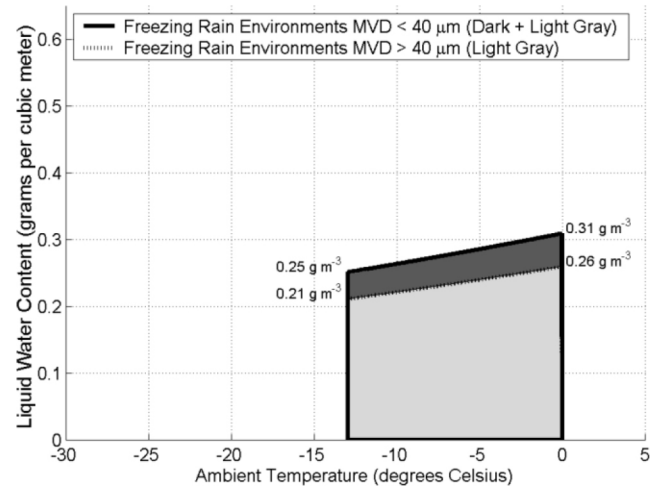


Figure 6. Freezing rain, LWC [1, Appendix O]

IWT MODIFICATIONS FOR SLD MODE

Two modifications were required for running SLD simulations in the RTA IWT: suitable nozzles and modifications of the water supply system compatible with the existing system.

Nozzle Selection

Before selecting the most suitable nozzles it was important to define two main parameters: the Median Volumetric Diameter (MVD) and the flow rate which was used for the theoretical Total Water Content (TWC) in the IWT. The following approach was used for the theoretical analysis of the MVD. The distributions given in Figures 3 and 4 have bimodal characteristics. Each distribution may be closely represented using a sum of two Gaussian distributions. This results in five parameters for each type of rain: MVD and standard deviation of small droplets, MVD and standard deviation of large droplets and mass fraction of small droplets related to total mass. Table 1 below shows the parameters for the types of rain as defined in EASA CS-25 [1, Appendix O].

Table 1. Parameters for SLDs

	Total		Small droplets		Large droplets	
	MVD	ϕ	MVD	σ	MVD	σ
	(μm)	(-)	(μm)	(μm)	(μm)	(μm)
Freezing drizzle	< 40	0,85	19	11	100	73
	> 40	0,31	24	14	182	147
Freezing rain	< 40	0,69	14	10	559	447
	> 40	0,19	20	13	644	532

The LWC according to EASA CS-25 [1, Appendix O] is based on the water flow rate versus the IWT cross-section (theoretical TWC). The flow rate can thus be calculated as follows (see Equations 1, 2, 3, 4):

$$\dot{m}_{Nozzle_S} = \frac{LWC \cdot \varphi \cdot Vt \cdot A}{n \cdot \varepsilon} \quad (1)$$

$$\dot{m}_{Nozzle_L} = \frac{LWC \cdot (1 - \varphi) \cdot Vt \cdot A}{n \cdot \varepsilon} \quad (2) \text{with}$$

$$\varepsilon = \frac{LWC}{TWC} \quad (3) \text{and}$$

$$\varphi = \frac{LWC_S}{LWC_S + LWC_L} \quad (4)$$

This approach requires homogeneous LWC distribution in the test section. Furthermore, ε was estimated at 0.9 based on the small droplet (see EASA CS-25 [1, Appendix C]) calibration of the IWT according to SAE ARP5905 [5], which was carried out in 2013/2014. A value of 1.0 was assumed for large droplets because of the missing effects of air influence (expansion and evaporation) when using a single-medium nozzle. The values (shown in Table 1) provided the basis for selecting the most suitable nozzles for the existing icing system. The selection process produced the following results:

- For MVD < 200 μm : pneumatic atomizer nozzles
- For MVD > 200 μm : single-medium nozzles

A feasibility study [6] carried out at the RTA IWT with the new configuration showed that conditions for “Freezing Drizzle MVD < 40 μm ” and “Freezing Rain MVD < 40 μm ” cannot be met in the current IWT setup. The reason for this is that there are no nozzles available that can produce droplets of approx. 560 μm or 100 μm MVD at the extremely low mass flow rate required. Research was therefore focused on the SLD simulation of freezing rain > 40 μm MVD and freezing drizzle > 40 μm MVD because of the promising results achieved during the mentioned feasibility study 2015.

