Katalin Hadobács

RISK OF AIRFRAME IN-FLIGHT ICING AND ICING PREDICTION ALGORITHMS

Despite the stormy evolution of technical aspects, on-board applications and the great development in the field of weather forecast in the last decades, aerial operation still greatly depends on weather conditions. The majority of weather condition related flight accidents are consequences of icing. It is essential to pay full attention to the physical processes of icing, to recognize these factors in detail. On the basis of studies it was also required to set up and develop modern weather forecast procedures. Today, it is still not possible to say whether the flight meets icing zones or not, and still meteorologists can only advise us on the potentially dangerous icing areas. All this information supports us to avoid hazardous airspaces. Notwithstanding, in case the flight crew faces a large icing area on its route, it already has got means to fight against icing. Today, several types of aircraft are equipped with protection systems against icing to decrease the possible risk. These can be preventer or de-icing systems. The topic of this article is the icing itself, the forecasting methods of icing and icing prevention systems. This article provides us with a short but comprehensive outlook on the topic.

Keywords*: flight safety, aircraft icing, forecast of icing, de-icing systems, icing prevention systems*

INTRODUCTION

Aviation has become an integrated part of our life. Aircrafts are combat and work equipments, common means of transportation, and also influenced the field of sports.

It is obvious, that as in our everyday life, as well in the field of aviation, we cannot avoid a certain level of obvious or hidden risks. Several weather conditions can be mentioned as risk factors that influences how aircraft advance in airspace.

The evolution of instrument flight enabled aircraft and their crew to fly in clouds for longer periods without having a clear view on the terrain. Then we had to face some new hazards, and one of them was icing. During icing, water ice forms on the airframe, antennas etc. of the aircraft. Ice accumulation significantly influences the stability and control of aircraft, so it makes it even more important to predict icing accurately [1]. One of the most emphasized tasks of flight meteorology in particular is to give prompt information in time for the crew, about potential icing risks. For this forecast professionals use accumulation models and algorithms [2]. Despite these calculations and due to dangerous weather conditions, incidents and unfortunate disasters can also occur today. Neither the most modern algorithms, nor the latest models of today are capable to precisely highlight icing zones. Therefore, it may happen that the aircraft enters an icing zone. To decrease ice accumulation in such cases, engineers apply ice protection systems onboard; however, under extreme weather conditions icing can be formed on the airframe even if we already use the mentioned systems.

THE AIRFRAME ICING PROCESS

Surface icing is understood as ice accretion that occurs and develops during inflight in a cloud or in a precipitation zone − rain or snow −, but it also occurs sometimes while flying below the cloud level. It develops on the aircraft below zero when supercooled droplets impact with any part of the external structure of an aircraft during its inflight [3][4]. Its intensity and its type are influenced by several physical characteristics, which can be divided into two main groups. Because aviation occurs in the atmosphere, the first group is determined by the parameters of the atmosphere. The second group consists of the aerodynamic qualities of the aircraft [5].

Meteorological parameters consist of temperature and moisture of the surrounding atmosphere, liquid water content, the concentration of supercooled water droplets and their distribution according to their size (average diameter), quantity of ice crystals within the cloud and the rising speed of air masses. Aerodynamic qualities that are taken into consideration are the speed of the aircraft (Mach number), the temperature of the airframe of the aircraft and its geometrical dimension, its material and roughness and also its structural curvature conditions [6].

The three main conditions of ice accretion among the above mentioned ones [7]:

- presence of water droplets in the atmosphere;
- sub-zero or near-freezing ambient temperature;
- surface temperature of an aircraft structure below zero.

The so called supercooled water droplets are responsible for the development of hazardous airframe icing, they are purified and small in diameter, and they can still exist in liquid form up to a temperature limit of –30 °C. It is an unstable state, which can be easily ended by an external perturbation[1], and water droplets may turn to ice immediately [8].

The larger the size of the droplet (aerodynamic drag proportional to square diameter) the lesser influenced by the flow velocity. On the contrary, smaller droplets are carried along by the stream. Consequently, larger droplets may easier hit the airframe of the aircraft. With the decrease of temperature, the diameter of supercooled droplets will become smaller too, which means that they will not reach the size of 1 mm in –20 °C atmosphere [8]. It is clear from the above considerations that we may face the most dangerous icing conditions when the atmosphere is quite warm but still subzero, and the concentration of supercooled droplets is high.

As highlighted in figure 1, several tests have been made to prove that supercooled droplets with different diameters form various types of ice accretions. It was also confirmed, that the most dangerous ice accretion may occur if the diameter of the droplets is smaller than 50 µm [10].

Larger supercooled droplets can be found in the atmosphere in two forms:

1. freezing rain;
2. larger droplets formed by merged smaller droplets.

The first case is triggered by a vertical atmospheric temperature layering. An airmass, that is warmer than the inversion freezing point stuck between the upper and the lower atmosphere. Snow precipitation from the upper atmospheric layer melts in the warm inversion zone and

[1] external influence

eventually cools down in the subzero atmospheric layer. The latter must be sufficiently thick to have the temperature of the droplet cooled under 0 °C. As will be shown later, these supercooled droplets will form clear ice on specific surfaces of the aircraft. This kind of precipitation is easily predictable due to typical vertical atmospheric temperature layers. It also makes the forecast simpler, because most often it coincides with a warm front [11].

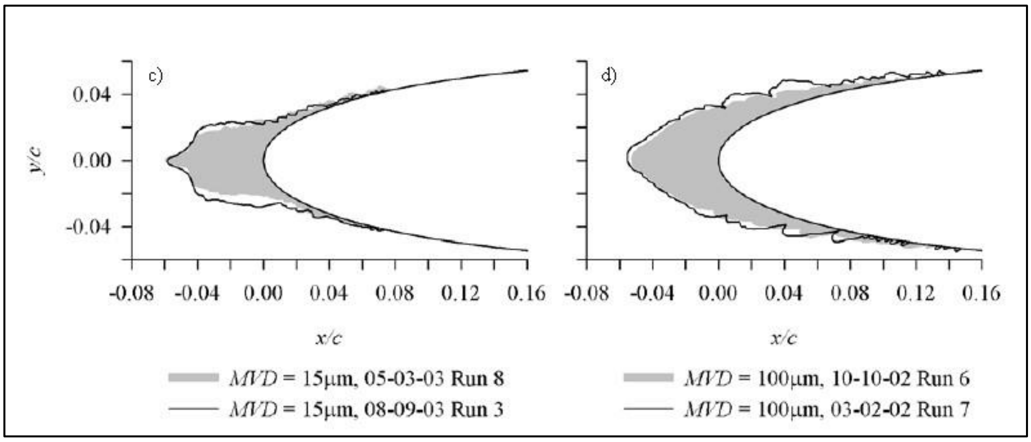


Figure 1. Typical shapes of ice accretion
(MVD: average droplet diameter y/c: chord of airfoil normed width;
x/c: length of airfoil normed by its length) [10]

However, the second case is a challenge for meteorologist professionals. In this case, larger droplets form due to the crash and merge of smaller droplets in the atmosphere. Through the mixing of atmospheric layers, wind shear located at the top of the layered clouds accelerates the development of large droplets [12]. The more supercooled droplets are in the atmosphere, the greater the chance for intensive icing.

