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New UAV ice tunnel characterization

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Abstract. In the recent years, the field of unmanned aircraft vehicles (UAVs) has shown great technological progresses and many new applications have born. To assess the potential of this technology and to improve the availability and reliability of the rising services it is critical to overcome operational limitations. One key operational hazard is atmospheric in-flight icing, resulting in large aerodynamic penalties, unbalances and other detrimental phenomena that sometimes can lead to catastrophic consequences. In this paper, a new ice tunnel developed in the large hypobaric and climatic chamber of the terraXcube facility of Eurac will be presented. A preliminary characterization and calibration of the system has been also performed following the EASA regulation reported in the Easy Access Rules for Large Rotorcraft (CS-29) (Amendment 6).

Introduction

While UAV systems offer numerous features and performance capabilities, there are areas in need of improvement, particularly in terms of reliability. Unmanned aircraft are often deployed on high-risk missions, operating in marginal weather conditions for purposes such as search and rescue or military operations. Therefore, the development of an effective tool to assess performance in these challenging conditions would be highly valuable. Currently, only a few unmanned aircraft are specifically designed to address the challenges of icing. These aircraft are primarily large military UAVs developed for long-range missions in harsh environments. While smaller UAVs may have some level of rainproof or snowproof certification, there is generally no specific consideration for icing (EU 2019/945 EU 2019/947). In the aviation industry, there are well-known and established facilities dedicated to icing testing, however, these facilities are both complex and expensive. Consequently, integrating an icing testing program during the development of a small or mini-UAV can be highly challenging. For example, the estimated cost of regional transport aircraft icing tests, as mentioned in the IPHWG Task 2 WG Report - Appendix J, is approximately 700,000 € [1]. Here we propose a more cost-effective alternative, a home-made ice tunnel developed in our climatic chamber. This new facility could allow for the testing of a full-scale UAV under realistic icing conditions.

Experimental setup and Methods

Facility

TerraXcube is an infrastructure for research and testing that leverages a multi-dimensional approach for environmental simulation part of Eurac Research Institution. With a useable volume of 360 m³, the climatic chamber Large Cube can simulate the most extreme environmental conditions on the Earth's surface, allowing the synchronous control of multiple complex environmental parameters for long duration analysis.

Wind tunnel
Inside the climatic chamber an open-loop wind tunnel was developed. The chamber was hypothetically divided into two sections as showed in Fig. 1: testing section on the right and production section on the left. The testing section is the volume where the UAV is placed and the subcooled cloud is fully developed. The production section is composed by the wind tunnel, fan and nozzles which contributes to the formation of the ice conditions.

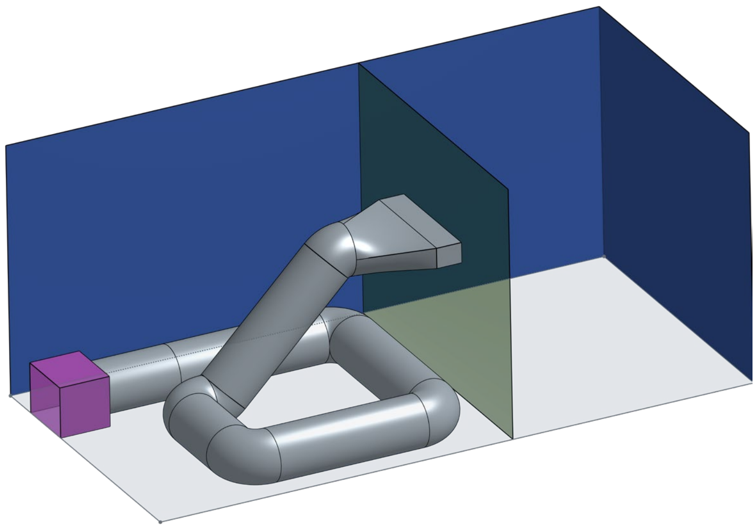

Fig. 1 - Layout

Fig. 2 - Setup

The climatic chamber works as a closed loop system. The air is extracted from the wall on the right side of Fig. 1 (North side), it is treated by heat exchangers and it returns from the left side (South side) inside the chamber. Almost all the flow treated by the chamber is streamed to the axial fan, depicted in purple on Fig. 1. The fan (volume purple in Fig 1) controls the air speed inside the wind tunnel. Immediately after the fan there are 25 nozzles which can be controlled in terms of air and water pressure leading to different subcooled cloud properties described in the next section. The ice tunnel allows to test UAV platforms up to 2 m^3 (Fig. 2).

