International Conference on Icing of Aircraft, Engines, and Structures
June 20 - 22, 2023 | Vienna, Austria

A FLUID BASED sUAS PROPELLER ICE PROTECTION SYSTEM

2022-11-28

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ABSTRACT

In recent years, there have been numerous advancements and developments in small unmanned aerial systems (sUAS) and their applications. The future of sUAS applications, whether the delivery of consumer goods, medical supplies, emergency response, or research instrumentation, include missions beyond visual line of sight (BVLOS) and penetration into clouds. Adverse weather conditions, particularly in-flight icing, will be a significant hurdle to overcome. Currently, some estimates suggest that forecasted icing results in the cancelation of more than 50% of critical UAS operations [1]; However, successful implementation of protective systems will promote full utilization of sUAS and the associated networks and infrastructure.

In-flight icing occurs when small, supercooled water droplets impinge and freeze on the exposed surfaces of an airborne vehicle. Accumulated ice drastically affects the performance of aerodynamic surfaces by degrading lift and increasing drag, which can increase an airfoil's stall speed and reduce the efficiency of a propeller. These adverse effects are inversely proportional to the size of the impacted surface since they tend to have a higher water catch efficiency. Additionally, a fast-moving surface, such as that of a propeller blade, collects more water than a slower-moving object, diminishing its aerodynamic performance further. This combination of small, sharp leading edges and quick rotational speeds is a common characteristic of propellers used in sUAS applications and is an important reason why they must be protected from in-flight icing if they are to be operated in adverse weather conditions.

ASTM Committee F38 on Unmanned Aircraft Systems has developed a standard specification for sUAS that addresses flight within atmospheric icing conditions F3298-19 A2.4.5 [2]. In this standard, the sUAS can either avoid potential icing conditions or detect and safely exit icing conditions. For sUAS requiring all-weather flying capabilities, detect-and-exit is the most likely path. An sUAS without ice protection must demonstrate flight capabilities using ice accretions greater than 5 minutes to comply with this standard. Therefore, reducing ice accretion using an ice protection system is critical.

Numerous methodologies exist for protecting larger aircraft but don’t scale well to sUAS-sized aircraft. These include bleed air systems that require powerful turbine-powered compressors often found on large transport aircraft, electrothermal systems that consume large amounts of electrical power, and other technologies that are low power but have a combination of unproven efficacy, complexity, and poor anti-ice capabilities.

An ice protection technology that is low-powered, effective in anti-ice and de-ice, and scales well to larger and smaller aircraft is freezing point depressant (FPD) systems. FPD systems use metered amounts of ice protection liquids that lower the freezing point of the impacting water droplets beyond the ambient temperature, forcing the water to remain in a liquid state as it sheds from the protected surface. This form of protection has proven results for certification on the lifting surfaces and propellers of general aviation (GA) aircraft.

For an sUAS platform to be effective, it must be able to carry a payload efficiently. Contradictorily, the addition of any system that protects against icing affects the ability of the sUAS to carry its cargo, so it is of utmost importance to minimize the impact that an IPS has on carrying capacity. Adding ice protection system components increases the base sUAS weight, and an increase in power usage to operate the ice protection system decreases the aircraft's endurance or requires an increase in useable energy, such as a larger battery. Traditional freezing point depressant systems are low-powered and mechanically simple, usually requiring only a low-wattage pump, sensors, and a control box, but they also need consumable fluid to be carried onboard.

This presentation shows the results of designing and testing a fluid-based freezing point depressant system to protect the propellers of a typical off-the-shelf octocopter. Initial icing tunnel testing for the sUAS was completed on an 18" diameter, 6" pitch, MF1806 folding polymer propeller to determine the effects of icing. This propeller was attached to a T-Motor MN501-S KV300 motor mounted on a thrust stand that can measure thrust, torque, and RPM, as well as motor voltage and current draw.
The propellers were evaluated using two deck angles, 18° (forward flight) and 90° (stationary hover), at 80% throttle. This setup was tested within a supercooled, freezing fog environment defined as a combination of the atmospheric conditions shown below.

