

Abstract

Data-Driven development of Icing-Resilient Control for Urban Air Mobility UAVs

Arno Fallast^{1,2}, Samuel Lesak¹, Holger Friehtmelt¹

¹ FH JOANNEUM, Institute of Aviation, Graz, Austria, arno.fallast@fh-joeanneum.at;

² Graz University of Technology, Institute of Machine Learning and Neural Computation;

Innovative Air Mobility (IAM), including Urban Air Mobility, regional UAV operations, and unmanned logistics, requires robust flight-control performance under non-ideal environmental conditions. Icing remains a critical limitation for small and medium-sized multicopter UAVs, especially in cold-weather regions. Weather constraints can substantially reduce drone flyability [1], and icing assessments for air-taxi services show strong seasonal, regional, and altitude-dependent exposure differences across UAM-relevant cities [2]. For multicopter UAVs, icing is particularly critical because lift, stabilization, and manoeuvring authority are generated directly by the propeller–motor systems. Ice accretion on propeller blades reduces propulsive efficiency, increases torque and electrical power demand, and reduces the actuator authority available to the flight controller. From a control perspective, propeller icing can therefore be interpreted as a time-varying actuator-effectiveness degradation.

This contribution presents a data-driven modelling and control-design workflow for icing-resilient IAM UAV operation. The workflow translates experimental icing data into degradation-aware simulation models, telemetry-based degradation detection, and adaptive control strategies. Motor test-bench, climatic-chamber, and full-UAV wind-tunnel data are used to model the relation between motor command, rotational speed, current, voltage, electrical power, generated thrust, and icing-induced performance degradation. The full-UAV mock-up tests are included to capture vehicle-level effects that cannot be observed in isolated motor tests, such as rotor-specific degradation under realistic motor speed variations and asymmetric loading during forward-flight-like operation. Deviations between expected clean propulsion performance and measured behaviour provide residuals for ice and degradation detection. The estimated degradation state is then used as a scheduling variable for controller adaptation.

The work builds on previous data-driven powertrain modelling by Fallast and Ghoddousi, where a multicopter powertrain with icing-induced degradation was identified for simulation-based training of a fault-detection neural network [3]. Dynamic Mode Decomposition with control provides a suitable basis for such input-output degradation modelling [4]. The present paper further extends a recently finalized controller-oriented study on multicopter UAV operation under icing-induced propulsion degradation [5]. In that study, prior motor–propeller icing experiments and full-UAV icing wind-tunnel test-stand data were combined to obtain a data-driven degradation representation for a quadrotor UAV mock-up. The model was embedded in a six-degree-of-freedom UAV simulation and used to compare a fixed-gain baseline controller with a degradation-aware control strategy. First results showed that propeller icing leads to increased motor command and electrical power demand. For a maximum-payload UAV configuration, pre-accreted ice caused the fixed-gain controller to operate close to

the actuator command limit, while a degradation-aware controller with adapted gains and modified reference velocities reduced the required actuator usage during an evasive return manoeuvre.

The new contribution strengthens the experimental basis and shifts the focus towards data-driven model-based controller design. Already available motor test-bench icing runs are currently being evaluated and additional climatic-chamber experiments planned for September 2026 will provide further data for degradation-model training and validation.

The degraded-performance simulation model is used for model-based controller design. The controller is not tuned only on the nominal clean UAV model, but on models representing different degrees of icing-induced degradation. The objective is not only trajectory tracking, but preservation of actuator authority. Main evaluation metrics are normalized motor command, peak actuator usage, electrical power demand, and remaining propulsion reserve. First simulation results indicate that degradation-aware control and manoeuvre adaptation can reduce actuator saturation risk and extend the remaining flight capability margin under icing conditions. The workflow also provides a foundation for future model predictive control, where actuator limits or degraded propulsion authority can be considered explicitly. The long-term objective is not unrestricted flight in icing, but model-based risk awareness, trustworthy degradation detection, and safe exit strategies for IAM UAVs operating in adverse weather.

References

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Biography

Arno Fallast



A. Fallast is a researcher and senior lecturer at the Institute of Aviation at the University of Applied Sciences, Graz where he leads the research Group “Intelligent Systems”. He is a PhD Student at the Technical University Graz (Institute of Machine Learning and Neural Computation) researching Machine Learning methods for anomaly detection and data driven modelling.

He received his bachelor’s degree and his master’s degree in aviation engineering from the FH JOANNEUM. For 13 years he has been working as a researcher and lecturer