https://doi.org/10.26552/ pas.Z.2022.2.01

DANGER OF ICING WHEN OPERATING UNMANNED AERIAL VEHICLES

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Abstract

The paper examines icing on Unmanned Aerial Vehicles (UAV) during the flight. We chose the Mavic Pro and Mavic 2 Pro UAV by company DJI to carry out the research. Research flights are performed during the early morning hours with meteorological conditions suitable for icing. We use the AirData application to analyse flight data. The aim of the work is to find out how dangerous icing is, what meteorological conditions are suitable for icing, how fast icing is formed during the operation of an unmanned aircraft and how it is possible to suppress or eliminate icing.

In introduction of this work elaborated theoretical knowledge about the formation of icing and its types. Subsequently, the negative effects of icing on the flight are described, such as changes in lift, drag, controllability of the aircraft and others. The following section describes the accidents of UAV due to the impact of icing. After analysing the data from the mentioned application, we proposed recommendations for pilots of UAV. Before the flight, we recommend checking the meteorological forecast, focusing on the temperature and humidity at the flight area, usually up to 120 meters above the Earth surface. In-flight recommendations include monitoring rotation speed of propellers and frequent inspection of propellers in meteorological conditions suitable for icing and others.

Keywords

Icing, Lift, Drag, UAV

1. INTRODUCTION

Icing is a significant danger to air transport. It is known from the aviation incidents which happen in the last century that the de-icing and anti-icing systems were not sufficiently researched and developed at that time. This meteorological phenomenon has not been given due importance and attention. Icing on an aircraft can reduce flight performance to a minimum when the aircraft is no longer capable of flight. A very similar phenomenon can occur on unmanned aerial vehicles.

Unmanned aerial vehicles are becoming a more popular tool to use thanks to the built-in camera. Often many laic drone pilots do not look out to icing conditions and in the winter months they like to shoot the snowy landscape or exemplary cold mornings.

In this diploma thesis we focus on this meteorological phenomenon, which is quite common in commercial air transport. In the first chapter, we discuss in detail icing, icing conditions, types of icing, describe how icing is predicted and how it is separated according to intensity. In the second chapter we will describe how much icing affects the aircraft during the flight, it means how negative icing affects the lift, aircraft drag, stability of the aircraft and others. Subsequently, we will describe documented examples of air incidents at the UAV due to icing.

In the practical part of this thesis, we describe the technical parameters of the selected DJI technology - Mavic Pro and Mavic 2 Pro. Next, we will closely describe the methodology of work, it means how we will conduct research flights and analyze the necessary data about these flights from the AirData application. In the end, we will present the results of work from research flights and our recommendations, especially to laic UAV pilots, to know in the future how to prevent icing on the drone and its possible damage.

2. ICING

In general, water on the earth's surface begins to freeze at 0°C, but in the atmosphere the air density is lower, and temperatures are significantly lower, so the freezing point in the atmosphere is not precisely defined and we can find the term "subcooled" water in expert documents. The proportion of this subcooled water decreases together with the static pressure temperature to approximately -40°C and changes to a solid state, in a Cumulonimbus cloud the subcooled water temperatures may be even lower.

2.1. Conditions of icing

Icing usually forms in the frontal area. Atmospheric fronts form when two different air masses collide and cause a weather change in the given area. Many fronts are caused weather events such as rain, storms, gusts of wind or tornadoes. During the cold front, massive and dramatic storms can occur, during the warm front, low stratified clouds such as Stratus, Altostratus, Nimbostratus and similarly. The sky usually clears up after the frontal activity. [1]

2.2. Frost formation

The size of the subcooled water droplets and the nature of the air flow around the surface of the aircraft determine the extent to which these subcooled droplets fall on its surface. Large droplets often break up into smaller ones, which freeze faster. Undivided large subcooled droplets freeze more slowly due to the greater release of latent heat and can form a surface layer of liquid water before the change of state occurs. Factors influencing icing include: [2]

- droplet size

- concentration of drops
- shape of aircraft surfaces
- aircraft speed
- ambient temperature
- aircraft surface temperature (must be below 0°C for icing)