- Temperature: -12°C, -8°C, -4°C
- LWC: 0.03 g/m3, 0.3 g/m3
- Droplet Diameter: 16 μm, 26 μm

A method was developed to deliver an appropriate amount of fluid to the blade such that it protects the entire suction and pressure surface. The maximum amount of fluid needed to protect against the most critical freezing fog condition (-12°C, 0.3 g/m3, 26 μm) was calculated to be 4 ml/min per propeller. Based on this, for an octocopter with a 30-minute endurance, the required amount of fluid is roughly 1 L. With a smart system that can detect the severity of icing, fluid amounts can be tailored to further reduce fluid requirements.

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Figure 1. The motor and propeller used in IWT testing and IPS development.

Without ice protection, ice was allowed to accumulate on the blade for 3 minutes and 24 seconds, which, based on earlier test runs, was just before the ice was expected to shed from the blade. The resultant ice was a double horn shape roughly 0.2" wide, had a thickness of about 13% chord, and spanned the entire leading edge. Figure 2 shows ice shape after completion of the encounter.

Figure 2. Ice accumulation on an unprotected propeller in an icing wind tunnel.

At the point where the run was stopped, the propeller thrust had decreased by 43%, and the electrical power draw increased by 116%. Based on these results, estimations were made to show how quickly an sUAS in this icing condition would start losing altitude and subsequently crashing. While attempting to maintain an altitude of 122 m (400 ft), the aircraft would start losing altitude after 115 seconds (1.9 min) and would impact the ground after another 28 seconds. In summary, from the onset of icing the sUAS would crash within 2.5 minutes.

To evaluate the effectiveness of the IPS, fluid was delivered to each blade such that the suction and pressure surfaces were protected along the chord and spanwise directions. The average steady-state thrust loss was 10-15%, with a power increase of 10-20%. Minimal ice was observed on the blade surfaces after stopping the test runs. A comparison of thrust performance between an unprotected propeller and an assortment of protected propellers is presented in Figure 3.

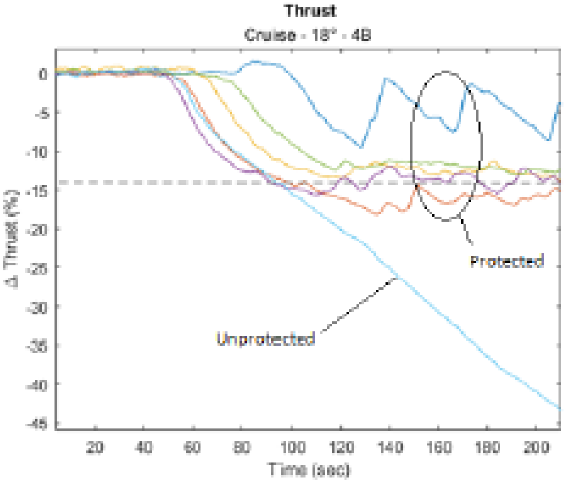

Figure 3. Comparison of thrust performance of an unprotected propeller and various protected propellers in an icing wind tunnel.

In addition to icing tunnel propeller tests, the ice protection system was integrated into a Tarot T18 airframe. The system comprises a low-power system (less than 10 watts) that delivers fluid throughout arterial tubing to each propeller blade. At the current prototype level, the system weighs roughly 2 kg (4.4 lbs) when filled with fluid. Ground and dry-air flight tests of the installed system with the same propeller/motor configuration as the icing tunnel and complete freezing point depressant system showed minimal impact on flight performance and endurance. This research demonstrates that an FPD system for sUAS is a simple, effective, low-powered, and scalable solution.

Preparations are being made for natural ice flight testing expected to take place in the 2022/2023 winter season. The flight tests will collect data to better understand the effects of icing on sUAS performance and contribute to industry and regulatory efforts to establish the requirements for sUAS certification in icing environments. Additionally, the efficacy of the freezing point depressant system will be evaluated in different natural icing environments and can be used in the development and validation of icing models that are emerging for the sUAS sector.

References:
1. Hann, R. (2022). Hazards of In-flight Icing on Unmanned Aircraft. Conference paper. SCI-328 Symposium on 'Flight Testing of Unmanned Aerial Systems (UAS).
2. "Standard Specification for Design, Construction, and Verification of Lightweight Unmanned Aircraft Systems (UAS), "ASM F3298-19, in Annual Book of ASTM Standards, vol. 15.07