INTENSITY OF ICING

Intensity of icing is measured by the speed of ice accretion. Namely, it is described by indicating the thickness (measured in mm) of the ice accreted per minute on a particular unit of the airframe. In science of meteorology, the latter is determined by a three point scale (Table 1) [12].

Category	**Velocity of accretion** [mm/min]
Light	< 0,6
Moderate	0,6–1,0
Severe	> 1

Table 1**.** Types of icing and velocity of ice accretion [3]

Another approach that is usually used by the flight crew is the following: icing depends on the severity of icing environment and how the aircraft acts in these conditions. It also depends on the response of the pilot to the above mentioned conditions. (Table 2)

Type	Description
Trace	Ice becomes perceptible. Rate of accumulation slightly greater than rate of sublimation. It is not hazardous even though de-icing /anti-icing equipment is not used unless encountered for an extended period of time (over one hour).
Light	The rate of accumulation may create a problem if the flight is prolonged in this environment (over 1 hour). Occasional use of de-icing/anti-icing equipment removes/prevents accumulation. It does not present a problem if the dicing/anti-icing equipment is used.
Moderate	The rate of accumulation is such that even short encounters become potentially hazardous and use of de-icing/anti-icing equipment or diversion is necessary.
Sever	The rate of accumulation is such that de-icing/anti-icing equipment fails to reduce or control the hazard. Immediate diversion is necessary.

Table 2. Severity of icing [14]

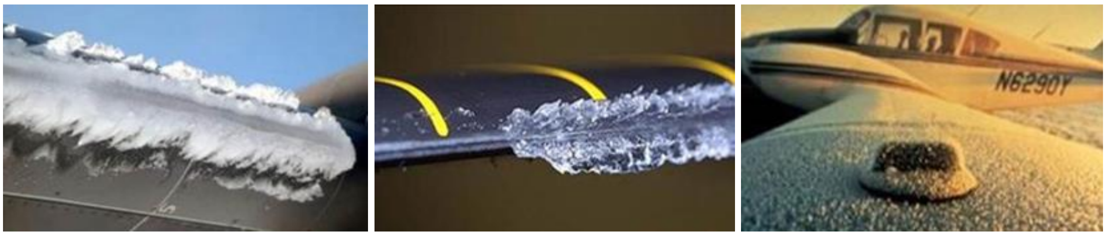
TYPES OF ICING

When aircrafts fly in such subzero airspace which contains supercooled water droplets, these droplets impinge the airframe of the aircraft. Through the impact they immediately form icing on the airframe structure. The outcome of this process is the accumulation of icing in different shapes, colour, density and solidity. In many cases, the surface of this icing is rough, and usually it accumulates on airfoils that are most influenced by airflows [15].

There are three types of icing:

- ✈ frost ice,
- ✈ rime ice,
- ✈ clear ice (figure 2) [7].

The above listed types often appear together. In this case we speak of mixed icing.



Rime ice Clear ice Frost ice

Figure 2. Types of icing [16]

Frost ice

This is the most frequently observed icing type. It is a thin and white crystal deposition that comes into being by direct icing of water-vapour in the atmosphere. Usually it develops in a clear atmosphere, where, with the support of sublimation, water-vapour immediately forms icing on the airframe structure. It does not directly pose a threat to the flight, but it could be the source of a subsequent accretion.

Frost ice can be observed mainly in two different situations [7]:

1. during a fast descent from an extremely cold area to a wet and relatively warm area,
2. during climbing from a subzero environment through an inversion layer.

Clear ice

Clear or glaze ice is formed by larger supercooled water droplets, of which only a small portion freezes immediately, other droplets will flow backwards in the direction of the airflow (run-backwater). It happens because the latent heat released during the freezing increases the temperature of the airframe to above subzero. Water flown backwards will form ice accretion on other areas of the airframe. This is what we call wet-growth icing. Icing developed in these circumstances is called clear or glaze ice [17]. Since the resultant frozen deposit contains relatively few air bubbles, the accreted ice accretion is transparent or translucent. The resultant transparent sheet of ice may be difficult to detect and to remove from the airframe. Contrary to other accretion types it has a more robust structure and it can reach larger sizes. Because of its uneven thickness and combinations of double ram's horns it can cause significant complications. It is complicated to identify this type of icing from the cockpit.

Rime ice

Rime ice is formed when small supercooled water droplets freeze rapidly on contact with a sub-zero surface before other droplets can get there. This is what we call dry-growth icing. All droplets form a separate ice crystal. The rapidity of the transition to a frozen state is because the droplets are small and the almost instant transition leads to the creation of a mixture of tiny ice particles and trapped air. The resultant ice deposit formed is rough and crystalline and opaque and because of its crystalline structure, it is brittle. Most often it forms on leading edges of the aircraft. This type is called rime ice. Due to air inclusion this type of accretion is weak and fragile. These types of small diameter supercooled droplets can be found mainly in the following cloud types: Nimbostratus, Altostratus, Altocumulus, Stratocumulus and Stratus. In some cases they can also be found on the top of Stratocumulus clouds [3].

In conclusion, it can be stated that different types of accretions (Figure 3) may be formed in connection with certain parameters of meteorological parameters. (Table 3) [14].

Type	Necessary conditions
Moderate or severe intensity clear ice	Large supercooled droplets Nimbostratus, Cumulonimbus clouds Temperature between −20 °C and 0 °C
Light or moderate intensity rime ice	Small supercooled droplets Layered cloudiness Temperature between −10 °C and ±0 °C
Light intensity rime ice	temperature lower than −10 °C Layered cloudiness Small diameter supercooled droplets
Frost ice	Temperature between −40 °C and −20 °C Cu, Cb and Ns clouds Small diameter supercooled droplets

Table 3. Necessary conditions of ice accretion [14]

