Hazards of In-flight Icing on Unmanned Aircraft

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ABSTRACT

The last decade has shown great technological progress in the field of unmanned aircraft systems (UAS) and many new applications have been introduced. To facilitate this fast-paced progress and capitalize on the potential of the technology, it is critical that comprehensive and standardized UAS certification and flight testing procedures are developed. One of the topics that will need special attention in this context is the hazard of atmospheric in-flight icing. In-flight icing occurs when an aircraft encounters supercooled liquid droplets in the air. These droplets impinge and freeze on the aircraft resulting in large aerodynamic penalties, sometimes with catastrophic consequences. While already an established phenomenon in manned aviation, little work has been done in the UAS community so far. Due to the operational profiles, the sizes of the aircraft, and not having human decision-makers in the loop, in-flight icing poses a severe threat to the UAS industry and should therefore be addressed with the same rigor as in manned aviation. This document attempts to give a brief overview of the in-flight icing threat. These recommendations consist of raising awareness, improving atmospheric forecasting and nowcasting, developing icing envelopes and regulations, and including in-flight icing in the UAS certification process.

1.0 INTRODUCTION

With the technological advances of the past decade, accessibility and applicability of UAS are rapidly increasing, where many of the most dangerous tasks could be supplemented, or even replaced by UAS operations. As present technologies develop further and novel technologies emerge, UAS will acquire abilities enabling them to perform increasingly complex tasks. Historically, most military UAS operations were conducted in the Middle East in warm climates with few cold weather challenges. In recent events, the conflicts of the future are likely to be focused at higher latitudes with cold climate being a significant factor, especially for UAS operations. In addition to military applications, civil services are also affected by cold weather and may limit commercial development, for example in:

- emergency response,
- humanitarian aid and disaster relief,
- conservation,
- disease control,
- health care,
- agriculture,
- weather forecasting,
- waste management,
- energy production,

- mining forecasting,
- construction planning,
- infrastructure development, and
- insurance inspection.

All of these services have potentially substantial societal, economic, environmental, and climatic impacts, highlighted by the current COVID-19 outbreak, which emphasizes society's vulnerability to immobility. Unmanned aircraft can be a critical tool in future emergency response situations. Through the delivery of crucial medical supplies, operating as communication relays in networks, and performing associated disaster management tasks, unmanned aircraft can add immeasurable value. Regrettably, current UAS lacks the weather-robust capabilities, particularly related to in-flight icing, to be a reliable tool in times of distress.

The in-flight icing phenomenon is one of the most significant weather hazards to aviation that is experienced in freezing conditions when liquid water droplets impinge on exposed aircraft surfaces. Upon impact, the droplets freeze and drastically reduce aircraft capabilities with potentially devastating consequences. Icing is a global phenomenon that is typically encountered at altitudes ranging from ground level up to 18,000 feet [1, 2]. First-hand interactions with some key operational stakeholders[1] in the UAS industry have revealed that more than 50% of their critical UAS operations are canceled due to the risk of icing conditions[2].

2.0 UAS ICING INCIDENTS

The first mention of UAS icing in the open literature dates back to 1990 in a comprehensive study by the US Naval Air Development Center describing the hazard of icing for military UA operations [3]. Further reports state that icing was responsible for UAS crashes in Hungary, Afghanistan, Serbia, and Kosovo during the 1990s [4, 5]. Since then, very little information is openly available, which is likely related to the fact that – up until recently – most UA operations were performed by the military. One more recent incident, that became publicly known, happened in February 2017, when a British Army Watchkeeper UAS stalled after its pitot tube got blocked, most likely due to icing [6].

3.0 IN-FLIGHT ICING

3.1 Background

In-flight icing, also called atmospheric icing, occurs when an aircraft encounters supercooled liquid water in the atmosphere, and that liquid water freezes onto the aircraft. The water occurs as cloud droplets or precipitation in liquid form with a temperature below the freezing point. When such supercooled droplets collide with an aircraft, they freeze on the surface and can grow into various ice shapes, see Fig. 1. Atmospheric icing conditions can be encountered all year round and all around the globe [1, 2]. The ice severity is characterized by the air temperature, size, and velocity of the vehicle, but also by the liquid water content and the droplet size.

[1] US Airforce pilots operating in the State of New York, and pilots and operators from the Norwegian Armed Forces and the Finnish Army Aviation.

[2] The risk of icing conditions is assessed in pre-flight meetings. Weather forecasts predicting freezing temperatures and cloud covers at operational altitudes and space constitute a risk of icing, where a consequence is typically canceling the flight.

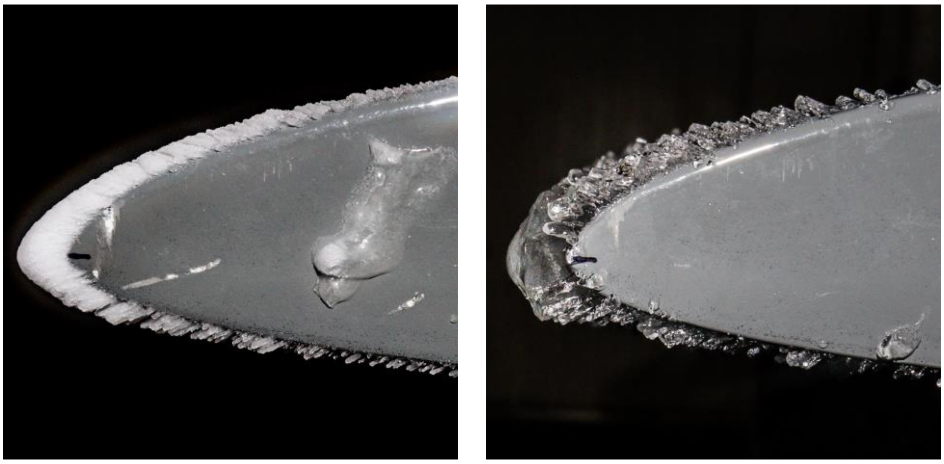

Fig. 1: Rime ice (left) and glaze ice (right) accretions on a UAS airfoil from an icing wind tunnel test.