Water Supply System Modification

The IWT was built to produce droplets according to EASA CS-25 [1, Appendix C] and thus required a modification of the water supply system. In the basic design the water circuits (see Figure 7) were all connected to one water supply so that the nozzles could only be operated with one temperature setting.

With the SLD modification, a second water supply was added to provide capability for two different temperature settings in parallel. The bimodal droplet spray needs two different nozzle types with different air and water settings for achieving various MVDs (a single-medium nozzle needs only a water pressure set point). On the one hand, the water supplied to the pneumatic atomizer nozzle must be preheated because smaller droplets tend to freeze before reaching the test section. On the other hand, the water supplied to the single-medium nozzle must be precooled in order to ensure that the larger drops in particular are supercooled when reaching the test section.

Future research will be necessary to determine the correct water temperature for freezing rain > 40 μm at certain ambient temperature, wind speed and residence time.

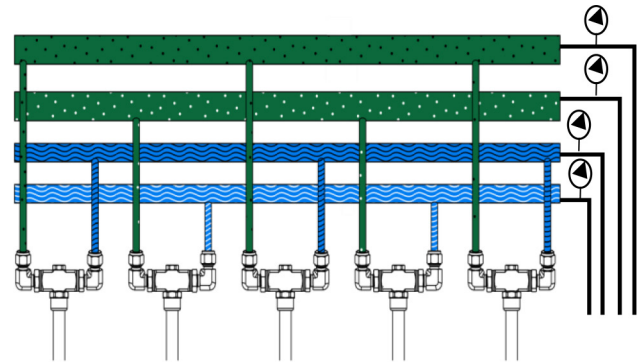


Figure 7. Piping system of the RTA icing rig; blue: water, green: air

CFD ANALYSES FOR SLD TRAJECTORY AND DROPLET BREAKUP

The challenge in simulating SLD icing conditions is the different behavior of large droplets (> 100 μm) compared to droplets < 50 μm . Gravitational influences as well as droplet breakup and high inertia are some of the major characteristics of SLDs [7, p. 1].

Droplet Trajectory in the IWT

A 2D CFD analysis of droplet trajectories was conducted in collaboration with the Institute of Aviation at the FH JOANNEUM (University of Applied Sciences) in Graz. This analysis was designed to estimate the trajectories of particles with different diameters and to determine the air velocity needed to transport large droplets (100 μm to 1200 μm) to the test section of the IWT. The particle trajectories of droplets with variable diameters were thus simulated at varying air velocities and two different temperatures. The analysis was done using ANSYS CFX15.0 [8]. The IWT at RTA has an asymmetrical contraction nozzle with a length of about 10 m, a height of 2.5 m and a width of 3.5 m at the outlet. The 2D simulation was performed for the geometrical center of the nozzle. The velocity field in the contraction nozzle and the particle tracks were exported in order to estimate potential droplet breakup. Figure 8 shows the mesh for the CFD analysis of the contraction nozzle and the region where the water droplets were injected.

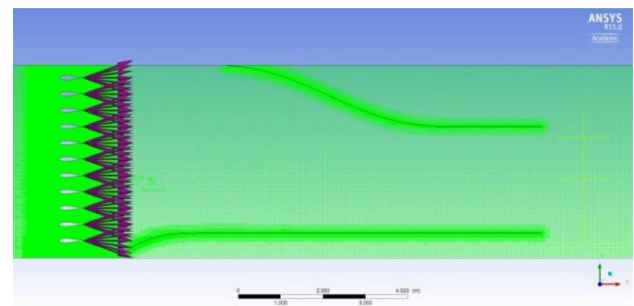


Figure 8. CFD analysis, mesh created with ANSYS CFX15.0 [8]