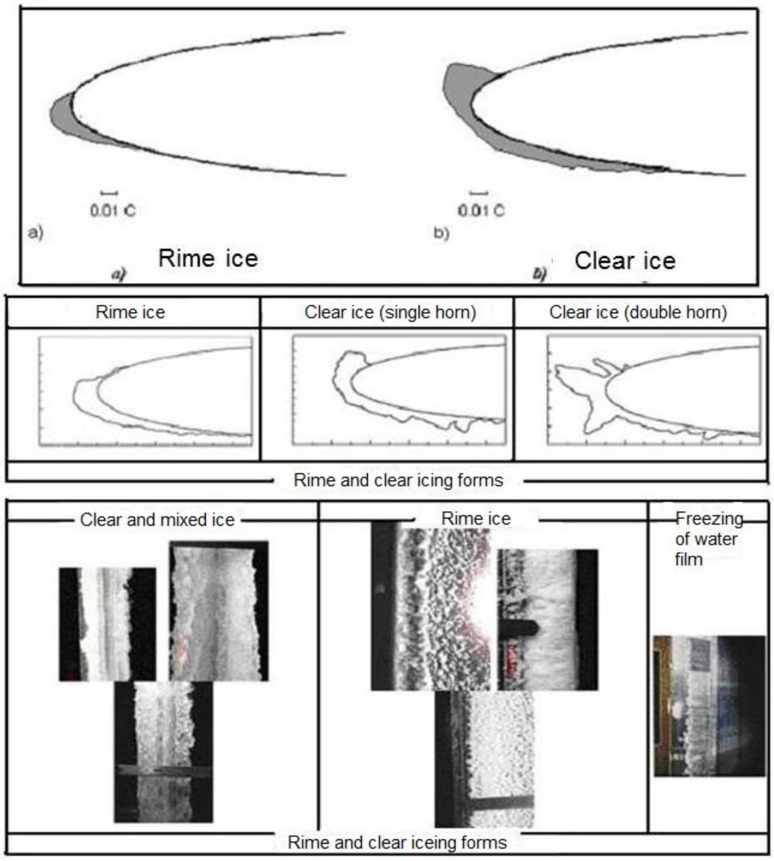


Figure 3. Types of icing [18]

Beside the above mentioned categories it is also worth to geometrically categorise ice accretion. It is interesting to do so, because shapes of ice accretion significantly influence e.g. the aerodynamic shape of the leading edges of the wings, and namely the airflow around it [18]. From a geometrical point of view, ice accretion is undertaken in four general categories. These are: roughness, horn ice (figure 5), stream wise ice (figure 4), spanwise-ridge ice.

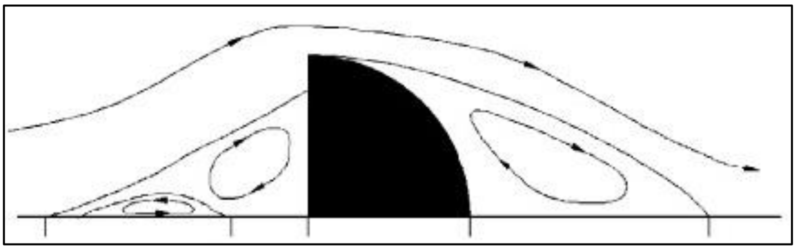


Figure 4. Streamlines by spanwise-ridge type ice accretion [20]

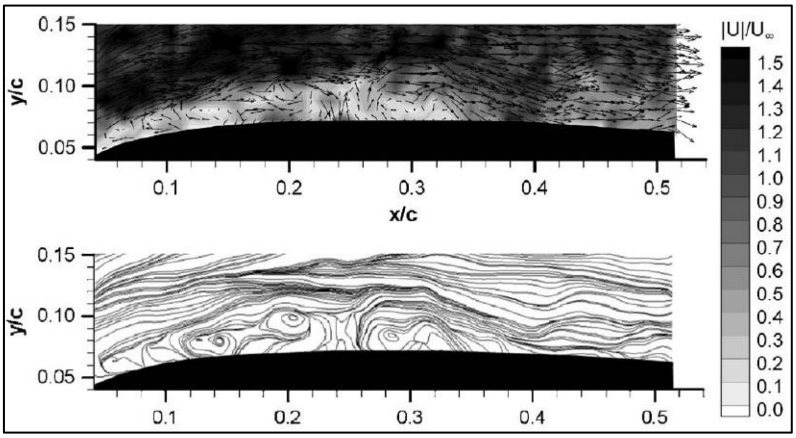


Figure 4. Airflow alteration caused by horn ice accretion type (x/c: average droplet diameter y/c: chord of airfoil normed width; x/c: length of airfoil normed by its length; U/U_∞: speed of clear airflow normed by speed of airflow) [20]

The impact of icing on AIRCRAFTS

During the flight, the above mentioned accretion forms may appear individually, but they can also appear collectively. Figure 6 illustrates clearly how different geometrical types of accretions influence the aircraft's shape and aerodynamic conditions [20].

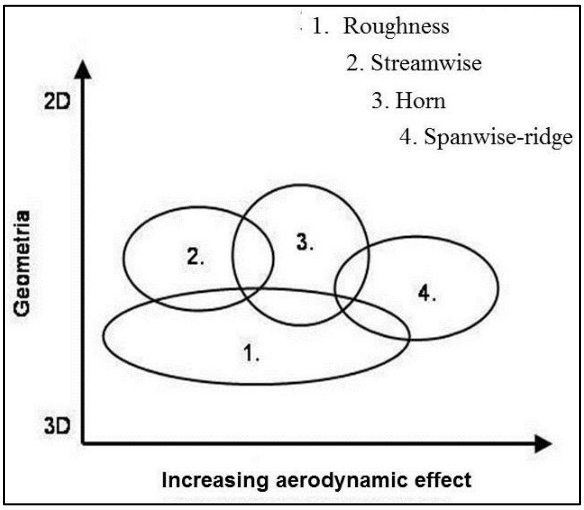


Figure 5. Aerodynamic impact of ice forms in case of ice accretion on the airfoils [20]

From a geometrical point of view, rough accretion does not change the shape of certain parts of the aircraft, but it can still cause aerodynamic effects. It may result in the increase of the aerodynamic drag and may cause a decrease in buoyancy. All the other types of ice accretion may change the shape of the aircraft, which may cause significant changes in the aerodynamic conditions of the aircraft. In relation to horn and spanwise-ridge types of accretion, a significant decrease of the buoyancy can be observed beyond the horn. In relation to spanwise-ridge, it also can be observed in front of the accretion due to turbulent zones. In connection with the flight, the above mentioned points are considered to be the greatest accretion risks.

Depending on the duration of the flight of the aircraft in the icing zone, depending on the weight of the airframe, weight of accreted ice can be significant. It can modify the flight profile of the aircraft and its aerodynamic conditions [21].