The main characteristics of the open-loop wind tunnel are briefly reported in the following Table 1.

Table 1 Technical data of wind tunnel

Fan	Konz Lufttechnik
Speed [m/s]	0 ÷ 30
Diameter [m]	1
Length [m]	About 18 m

Icing system
The icing system is composed by 25 nozzles supplied by pressurized air and water and managed as prescribed in [2-3] to produce different icing conditions. The main aspects of subcooled clouds are the mean volume droplets (MVD), which refers to the average size or diameter of water droplets, and the LWC, liquid water content, which refers to the amount or concentration of liquid water present in a given volume of air or cloud. Modifying the number of nozzles involved, the air pressure and the water pressure, MVD and LWC can be varied as desired. The water supplied is

ultrapure water (18 MΩ·cm) which allows to the water to remain in the liquid state until the impact with the UAV surface. The technical data are as follows:

Table 2 Technical data of icing system

LWC [g/m^3]	0 ÷ 3
MVD [µm]	15 ÷ 40
Operating temperature [°C]	-40 ÷ +0
Nozzles	Spraying System SUJ-12

Droplets measurements
The real time droplets measurements system consists in a low-cost optical system [4,5]. Based on shadowgraph, it is composed by a telecentric objective coupled with an industrial CMOS camera. After a proper calibration, the system takes pictures of the stream, an OpenCV algorithm detects droplets and measures their diameter. With such method, it is possible to have a real time measurement of MVD and LWC (indirect estimate) of the stream.

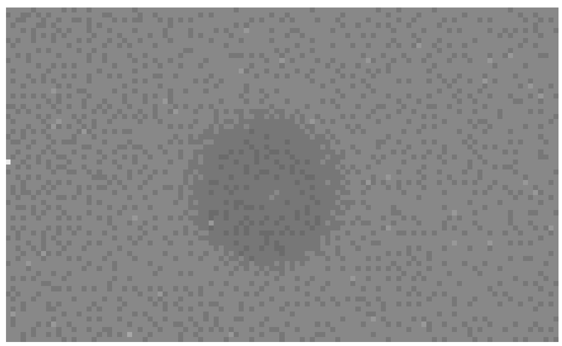

Fig. 3 - Example of a droplet detected by the optical system.

Results
The characterization and calibration of the system has been performed following the standard for calibration and acceptance of icing wind tunnel described by EASA [6] with the cylinder collection method. Three set of parameters were analyzed, the duration of each test was fixed at 10 minutes.

Table 3 System parameters

	Test #A	Test #B	Test #C
Temperature [°C]	-10 ± 2	-10 ± 2	-10 ± 2
Air pressure [bar]	3.1 ± 0.3	2.3 ± 0.3	1.1 ± 0.3
Water pressure [bar]	1.5 ± 0.3	1.5 ± 0.3	0.7 ± 0.3
Number of nozzles	4	4	4

Mean Volume Diameter. MVD data, collected with the optical measurement system, were compared to calibration chart as in [3].

Table 4 MVD measurement comparison

	Test #A	Test #B	Test #C
MVD theoretical [μm]	15	25	35
MVD measured [μm]	20 ± 4	31 ± 4	38 ± 4

Liquid Water Content. LWC data, obtained by the ice cylinder method, showed a good agreement between the technical datasheet of nozzles and [6].

Table 5 LWC measurement comparison

	Test #A	Test #B	Test #C
LWC datasheet [g/m^3]	0.16	0.23	0.18
LWC cylinder [g/m^3]	0.11	0.19	0.25

Conclusion

The preliminary characterization of the icing wind tunnel in the terraXcube facility yielded promising outcomes. The primary advantage of this new system lies in its potential to conduct full-scale UAV trials within the real operational environment. However, further refinements and investigations are required to ensure a complete understanding of its capabilities. Additionally, an important area for exploration involves the simultaneous utilization of the icing system and hypobaric capabilities of the chamber. This integration holds the potential to significantly impact UAV testing within icing conditions at high altitudes (up to 9000 m).

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