3.2 Icing Effects

Numerous wind-tunnel experiments, in-flight tests, and numerical simulations show that ice accumulated on the leading-edge of a lifting surface will lead to a degradation of its aerodynamic performance. The ice shapes modify the airfoil geometry and typically lead to a significant decrease in lift, increase in drag, change in pitch moments, and deterioration of the stall behavior. Furthermore, icing negatively affects aircraft stability and control. The degree of performance degradation depends on the form of the ice shapes and the degree of disruption of the airflow. A numerical study on the icing penalties of a typical UAS airfoil for a wide range of meteorological icing parameters showed that lift can be decreased by 35%, stall angles can be reduced by 33%, and drag can be increased by up to 400% in the linear region [7]. One study on a UAS propeller shows that glaze ice conditions can lead to a thrust reduction of 75% coinciding with a required power increase of 250% after only 100 seconds of exposure to moderate icing conditions [8]. Icing on rotary-wing UAS rotor blades has similar negative effects and can build up very quickly [9]. In addition, icing can introduce imbalances between the rotors, leading to control issues and loss of stability.

3.3 Special Issues of UAS Icing

The history of icing studies on manned aircraft dates back to the 1940s and 1950s, when the foundation for modern icing research was laid. Today, icing in manned aviation is generally a well-understood problem. A large amount of research has been performed on the consequences of icing on aircraft. Commercial and military all-weather capable UASs are expected to be just as reliable as piloted aircraft. Therefore, the icing issue needs to be solved just the same, but there are different challenges to overcome for UAS. There are several differences between manned and unmanned aircraft that are relevant in the context of icing [10]. The comparison between the two types of aircraft is somewhat difficult since UAS come in a great variety of forms and sizes, ranging from hand-launched micro UAS to large high-altitude military aircraft.

Generally, unmanned aircraft tend to fly at lower velocities compared to manned aircraft. The reason for this is that most UAS mission profiles are endurance-driven with the objective to loiter for extended durations above an area of interest. Due to the lower speed requirements, most UAS utilize propellers for propulsion, with electrical, piston, or turbo engines instead of jet engines. UAS tend to be significantly lighter than manned aircraft as their payload capacity is smaller too. The wingspans of the largest UAS are comparable to small manned passenger aircraft – but the majority of UAS have much smaller wings. Smaller airframes are also more sensitive to icing as they accrete larger ice horns relative to their size, which lead to substantially larger performance penalties compared to larger airframes.

The operational altitude is also largely varying for UAS. On one end of the spectrum are large UAS, used primarily for surveillance, that operate at altitudes higher than manned aircraft. On the other end are small UAS that operate in limited areas, flying in close proximity to the ground level. The existing icing nowcasting and forecasting products are developed for manned aircraft and lack the spatial and temporal resolution for many UAS applications, especially for near-ground operations.

Finally, the most obvious difference is that UAS do not have a pilot on board that can identify icing conditions but instead must rely completely on onboard instruments. Consequently, the overall degree of automation tends to be larger in UAS than in manned aircraft. Therefore, there is a need for lightweight, accurate, and sensitive ice detection systems that can operate as primary automatic ice detection systems.

4.0 UAS TESTING AND IN-FLIGHT ICING

Cold climate UAS capabilities are an increasingly important element for future missions. Hence, testing the cold climate capabilities is becoming an important aspect of flight testing. In manned aviation, icing capabilities are typically tested in a combination of icing wind tunnel tests and flights into natural icing conditions. The goal of such tests is to identify the performance penalties that originate from icing conditions, validate ice detectors, and verify the performance of ice protection systems. Flights into natural icing conditions are a hazardous operation, as excessive icing or the failure of an ice protection system can quickly endanger the aircraft and potentially lead to a crash. Another key challenge during flight tests is to obtain knowledge about the current icing conditions, i.e. droplet sizes, liquid water content, and air temperature. This may require special instrumentation or support from manned aircraft. Similarly, it is a challenge to find suitable icing conditions to fly into.

5.0 RECOMMENDATIONS

Atmospheric in-flight icing is a severe hazard and needs to be addressed for UAS with the same rigor as for manned aircraft. First, awareness needs to be raised of the dangers of icing to UAS for all stakeholders. Second, proper certification and technical requirements that enable safe and continuous operations of UAS in icing conditions need to be developed. This includes the development of unified requirements for ice detection systems, ice protection systems, and general safe autonomous operation in icing conditions. Third, testing procedures need to be developed that can validate the cold climate capabilities of UAS. This includes icing wind tunnel tests, flight tests, but also the use of computational simulations. Last but not least, more research is required in this field. Most importantly, studies to characterize the meteorological icing conditions that are typically encountered by UAS and their effect on different UAS types. This is required to develop UAS icing envelopes, especially for low altitudes, which are a key element required to assess the icing hazards and to develop suitable regulations and technological solutions.

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