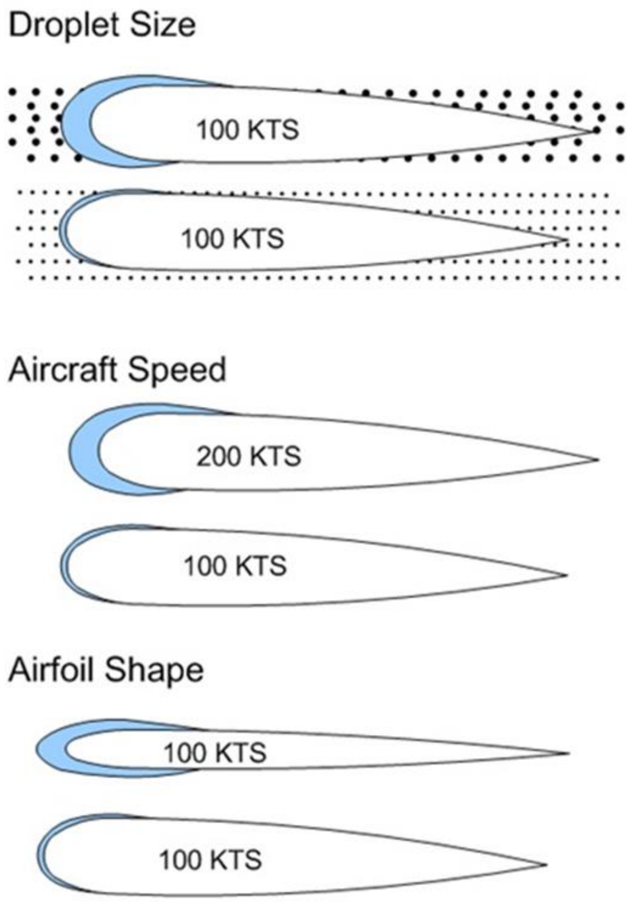

Figure 1: Ice formation analysis [3]

2.3. Types of icing

Frost on the aircraft in the atmosphere can be formed in two ways: directly from water vapor – desublimation, or freezing of liquid water droplets. In aeronautical meteorology, we recognize icing according to the conditions of origin, structure and according to the surface and distribution on the aircraft. The type of icing is mainly affected by the air temperature and the size of the subcooled water droplets in the air. According to the structure, we distinguish the following types of icing: [4]

1. Rime ice
2. Glaze ice
3. Hoarfrost

2.4. Frost forecast

The amount of icing on the aircraft depends on the air temperature, the amount of liquid water, the size of the droplets and the vertical movement of the air mass. In order to predict these parameters, it is necessary to evaluate the current and probable vertical profile of the atmosphere, the rain of radar images, satellite images and knowledge of the various clouds and their characteristics. [5]

3. NEGATIVE EFFECT OF ICING ON FLIGHT

Icing in aviation has a major impact on the aerodynamic configuration of the aircraft, affects airflow and gets worse the aerodynamic characteristics of the aircraft, which causes deterioration in controllability and stability.

Icing on the surface of the aircraft changes its aerodynamic properties, reduces lift and increases drag for a given angle of attack. Icing on the propeller blade reduces the thrust and efficiency of the propeller. The total icing contributes to a significant increase in the weight of the entire aircraft, which needs increased lift. Therefore, for a given flight speed, it is necessary to increase the angle of approach to achieve the required lift and the critical angle of approach can be reached at a higher speed. This means that icing on the plane increases the fall's speed. [6]

4. OPTIONS FOR ELIMINATION AND PREDICTION OF ICING

The subject of research is the effect of icing on unmanned aerial vehicles and how icing affects the efficiency of UAV propellers. First, we characterize the selected technologies that are used for the implementation of research, then we describe the research methodology, it means how we proceeded during the research flights and subsequently in the results of the work we will determine our recommendations for the elimination and prediction of icing on the UAV.

4.1. Technology used

In the practical part of this thesis, we use DJI technology - Mavic Pro and Mavic 2 Pro, due to their good flight characteristics and compactness. We analyze the flight data using the AirData application.

Mavic Pro is one of the smallest drones manufactured by DJI since 2017. Its dimensions are 83mm x 83mm x 198mm and the weight with the gimbal case is 743g. The weight shows that the DJI Mavic Pro belongs to category C1. The Mavic Pro is easily portable, as the entire drone can be easily folded. It is equipped with a fully stabilized camera thanks to the integrated gimbal on the bottom of the drone. Safe flying is ensured by an intelligent flying mode and an obstacle avoidance system. [7]

The Mavic 2 Pro drone is a newer and larger model from DJI. The dimensions of the drone are 214mm x 91mm x 84mm and the weight is 907g, which means that it belongs to category C2. The Mavic 2 Pro is also easily portable, as the entire drone can also be folded. It is equipped with a fully stabilized camera thanks to the integrated gimbal on the bottom of the drone. Safe flying is ensured by DJI technology - intelligent flying mode and obstacle avoidance system. [8]

4.2. Work methodology

The research part of the work was carried out in the morning hours in the winter month - February, when the air temperatures were below 0°C and the humidity was higher than 80%. The measurements took place over three days at an elevated place near the campus of the University of Zilina in Zilina.

