ICING FLIGHT TEST CAMPAIGN ON THE H175B

Setareh TAHERI, setareh.taheri@airbus.com, Airbus Helicopters Marignane (FRANCE)
Andrea CIABRINI, andrea.ciabrini@airbus.com, Airbus Helicopters Marignane (FRANCE)
Alain DELAVET, alain.delavet@airbus.com, Airbus Helicopters Marignane (FRANCE)

Abstract

This paper describes the icing campaign carried out by Airbus Helicopters on its twin H175B prototypes over the winter 2023/24 in Canada and Norway. The primary objective of this campaign was to demonstrate the compliance of the helicopter's ice protection system with the regulatory requirements of EASA for an upcoming certification of H175B for flight in icing conditions. In close coordination with the lead engineering team in France, two prototypes were flown simultaneously in Canada and Norway to validate the efficiency of the system and the proper behavior of the helicopter in terms of performance, vibrations and loads. The efficiency of the Full Icing Protection System (FIPS) in icing conditions as well as the material limit margins of the blades – also known as the "overheating demonstration" – in dry conditions were validated in accordance with CS29 Appendix C, limited to the requested 10.000ft altitude envelope.

Definitions of icing and descriptions as well as an overview of the regulatory requirements for icing capabilities are presented, with a focus on the distinction between limited icing, restricted icing and full icing flight domains and the associated justifications. The origin of these requirements, and the pioneering role of Airbus Helicopters in the field of helicopter icing protection, are also highlighted.

This presentation covers a description of the H175B ice protection system and flight test installations as well as the methodology involved in finding and performing the different flight test points of icing certification. Finally, the preliminary results of this icing flight test campaign are outlined.

1. NOTATIONS

AC	Advisory Circular
AC	Alternative Current
ACEMB	Alternative Current Electrical Master Box
ALT	Alternator
CDP	Cloud Droplet Probe
CIP	Cloud Imaging Probe
CCP	Cloud Combination Probe
CG	Center of Gravity
CMI	Continuous Maximum Icing
CS	Certification Specification
EEW	Equipped Empty Weight
FADEC	Full Authority Digital Engine Control
FIPS	Full Icing Protection System
FLI	First Limit Indicator
FTE	Flight Test Engineer
ICB	Icing Control Box
IDMS	Ice Detection and Measurement System
IGE	In Ground Effect
ISA	International Std Atmosphere
KVA	Kilo Volt Ampere
HMI	Human Machine Interface
HVTRU	High Voltage Transformer Rectifier Unit
MFD	Multi Functional Display
MRB	Main Rotor Blade
MRD	Main Rotor Distribution
MTOW	Maximum Take-Off Weight
MVD	Median Volumic Diameter
NR	Rotor Speed
OAT	Outside Air Temperature
OGE	Out of Ground Effect
PSD	Particle Size Distribution
RFM	Rotorcraft Flight Manual
SLD	Supercooled Large Drops
SLL	Service Life Limit
TR	Tail Rotor
TRD	Tail Rotor Distribution
TRB	Tail Rotor Blade
TRU	Transformer Rectifier Unit
WHC	Windshield Heater Controlers
Zσ	Density Altitude
ZP	Pressure Altitude

2. INTRODUCTION

Over the winter 2023/24, the prototype department of Airbus Helicopters has been carrying out a full icing flight test campaign across 8 time zones, coordinating its teams in four countries – France, Canada, USA and Norway – and flying with two twin aircraft simultaneously.

The overall aim of this exceptionally dense and complex campaign was to demonstrate the compliance of the H175B Full Icing Protection System (FIPS) with the EASA Certification Specification (CS29). Its objectives were to assess the H175B behavior, in both dry air and natural icing conditions, with the FIPS installed and operating. The efficiency of the FIPS in icing conditions as well as the material limit margins of the blades – also known as the "overheating demonstration" – in dry conditions had to be validated with the rules defined in CS29 Appendix C, limited to the 10.000 ft altitude envelope as requested in AC29 2C §1419. The limited envelop being applicable only for the efficiency demonstration, whereas the overheating verification has to cover the whole helicopter envelope (OAT < 5°C) up to the helicopter's ceiling (15,000ft).

Figure 1: H175B prototypes in Canada and Norway equipped with FIPS system

3. ICING DEFINITION

AC29-2C defines the *supercooled cloud environment* necessary for certification of rotorcraft in icing condition as clouds containing water droplets below 0°C (32°F) that have remained in the liquid state. These supercooled water droplets are metastable, they will freeze upon impact with the helicopter. Water droplets have been observed in the liquid state at ambient temperatures as low as -51°C (-60° F). The rate of ice accretion on a helicopter component is dependent upon many factors such as droplet size, cloud liquid water content, ambient temperature, as well as component size, shape, blade loading, Mach number, velocity…, etc. Mixed conditions (i.e.; a combination of ice crystals and supercooled water droplets) and freezing rain or freezing drizzle are not addressed by the certification for helicopters. That is why a caution notice often exists in the RFM advising that the rotorcraft is not certified for operation in freezing rain of freezing drizzle.