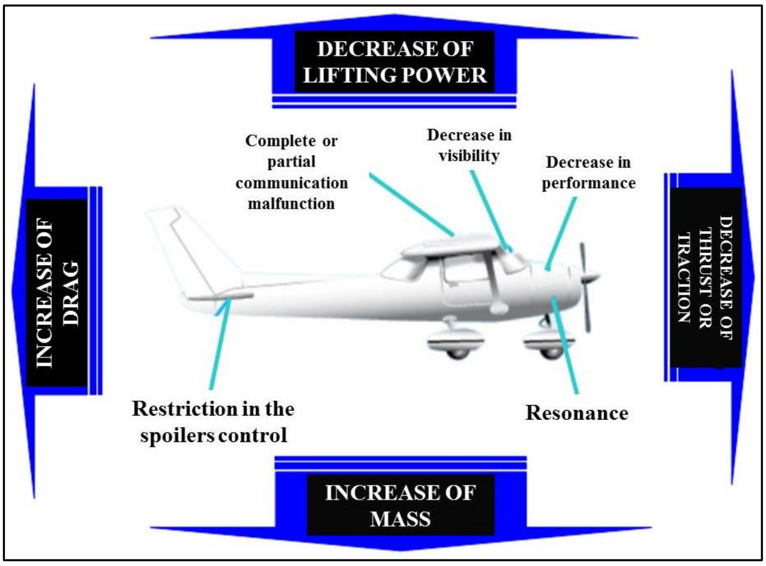


Figure 6. Impact of icing to aircrafts [23]

The impact of the ice accretion on the performance and flight characteristics of the aircraft greatly depends on the design of its airframe and aerodynamic construction. As is shown in figure 6, it also depends on the width of the ice accretion. However, in general it can be said that the weight of the aircraft must be considered. In addition, the decrease of the buoyancy and the increase of the aerodynamic drag in connection with the rough surface also have to be considered as well. To maintain the same flight conditions, thrust or traction has to be increased. The critical angle of the aircraft will also decrease. Because of this decrease, the flight control process may be significantly changed. Prudent control shall be applied to enable the pilot to leave the icing zone as soon as possible (Figure 7) [22][23].

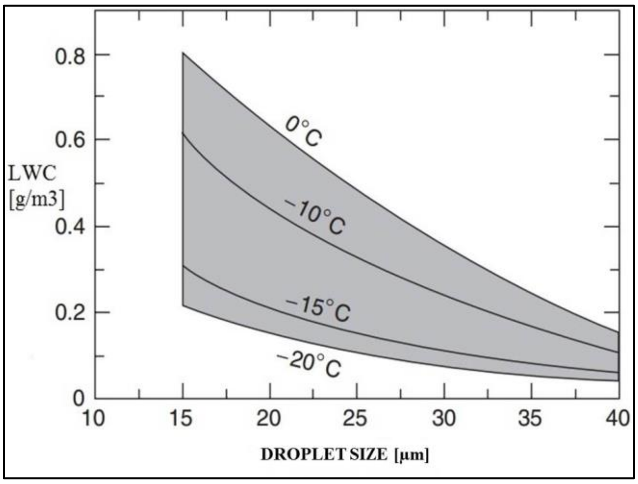


Figure 7. Icing according to temperature and liquid water content (LWC) (the grey area highlights the conditions in which the aircraft has to safely execute its flight tasks in order to get a licence to fly among icing) [24]

Certainly, a large percentage of aircraft is capable to fly in icing conditions. To get the required authorization to do so, certain aircraft have to pass different investigations. During these tests, flight tasks have to be executed in different types and intensity of icing conditions. The results must prove that ice accretion formed on the airframe does not significantly hamper flight procedures, i.e. that the flight can be safely implemented. Environmental conditions and limit values are determined by measurements (Figure 8) [24].

Almost all aircraft that are allowed to fly in icing conditions are equipped with anti-icing and icing detection systems. These systems are developed and applied to prevent ice accretion, or to have ice accretion removed from the airframe.

ESTIMATION OF ICE ACCRETION AND POSSIBILITIES OF ICING PREDICTION

Developing ice accretion during the flight may present a significant danger to flight procedures and to the execution of the flight. Despite the fact that pilots have been confronted with icing since the early years of flying in clouds, a catastrophe that happened in Indiana [25] in 1994 and left 68 victims, was necessary to make the National Transportation Safety Board establish its first recommendations regarding icing [26]. In accordance with these recommendations, the Federal Aviation Administration has encouraged research regarding with icing prediction and the establishment of appropriate regulations and procedures.

Today, the icing prognosis presented to the flight crew has to contain a lot of information:

1. The area of the forecasted icing zone in the atmosphere;
2. The intensity of icing (in consideration with ICAO recommendations);
3. The predicted form of ice accretion, in particular to the most hazardous, the horn shape dice.

The above mentioned data is to be provided by meteorologist professionals and applicable a certain type of aircraft or to a certain class of aircraft. Data shall be provided reflecting the initial geometric and aerodynamic conditions of the actual aircraft [23].

In the beginning, meteorologists established their predictions based on their own experience and observations, and they also used the results of numeric models [27]. During subsequent scientific research, a connection was found between the temperature (T) and the relative humidity (RH). With the assignment of certain limit values, areas of icing reported by the flight crew via the PIREP[2] system were almost corresponding, a simple, dual layer icing model was established. This model is based on the relation of temperature and relative humidity [28]. The next step was to apply among T and RH data the vertical temperature distribution as well [29], and then, microphysical schemes were established too. These schemes were used to precisely predict the quantity of supercooled droplets in the atmosphere [30].

Beside numeric tendency, evolution could be observed in the field of satellite and radar data application [31]. The aim of scientists was to establish such an autonomous algorithm. It enables the forecaster not to collect and analyse the data of several sources by person. The main objective is to get the possible areas of icing and the concentration of supercooled droplets in a

[2]PIREP telegram is a report issued by the flight crew that contains information in relation to the actual meteorological conditions relevant for the ongoing flight procedures. Usually, basic information is transmitted via radio-mailing, then ground authorities continue to spread the information in an appropriate form.

3D model domain. To achieve this, satellite, radar, surface measurement, lightning and PIREP data were combined with the results of the model (Figure 9), [26].

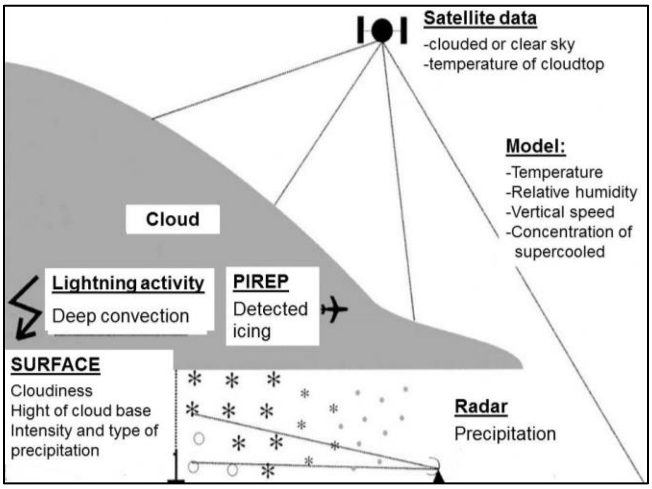


Figure 8. General schematic model of CIP [26]

The procedure that links together the above listed data is called Current Icing Potential – CIP.