The first recorded research flight took place using the above-mentioned DJI Mavic Pro technology. It was only a brief verification of icing and its impact on the flight characteristics of the UAV. Icing was formed using a sprayed aerosol on UAV propellers.

The second test day took place with using DJI Mavic Pro technology, similar as previous test day. During the test period, we performed several flights, during which we kept adding an aerosol to the drone propellers, which froze due to low temperatures (higher drag, lower lift of the propellers). We gradually increased the state of icing on individual flights. Subsequently, we discontinued research flights due to improving meteorological conditions (increasing air temperature). We named the four most significant flights, which rightly illustrate the evolution of icing.

The third test day took place in the early morning hours with DJI Mavic 2 Pro technology. We performed ten research flights, closely monitoring how flight characteristics changed during the flight. During these flights, icing formed naturally, without the application of an aerosol, due to moderate ground clouds. We listed the three most significant flights, during which we noticed significant icing and deteriorating aerodynamic characteristics. Due to the very intensive formation of icing, we thoroughly removed icing from the previous flight from the propellers before each flight.

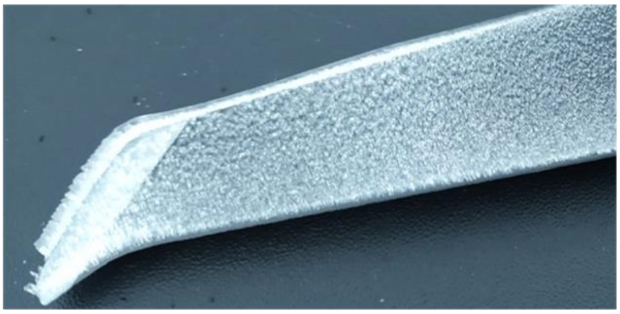

Figure 2: Icing on the propeller during [Source: Author]

4.3. Work results

We deduce from the research flights that icing is formed mainly at temperatures below freezing, it means 0°C and at elevated humidity of 80% and more. Icing does not require low clouds or fog, but its occurrence at the flight area helps to create icing faster. The graphs on the change in current consumption during the flights show that the icing generated increased the drag of the UAV propellers and decreased the lift. Therefore, to maintain sufficient propeller power, the drone needed to draw more electricity from the battery. As a result, the battery overheated and discharged faster during the research flights. It can be seen in the figures describing the changes in battery temperature. During the second day, when Mavic Pro did not manage the icing on its propellers, the UAV fell from a minimum height due to insufficient lift and increased drag. Last day measurements showed that if the pilot is informed of the consequences of flying in icing conditions, maneuvering the UAV carefully and slowly, the icing may not have the catastrophic consequences as the previous day. We also noticed very fast natural icing and significantly warmed UAV engines during the last day. During the first flight on this day, the UAV started automatic landing after only 3 minutes and 28 seconds to prevent a fall, which means that icing formed extremely quickly. During the research flights, we also monitored the speed of propellers rotations. The speed of propellers rotations on the Mavic Pro drone (used on the first and second test days) without icing was 5270 per second, with icing the speed increased by almost 22%. Mavic 2 Pro (used on the third test day) without icing had 5010 rotations per second, with icing the speed increased by almost 8%.

4.3.1. <u>Recommendations For Pilots:</u>

Pre-flight preparation is an important part of every flight. Thanks to it, the pilot knows what to expect during the flight and can prepare for certain situations. We recommend UAV pilots to check the meteorological forecast at the place of flight before the flight. It is necessary to focus mainly on the air temperature and relative humidity, or the height of the cloud base.

It is also necessary to have several fully charged batteries in good condition. They should be charged the earliest day before flight to ensure that they do not discharge over time. We recommend warming the batteries to 20°C or more before the flight, because at temperature below 15°C there may to increase resistance inside the battery, which results in a reduction in battery capacity and a voltage drop during discharge, it means during flight.

The UAV itself and its accessories should be stored in a dry place with an air temperature of approximately 20°C to 25°C away from direct sunlight. Before the flight, we recommend removing any dirt, water drops, moisture or snow from the UAV so that it does not increase the drag and weight of the entire UAV during the flight and to prevent icing.

For the first minute after take-off, we recommend that pilots let the UAV to hover so that the battery warms up to operating temperature, while monitoring the speed of propellers rotations. If the speed increases rapidly, we recommend landing and checking the propellers, there is most likely icing on them. We do not recommend long flights at maximum speeds and sudden ascents and descents. We recommend not to let the battery completely discharge, the battery should be in condition to allow the UAV to return home called Home Point or change the battery after each flight.