According to the World Meteorological Organization, there are several types of icing:

- **Rime Ice**: white, porous, opaque, brittle and rough due to the high amount of air. It is formed by supercooled drops rapidly freezing on impact, forming mostly along an airfoil's stagnation point, it generally conforms to the shape of the airfoil and therefore has a limited aerodynamic impact on the profile. This occurs at low temperatures (OAT< -10°C) and/or low liquid water contents.
- **Glaze Ice** (also known as clear ice): clear, tough, adhesive, dense and smooth. It is formed by supercooled water droplets, or freezing rain, striking a surface but not freezing instantly. Often "horns" or protrusions are formed which have a strong aerodynamic impact on the airfoil. It occurs usually at warmer temperatures (OAT > -10°C) and/or high liquid water contents.
- **Supercooled Large Drops (SLD)**: have been identified as main contributors in noteworthy accidents, including Roselawn [14]. SLD icing involves much larger drops than covered by the icing envelope in Appendix C such as freezing drizzle (40-500 μm) or freezing rain, with drop diameters extending beyond 500μm. Indeed, the mass of these large droplets is so great that they can strike well aft of the protected regions on an ice protected aircraft. Once ice has formed aft of the ice protection system, it can only be removed by melting or the gradual process of sublimation. With the ice protection system working and removing ice from the leading edge, any ice aft of the protection system may quickly grow into a ridge. Such a ridge will substantially disrupt the flow over the airfoil and could lead to handling problems and/or performance degradation [15]. New icing regulations defining an Appendix O SLD icing

conditions envelope have been issued by EASA and FAA early in 2015 for Large Aircraft (CS/FAR25 §25.1420). To meet these new certification requirements, it has either to be demonstrated that the SLD conditions can be detected and then avoided by the aircraft, or that the aircraft can sustain the SLD conditions. SLD is not applicable to rotorcraft. Therefore, meteorologists are requested to carefully forecast SLD (freezing drizzle) so that pilots can avoid these conditions.

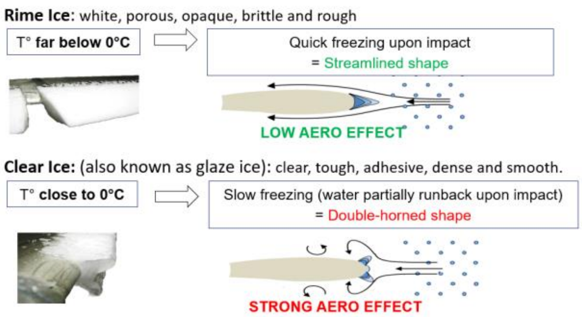

Figure 2: Droplet solidification when impacting a surface according to the environmental conditions

4. REGULATORY ASPECTS

The first regulation about icing concerned airplanes and was the “Federal Aviation Regulation 1975 part 25, Appendix C“ or simply FAR25-Appendix C linked to §1419 “Ice Protection”. This regulation was based on the NACA technical note n°1855 [8] defining the various icing conditions that could be encountered in flight by aircrafts. The data were collected on 1038 aircraft flights between 1947 and 1948 in the north of the United States, in the great lakes area. For present state-of-the-art rotorcraft, an altitude limited icing envelope based on the same data than Part 25 is presented by AC29-2C.

Appendix C of the CS29 requires that a helicopter be able to demonstrate that it can safely operate in specific atmospheric conditions defined by 4 main parameters:

- The Liquid Water Content – LWC – in grams per cubic meters (g/m^3). This represents the mass of condensed liquid water by unit of volume inside the cloud
- The Median Volumic Diameter (MVD) – in microns (µm).
- The Outside Air Temperature (OAT).
- The altitude.

The Figures below illustrate the icing envelope defined in Appendix C of CS29 for continuous icing conditions (also called CMI for Continuous Maximum Icing)

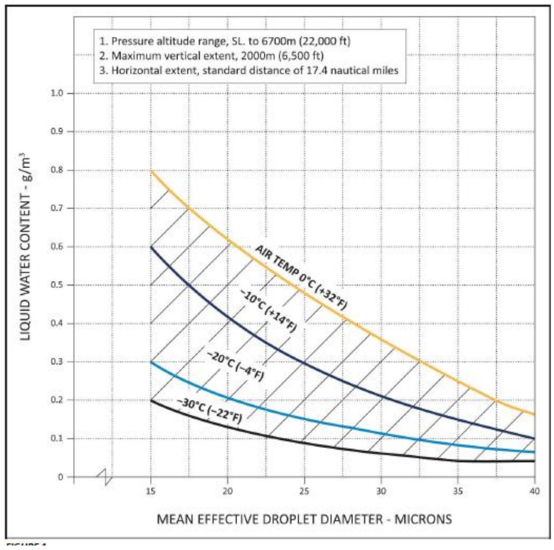

Figure 3: Continuous maximum (stratiform clouds) atmospheric icing conditions: LWC vs MVD