The algorithm is highlighted in figure 10 and consists of six main steps.

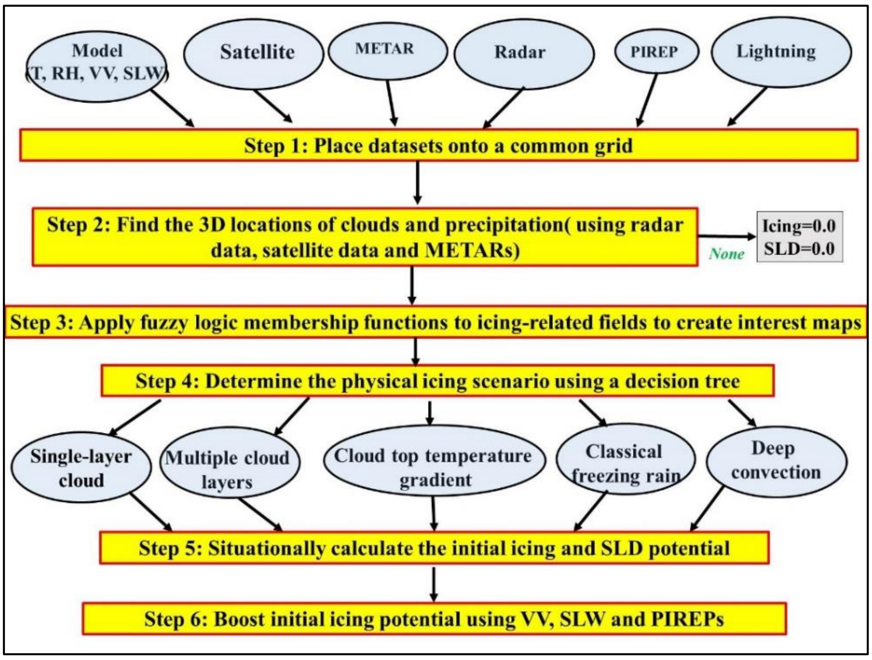


Figure 9. CIP algorithm [26]

Although CIP algorithm is not yet used in Hungary, several case studies prove that its application would improve icing related predictions significantly.

It is recommended to determine the area of possible icing, its intensity and the geometry of possible ice accretion in order to make flight activity even safer. This model consists of three main steps. First, we have to identify the possible area of the airflow in case of a clean airframe surface, then the quantity of the water droplets impacting the surface has to be determined (additional thermo dynamic analysis is also needed); finally, the ice type of the possible ice accretion has to be estimated (Figure 11) [18].

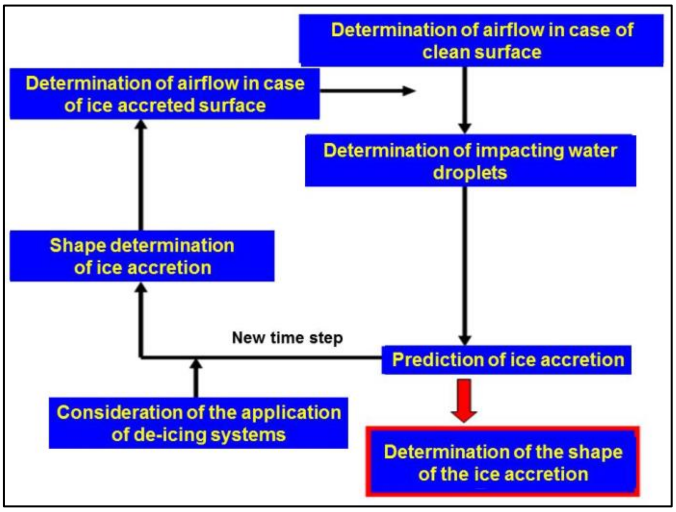


Figure 10. Estimation of ice accretion [18]

In the recent years, several algorithms have been established. One of them was created by *Lozowski* in 1983 [32][33] and this one possibly achieved the biggest breakthrough. His icing accumulation model presents the airfoil of the aircraft as a non-heated and non-rotating cylinder that is placed under moderate streaming (Figure 12). He describes the conduct of the formed ice accretion in certain environmental and aerodynamic conditions.

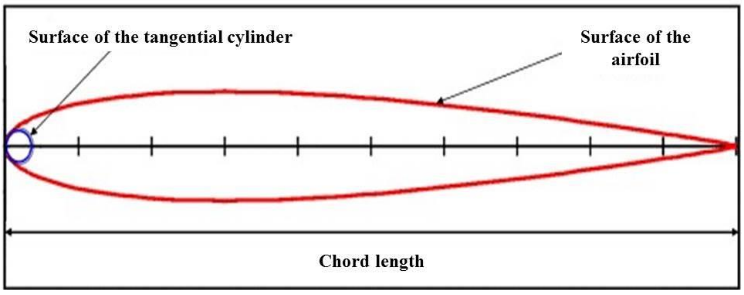


Figure 12. Cross-section view of the airfoil and its tangential cylinder [19]

The algorithm consists of 3 main steps. First, the side part of the cylinder facing the airflow is divided into sectors, then; the size spectrum of particles is also categorized. After the appropriate discretizations are performed, impact efficiency and mass flow rate of liquid water content shall be indicated for all sectors and scale. The second part of the prediction algorithm is to solve the energy imbalance equation concerning the surface of the airframe.

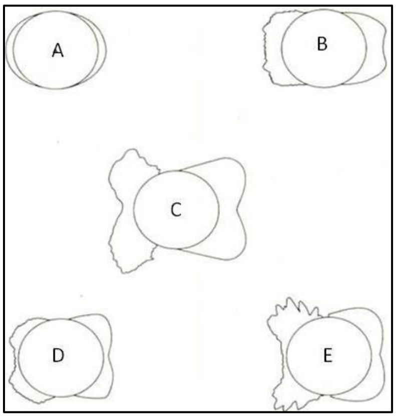


Figure 13. Certain possible forms of ice accretion [32]

After solving the numeric equation, the next step is the specific prediction of the type and extent of possible ice accretion. Results can also be highlighted graphically; in this way the intensity and geometry of the possible ice accretion can be easily demonstrated (Figure 13).

Detailed descriptions of the algorithm can be found in Lozowski’s article [32][33]. Today, this model is commonly used in several forecast centres.

At present, the aim of some researches is to find a more efficient and accurate way with regard to icing prediction [34]. Main breakthrough in the future may be, the establishment and application of such algorithms, which are based on neural networks. Cornerstones of these algorithms have already been settled. However, additional research is needed for applying them to operational prediction.