During the flight in icing conditions (temperature below 0°C and humidity above 80%), we recommend constantly monitoring the meteorological situation, due to possible deteriorating weather changes - in a mountain environment, the weather tends to change faster. The pilot should avoid places with strong winds, rain, storms, snow, fog and significant clouds. Snow may not have fatal consequences for UAVs in the first moments, but it can obscure the UAV's sensors, which guide the UAVs and therefore, together with the icing created, would most likely make an automatic landing at best, at worst, the UAV would fall.

We do not recommend adding additional components (cameras and others) to the UAVs due to their excess weight, which could cause UAV overload, insufficient performance and shortened flight time.

According to Slovak regulations, the UAV should not fly higher than 120 meters above the earth's surface. In cold weather, we recommend lower altitudes, because the UAV must break through a smaller vertical distance and the battery will keep longer. In cold weather, we also recommend having a fully charged phone or tablet with which the pilot controls the UAV or have an external charger.

After the flight, we recommend checking the UAV for accidental damage or wear to some parts. It is also necessary to remove water from the surface of the UAV, as possible moisture can damage the electronic parts of the UAV.

To protect the propellers, we recommend using liquids like those used in transport aircraft, such as ethylene glycol or propylene glycol, which prevent the deposition of snow, water, dirt and others. The pilot should spray similar liquid from a safe distance on the propellers, shoulders and body of the UAV, wait a few minutes and start the first test flight. We recommend further research in anti-icing fluids for UAVs, in search of suitable effective and available medium that would prevent the deposition of water droplets throughout the UAV.

5. CONCLUSION

The work deals with the effect of icing on drones during the flight. The purpose of the work was to find out how dangerous icing is, in what meteorological conditions and how fast icing is formed, how it can be suppressed or completely eliminated. In the first part, we analyzed the basic theory of icing, it means in which clouds we can expect icing, what are the factors influencing formation of icing, how intense icing can be, what are the three basic types of icing and how we can predict icing. We also described the negative impact of icing on the aerodynamic characteristics of the aircraft, such as a reduction in lift, a significant increase in drag regarding the angle of attack, deterioration of controllability and stability, and an overall decrease in aerodynamic performance. Subsequently, we looked at examples of documented drone incidents caused by icing. The practical part presents the used drones from the company DJI - Mavic Pro and Mavic 2 Pro. Subsequently, the methodology of research flights is described, during which we looked at how fast and in what meteorological conditions icing will form. The methodology of the work contains data from flights, which we obtained using the AirData application, which recorded this data in real time. This application also offers a record of approximate meteorological conditions during the flight time, which we have included in the methodology of work.

Analysis of data from the mentioned application AirData showed that during the research flights the meteorological conditions at the flight aera were suitable for icing, it means low air temperature, high relative humidity and low clouds, which was confirmed by a record from the meteorological station in Zilina, available on the internet SHMU website. The analysis also confirmed icing on the UAV by changing the current consumption during the research flights, it means if there was no icing on the UAV, the current consumption was in reasonable values (in green). With more icing, the current consumption sometimes increased up to three times the normal values (in the pictures, the change in current consumption is shown by the change in colors from orange through red to purple). During the flights, the battery temperature also changed depending on the difficulty of maneuvering and the amount of icing on the arms and propellers of the UAV. The more frost, the more the battery warmed up, the speed of propellers rotations increased, and the engines overheated. During a long and demanding flight in icing conditions, we expect that UAV engines could be permanently damaged by icing. We also observed that icing affects battery life and flight efficiency, as data analysis showed that the combination of icing and maneuvering with UAVs (even a small number of gentle maneuvers) reduces battery capacity, it means time that can still be used for full-fledged flying with UAV.

From dataS of research flights, we evaluate that icing is formed fast enough to mean a significant hazard to drones. Icing began to form after take-off, usually after about three minutes it was obvious from the speed of propellers rotations on the controller that the icing formed to such range that the UAV had difficulty maintaining the specified altitude and the system itself recommended to us that the UAVs should land carefully and check propellers, because system cannot detect icing on the drone. In one case, the UAV did not even manage to land automatically and lost the required power from a minimum height and subsequently fell.

From the results of the work, we have compiled recommendations that can be very beneficial for beginners and professional UAV pilots. The work also serves to support the teaching of subjects included in the study plan at the Department of Air Transport of the University of Zilina in Zilina, Operation of Unmanned Aerial Vehicles and Flight Training of Unmanned Aircraft.

ACKWNOLEDGEMENT

This work was supported under the project of Operational Programme Integrated Infrastructure: "Research and development of contactless methods for obtaining geospatial data for forest monitoring to improve forest management and enhance forest protection", ITMS code 313011V465. The project is co-funding by European Regional Development Fund.

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