UAV Icing: Simulation of Aerodynamic Performance Degradation with CFD

R. Hann
Corresponding author: richard.hann@ntnu.no

Norwegian University of Science and Technology (NTNU), Trondheim, Norway
UBIQ Aerospace, Trondheim, Norway

Abstract: Atmospheric in-flight icing imposes a significant hazard for the operation of unmanned aircraft. This paper outlines the use of icing CFD method for unmanned aerial vehicles (UAVs) with the main objective to predict aerodynamic performance losses. Ice shapes are generated on a 2D UAV airfoil with ANSYS FENSAP-ICE for a wide range of meteorological icing conditions. Aerodynamic performance is calculated with ANSYS Fluent and FENSAP. The outcomes highlight the value of using icing CFD for design of ice protection systems. Futhremore, the work shows the knowledge gaps in icing CFD of UAVs compared to manned aircraft.

Keywords: Unmanned aircraft, UAVs, icing, in-flight icing, CFD, aerodynamics

1 Introduction

Unmanned aerial vehicles (UAVs) are a technology that is currently growing rapidly. In addition to the established use of UAVs for military purposes, more and more civil applications are emerging [1]. Many of these new applications rely on operations beyond visual line of sight (BVLOS), e.g. package deliveries, pipeline inspections, and remote operations. During these operations, there is a risk that the aircraft encounters meteorological conditions that lead to icing on the airframe [2]. These conditions are called atmospheric in-flight icing, and exist when supercooled liquid droplets inside clouds or in from of freezing precipitation exist in the atmosphere [3]. When an aircraft flies in such conditions, the supercooled liquid droplets will collide with the airframe and freeze. The resulting ice shapes typically accumulate on the leading-edge of lifting surfaces and disturb the airflow. This can severely degrade the aerodynamic performance. Icing on airfoils decreases lift, increases drag, deteriorates stall behavior, and decreases stability [4, 5]. Icing on propellers rapidly reduces thrust and increases torque [6]. Consequently, icing is a severe hazard for UAVs, that needs to be addressed adequately to expand the operational envelope into cold weather conditions.

The ability to accurately predict the aerodynamic penalties related to icing is important for the design of UAVs that are expected to fly in icing conditions. The understanding of the degree of adverse icing effects is a key component in the development of suitable icing protection systems (IPS) [2]. For manned aviation, several icing codes have been developed since the 1970-80s and that are able to simulate the ice accretion process numerically [7]. In addition, icing wind tunnel facilities exist where icing conditions can be simulated under laboratory conditions, see Fig. 1.

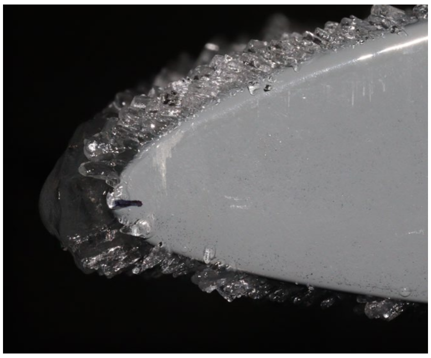

Figure 1: Clear ice accretion on a UAV airfoil form icing wind tunnel experiments

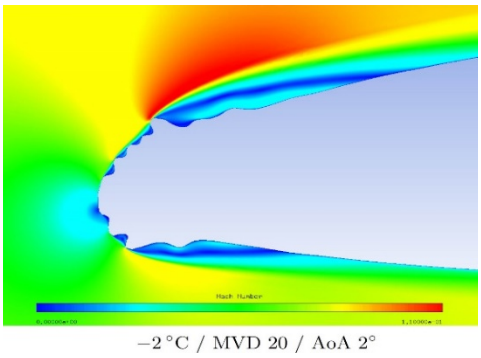

Figure 2: Flow field around an iced UAV airfoil.

2 Problem Statement

The existing numerical tools for icing simulations have been developed for manned aircraft. Typically, these aircraft operate at significantly higher Reynolds numbers compared to unmanned aircraft [2]. The difference in the Reynolds number regime plays a significant role in both the icing accretion physics and in the simulation of the icing effects [4, 8]. Since UAV icing is a fairly novel topic, there is a knowledge gap about the limitations of the existing icing tools for the applications on UAVs.

The objective of this paper is to investigate the icing penalties on a UAV over a range of meteorological parameters for icing in cumuliform clouds (intermittent maximum icing) and in freezing rain and drizzle (supercooled large droplet icing). The meteorological icing envelopes are based on the certification requirements for manned aircraft, described in 14 CFR Part 25 Appendix C and O. Ice shapes are generated using the icing simulation tool ANSYS FENSAP-ICE for a 2D UAV airfoil geometry. The performance degradation is simulated using computational fluid dynamics (CFD) tools, see Fig. 2. Two CFD codes are compared to each other and validated with experimental wind tunnel tests. The first tool is FENSAP, a Reynolds-averaged Navier-Stokes (RANS) solver that is part of FENSAP-ICE. The second tool is ANSYS Fluent which offers a wider selection of simulation models.

3 Conclusion and Future Work

The outcome of this study is an improved understand what type of meteorological icing conditions are the most hazardous to UAV operations. Furthermore, two CFD codes (FENSAP and Fluent) are compared in their capability to accurately predict the performance degradation due to the ice shapes. This knowledge is highly relevant for risk assessment of missions in potential icing conditions and for the design of icing protection systems for UAV.

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