ICING DETECTION AND DE-ICING SYSTEMS

Ice accretion on the structure of the aircraft has got potential hidden risks. It can cause serious problems during flight, unless accretion is prevented or the icing already established is removed in adequate time. To gain the effect of implementation of the required steps, the most influenced structural elements have to be identified properly. Today, based on several results of scientific experiments and flight experience it can be stated, that sensitive areas of the aircraft are as follows [35]:

- rotors; propellers; vertical stabilizers and tailplains, empennage;
- antennas, sensors and instruments applied outside the fuselage;
- leading cross-sections of engine inlet passages, dust protection systems and flow diverters;
- cockpit windows.

To avoid ice accretion on these surfaces, de-icing systems are used. They prevent ice accretion, or, during the flight they remove the icing from the aircraft. There are two main types of this equipment:

- de-icing systems (icing has not accreted already);
- anti icing systems (used against accreted ice).

To remove the already accreted and still growing icing, mechanical de-icing processes also may be used. Processes appropriate both for prevention and for removal of accreted icing are:

- physical and chemical de-icing processes;
- thermal systems.

In relation to the relatively high specific energy needs of de-icing systems these are usually operated cyclically. Duration of the active phase is determined by external thermal conditions.

Mechanical de-icing methods can be applied efficiently against icing which is not wider than 4-5 mm. Therefore, de-icing procedure has to be carried out at appropriate intervals in connection with the intensity of accretion.

There were some de-icing methods already in the 1930s. At this time, special inflatable rubber coating was applied on the leading edges of wings, tailplanes and vertical stabilizers. From time to time they pressed high-pressure air into these rubber coatings and pumped them up. Due to their increased volume the accreted ice cracked and was being detached by the airflow (Figure

14). This method seemed to be efficient earlier, but later on it was proved, that it significantly modifies the aerodynamic drag of wings and its operating time was also too short.

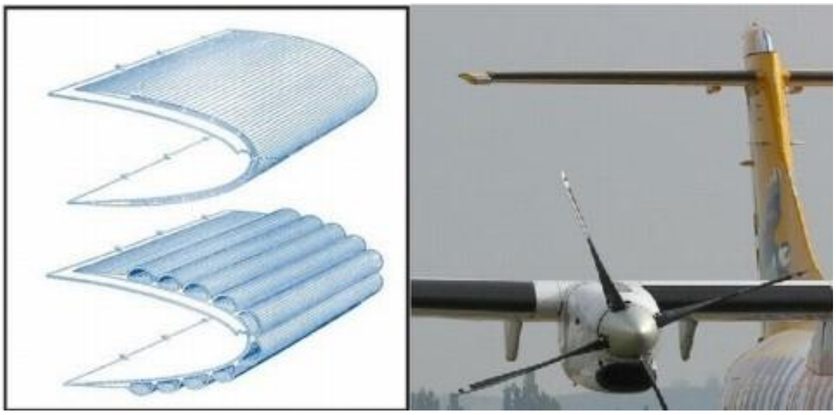


Figure 14. Pneumatic de-icing system [35]

Then, engineers tried to apply special water repellent layer on aircrafts. By covering the airframe surface of the aircraft with this layer, the ice binding capacity of the concerned areas increased. However, it also proved to be not an efficient solution, because the protective layer cracked and became detached in a short period.

Today's preferred type of de-icing system is the so called pneumatic de-icing boots. This equipment is cost-efficient and can be used in a wide temperature range, and can be operated without any collateral ice accretion.

Mechanical de-icing methods are used mainly by fixed wing aircrafts. [7]

Thermal, physical and chemical de-icing methods may be more efficient applications in relation to fixed wing and rotary wing aircrafts.

Application of chemicals is practical for the former that adhere properly on the treated surface and can get mixed together with supercooled water droplets, and do not destroy the airframe structure. The essence of this method is to establish a porous layer, or a layer that contains holes in significant segments of the aerofoil. Through these holes, the TKS fluid is injected on the wing or on the rotary wing, and it flows backwards and expands.

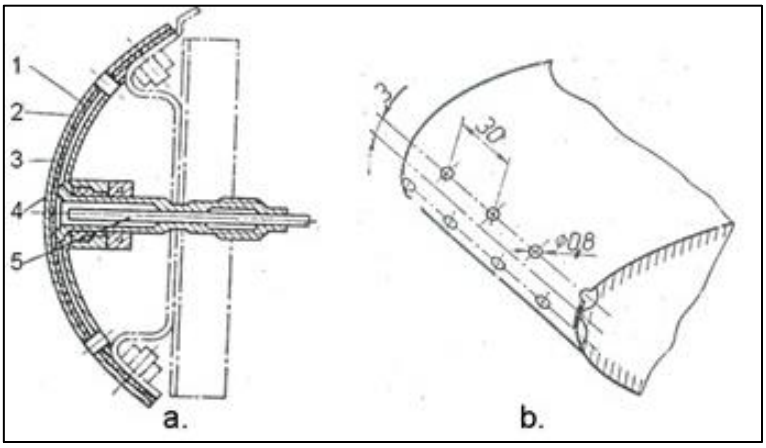


Figure 15. Chemical de-icing of the leading edge [35]

De-icing fluid can be injected on the external layer by two utilization methods. In case of a low operating pressure (figure 15.a) the fluid is directly injected into the supply channel (5), and from there it flows into the distribution channel (3). Finally, it is pumped through a dual layer porous coating (1; 2) onto the external surface of the wings. The internal part of the distribution pipe is made of sheet metal (4). At high-pressure systems (e.g. helicopter rotors) the chemical is pumped in the supply channel and injected through d $\approx$ 0,8 mm bores that are installed in every 300 mm on the surface of the rotor blades. (Figure 15 b).

This de-icing method is effective, however in adverse weather conditions its continuous application might be recommended. Unfortunately, due to the capacity of the de-icing liquid's container, only a limited utilisation of the system is available.

The dominant type of de-icing system is the electro-thermo de-icing method. By applying this method, the area that is to be protected is heated to such temperature on which ice is not able to accrete. Usually the heating takes place by hot air received from the high-pressure compressor of the jet engine, or the relevant area is heated by heating cords. Occasionally, the engine inlet is heated by hot engine oil.

The hot bleed air method is inefficient and it also reduces the efficiency of the engine. On the areas not effected properly by the heating, or not even heated, ice traverses may be accreted.

Today, the most effective and most modern thermal method is the electrical heating. It is high-efficiency and its application does not result a large increase in the empty mass, and de-icing of the smallest instruments is also feasible.

The power transmission of electric de-icing systems of certain aircraft is usually provided by three phase electric power network which is 115 or 208 V 400 Hz alternating current. The required unit per surface is 6–15 kW/m^2. Periodical operation of the system is absolutely necessary, e.g. in case of large size aerial vehicles the continuous operation of these de-icing systems would require several hundreds of KW. During such periodical operation it may happen, that intensity of ice accretion exceeds the intensity of de-icing. In such cases a thin water layer develops between the accreted ice and the surface of the airframe. Despite this course the ice already presented on the airframe cannot get off, moreover, on the external part it can further develop (Figure 16.a, upper part).

The above mentioned phenomenon can be terminated with the application of the so called bleed air method that routes the heat of the engine along the leading edges of wings and tailplanes It divides accreted ice into two separate layers, these layers get off from the airframe due to the effect of the cyclic bleed air system and the current airflow (Figure 16.a, lower part).

In case of a larger geometric surface size to be protected, bleed air method is not only needed by the leading edges of wings and tailplanes, but it can also be applied along the aerodynamic chord This kind of application of this method can be useful, because in case of a larger surface greater ice will be accreted and greater pieces can get off from the aircraft, which may cause damages on the airframe. In this case, cyclically operated heating elements are built in the bleed air system (Figure 16 b.) [35].

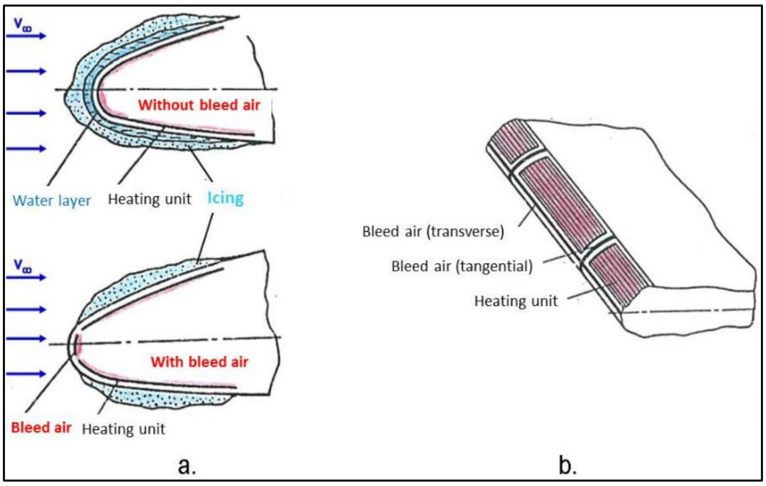


Figure 16. Operation of the bleed air system and its instalment options [35]

Jet fuel by itself also contains a certain quantity of water. When water is cooled and ice crystals are formed it can endanger the safe fuel distribution to the engines. To avoid it, anti-icing additives are mixed with jet fuel and with kerosene. Anti-icing additives reduce the freezing point of the water. Another solution is to apply a separate heating system to keep the temperature of the fuel above 0 °C.

The above mentioned methods and systems are only to be applied inflight. Anti-icing of aerial vehicles available at the airport is implemented by special equipments, methods and chemicals during their flight preparation. Required ground anti-icing procedures are executed by the ground staff (Figure 17).

Figure 17. Chemical defrosters and hot air engines [35].

In summary, on the one hand it can be said, that aerial vehicles may be applied with such de-icing systems which are capable to consistently provide de-icing capability in average weather conditions and in any flight modes, on the other hand these systems may be capable to provide proper de-icing in extreme weather conditions as long as the aircraft leaves the dangerous area.

SUMMARY

It can be stated, that, depending on the flight altitude and main features of the aircraft and weather conditions, a significant bulk and mass of ice can be accreted on the surface of an aircraft. It can considerably influence its flight characters (mass load, centre of gravity thus its stability and control), unless the accreted ice is not removed or the establishment of accretion is not avoided properly. One of the most efficient option to avoid icing is to avoid icing environment during inflight. In order to avoid this, a very precise and correct meteorological forecast is needed which is tailored to the needs of customers. This forecast have to contain data on the spatial and temporal distribution of icing conditions and on the possible forms of ice accretion, its geometry and intensity.

Prediction of ice accumulation claims professionals to a complicated task. Because of ice accretion, experts have to have comprehensive meteorological knowledge and they also have to fully understand events of ice accretion. In the last decades, aviation, technical conditions, onboard equipments and the quality of weather forecast significantly improved. However, application of modern icing prediction algorithms and models are at an early stage in Hungary, and several scientific researches have to be done prior to the adaption of these new models.

Certainly, the most modern prediction models are also not capable to perfectly predict icing zones nor on the spatial, neither on the temporal. So, preparations have to be made for a situation that aircrafts inflight may be operated in icing zone. Flight safety has to be sustainable also from this perspective. The most effective instruments of this foundation are de-icing systems of aerial vehicles.

REFERENCES

[1] Bottyán Zs.: A pilóta nélküli repülőeszközök (UAV-k) felületi jegesedésének aspektusai és a jéglerakódás becslésének lehetőségei. Repüléstudományi Közlemények, 24 (2012), 577-588.

[2] Bottyán Zs. és TUBA Z.: Felületi jegesedést okozó időjárási helyzetek statisztikai vizsgálata és a jégakkréció becslése pilóta nélküli repülőeszközök (UAV-k) esetében. Repüléstudományi Közlemények, 24 (2012), 642-651.

[3] Sándor V. és Wantuch F.: Repülésmeteorológia. OMSZ kiadványa. Budapest, 2004.

[4] Bottyán Zs.: A közszolgálati célú repülések meteorológiai támogatásáról II.: Légkörünk jelenségei repülésmeteorológiai megközelítésben. Repüléstudományi Szemelvények: A közfeladatot ellátó repülések meteorológiai biztosításának kérdései, 2017, 27-50.

[5] Gent R.W., Dart N. P. and Cansdale J. T.: Aircrafticing. The Royal Society, 358, 2873-2911., 2000.

[6] Bottyán Zs. és Hadobács K.: A repülőgépek felületi jegesedésének termodinamikai folyamatairól. Repüléstudományi Közlemény, 23 (2011), Special Edition, 2011

[7] Mingione G., and Barocco M.: Flight in icingcondition, Summary, url: http://www.developpement-durable.gouv.fr/IMG/pdf/DGAC_Icing_flight_manual.pdf

[8] Cober S.G., Isacc G.A. and Strapp J.W.: Characterizations of Aircraft Icing Environments that Include Supercooled Large Drops, Journal of Applied Meteorology, 40 (2001) 1984-2002.

[9] Fernandez-Gonzalez S., Sánchez J. L., Gascón E., López L., García-Ortega E. and Merino A.: Weather features Associated with Aircraft Icing Conditions: A Case Study. The Scientific World Journal, 2014.

[10] Tsao J.-C. and Anderson D.N.: Additional Study of Water Droplet Median Volume Diameter (MVD) Effects on Ice Shapes. 2005. url: https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20050215215.pdf

[11] Isaac G. A., Cober S. G., Strapp J.W, Korolev A. V. Tremblay A. and Marcotte D. L.: Recent Canadian Research on Aircraft In-Flight Icing. Canadian Aeronautics and Space Journal, 47(3) (2001).

[12] Rasmussen R.M., Geresdi I., Thompson G., Manning K. and Karplus E.: Freezing Drizzle Formation in Stably Stratified Layer Clouds: The Role of Radiative Cooling of Cloud Droplets, Cloud Condensation Nuclei, and Ice Initiation. Journal of The Atmospheric Sciences, 59 (2002), 837-860.

[13] ICAO, 2007: Meteorological Service for International Air Navigation. Annex 3 to the Convention on International Civil Aviation url: http://www.icao.int/
[14] Oxford Aviation Academy: ATLP Ground Training Series – Meteorology, 2008
[15] Bottyán Z.: In flight icing characteristics of unmanned aerial vehicles during special atmospheric condition over the Carpathian Basin. ACTA Geographica Debrecina Landscape and Environment, 7, 2 (2014), 74-80.
[16] Icingcondition. url: http://www.thefullwiki.org/Icing_conditions
[17] LIST R.: Ice Accretions On Structures. Journal of Glaciology, 19 (1977), 451-465.
[18] url: http://extice.cira.it/project/proposal-summary
[19] Bottyán Zs.: Estimation of structural icing intensity and geometry of aircrafts during different conditions - a fixed-wing approach. Időjárás, 115 (2011).
[20] Bragg M.B., Broeren A.P. and Blumenthal L.A.: Iced-airfoil aerodynamics. Progress in Aerospace Sciences, 41 (2005), 323-362.
[21] Bragg M.B., Hutchison T., Merret J., Oltman R. and Pokhariyal D.: Effect of Ice Accretionon Aircraft Flight Dynamics, 38th AIAA Aerospace Sciences Meeting & Exhibit January 10-13, 2000/Reno, USA, AIAA 2000-0360, 2000
[22] Anderson J. D.: Fundamentals of Aerodynamics. McGrow-Hill, New York, 2001
[23] Hadobács K.: Repülésre veszélyes időjárási helyzetek rekonstrukciójának alkalmazási lehetőségei – Felületi jegesedés becslése és a hozzá tartozó szimulációs környezet kialakítása. Diplomamunka, ELTE-TTK, 2011
[24] Politovich M. K.: Aircraft Icing url: http://curry.eas.gatech.edu/Courses/6140/ency/Chapter5/Ency_Atmos/Aircraft_Icing.pdf
[25] Accident description. url: http://aviation-safety.net/database/record.php?id=19941031-1
[26] Bernstein B. C., Mcdonough F., Politovich K. M and Brown B. G: Current Icing Potential: Algorithm Descripion and Comparison with Aircraft Observations. Journal of Applied Meteorology, 44 (2005).
[27] Jensen C. E.: Prediction of large scale cloudiness and air-frame icing conditions by machine methods. J. App. Meteor, 2 (1963), 337-344.
[28] Schultz P. and Politovich M. K.: Toward the improvement of aircraft icing forecast for the continental United States. Wea. Forecasting, 7, p 491-500, 1992.
[29] Forbes G. S., Hu Y., Brown B. G., Bernstein B. C. and Politovich M. K.: Examination of soundings in the proximity of pilot reports of aircraft icing during STORM-FEST. Pre-prints, Fifht Conf. on Aviation Weather Systems, Vienna, VA, Amer. Meteor. Soc., 282-286, 1993.
[30] Reisner J., Rasmussen R. M. and Bruintjes R. T.: Explicit forecasting of supercooled liquid water in winter storms using the MM5 meso scale model. Quart. J. Roy. Meteor. Soc., 124 (1998), 1071-1107.
[31] Reinking R. F.., Matrosov S. Y., Bruintjes R. T. and Martner B. E.: Identification of hydrometeors with elliptical and linear polarization Ka-band radar. J. Appl.Meteor, 36 (1997), 322-339.
[32] Lozowski E.P., Stallabrass J.R. and Hearty P.F.: The Icing of an Unheated, Nonrotating Cylinder. Part I: Icing Wind Tunnel Experiments. Journal of Climate and Applied Meteorology, 22 (1983), 2053-2062.
[33] Lozowski, E.P., Stallabrass, J.R. and Hearty, P.F.: The Icing of an Unheated, Nonrotating Cylinder. Part I: A Simulation Model. Journal of Climate and Applied Meteorology, 22 (1983), 2053-2062.
[34] Gyöngyösi a. z., Kardos p., Kurunczi r. and Bottyán zs.: Development of a complex dynamical modeling system for the meteorological support of unmanned aerial operation in Hungary. ICUAS: Conference Proceedings, 2013, 8-16.
[35] Dr. Óvári Gy.: Biztonságtechnika a repülésben: A repülőeszközök jégtelenítő rendszerei. Repülés-tudományi Közlemények, Special edition, 2008

REPÜLŐESZKÖZÖK REPÜLÉS KÖZBEN BEKÖVETKEZŐ JEGESEDÉSÉNEK KOCKÁZATAI, ÉS A KOCKÁZAT- CSÖKKENTÉS LEHETŐSÉGEI – JEGESEDÉST ELŐREJELZŐ ALGORITMUSOK ÉS JÉGTELENÍTŐ RENDSZEREK

Mindennapi életünk fontos részévé vált a repülés, mely nyilvánvalóan veszélyeket hordoz magában, egyértelmű vagy rejtett formában. A kockázati tényezők közé sorolható számos időjárási jelenség is. A műszeres repülés fejlődésével lehetőség nyílt arra, hogy a repülőgépek a felhők belsejében hosszabb ideig műszerek szerint repüljenek. Ekkor egy addig ismeretlen veszéllyel, a jegesedéssel találkoztak, mely jelenség során a repülőgépek sárkányszerkezetén stb. jég rakódik le, mely szignifikánsan befolyásolja a repülés folyamatait, a repülőgép irányíthatóságát. A repülésmeteorológia egyik kiemelt feladata, hogy a repülőgép személyzetét időben tájékoztassa a potenciális jegesedési veszélyről [1], mely előrejelzéshez akkumulációs modelleket alkalmaznak. Ennek ellenére repülésre veszélyes időjárási körülmények között ma is bekövetkezhetnek repülőesemények. Annak érdekében, hogy ilyen esetben csökkentsék az akkumuláció mértékét jégtelenítő rendszereket helyeztek el a repülőgépeken. De repülőgépek jegesedésének problémájával gyakran a jégtelenítő rendszerek megléte mellett is számolni kell.

Kulcsszavak: *repülés biztonság, jegesedés, jegesedés előrejelzés, jegesedést megelőző rendszerek, jégtelenítő rendszerek*

Hadobács Katalin hadnagy	Lt (OF1) Katalin Hadobács
meteorológus főtiszt	meteorologist officer
MH GEOSZ IESZO	HDF GEOS
katalin.hadobacs@gmail.com	katalin.hadobacs@gmail.com
orcid.org/0000-0003-1200-5098	orcid.org/0000-0003-1200-5098

http://www.repulestudomany.hu/folyoirat/2018_1/2018-1-14-0486_Hadobacs_Katalin.pdf