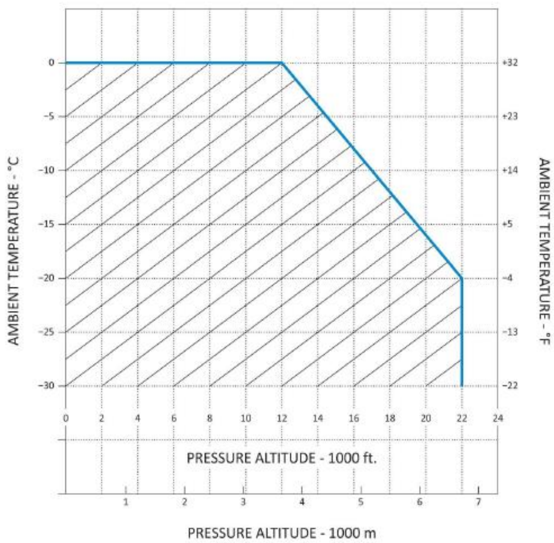

Figure 4: Continuous maximum (stratiform clouds) atmospheric icing conditions: OAT vs Zp

CS29 also specifies a correction factor to apply to the LWC according to the cloud horizontal distance, as the standard cloud distance considered for CMI conditions is 17.4 NM.

The same kind of envelopes, with higher LWC and shorter time required are defined for intermittent icing conditions (also called IMI for Intermittent Maximum Icing) - cumulous cloud forms - with a standard cloud distance considered for IMI conditions of 2.6 NM.

AC29-2C allows using a reduced envelope for rotorcraft defined by an altitude limited to 10000ft.

As observed in Figure 3, significant effects can result from various combinations of environmental parameters. For example, high LWC can lead to rapid ice accumulation and high MVD are associated to the greatest impingement areas and runbacks. As most critical ice shapes are a function of each of these parameters in addition to airspeed, surface temperature and surface profile, the applicant should explore the widest range of these parameters during the certification.

Moreover, in addition to C29 §1419, the applicant must show compliance with the following CS/FAR 29 requirements:

- §1093 Induction system icing protection
- §1325 Static pressure and pressure altimeter systems
- §1323 Airspeed indicating system
- §773 Pilot compartment view

Different methods are used depending on helicopter manufacturers as varied as simulations, icing wind tunnel tests, ground spray rig, and airborne icing tanker tests. Until now, none of these methods, either individually or collectively, has satisfied the full requirements for certification. According to the AC29-2C, until an artificial method has been successfully demonstrated and accepted, icing certification must include flight tests in natural icing conditions.

5. AIRBUS HELICOPTERS PIONEERING ROLE IN ICING CERTIFICATION

The world's first experience with helicopter icing clearance started in France in 1975 with the SA 330 J Puma [1]. The Puma ice protection system was composed of deicing main rotor laminated blades with electric mats and anti-icing metal blades with electric mats on the tail rotor [2]. Puma icing campaign was succeeding research experience gained on Alouette III and Super Frelon flights since 1964. The Puma n°04 performed between March 1975 and May 1978 flight in dry and icing conditions in France as well as in Canada. Canada trials during the winter 1977 at the NRC Spray Rig enabled to determine the heating and rest times of the system. The Puma then performed 87 flight tests hours in natural icing, including 39 flight tests hours with the deicing system on. Eventually, the flights showed the inadequacy of the rest times assumed at the Spray Rig. In March 1978, the SA330 J Puma obtained its flight icing clearance from DGAC, the first of its kind in the helicopter industry.

Figure 5: Puma icing test at the NRC Spray Rig, in Ottawa, Canada.

In May 1984, Super Puma AS332 B made a world premiere, by getting the first certificate of airworthiness issued by the FAA, for unrestricted flight into full icing conditions [3], [4]. Since then, others certifications have been granted to different manufacturers.

Regulations define different types of icing clearances. This paper focuses on the full icing certification of H175B, however a brief recall of existing icing envelopes and means of compliance are given below:

Baseline / Type Certificate:

Even for rotorcraft that are prohibited from flying in icing conditions, an inadvertent icing encounter is possible so substantiations require that:

- The engine will continue to operate
- The pitot and static ports can ensure navigation

Limited icing:

Limited icing was initially proposed by a CAA "white paper", adapted by the JAA for the AS332 and eventually by the EASA through a « Special Condition» CRI [11] for H225, applied in North Sea. Operations are limited to operations over the sea and require a 500 ft altitude band over the sea with positive temperatures into which the helicopter can descend to deice. The OAT limit is typically -6°C for an unlimited time and few minutes (5min) down to -10°C. Flights with such clearance have been performed in the North Sea area for about 40 years successfully.

Substantiations require the same elements than for baseline, in addition to validation of the following parts:

- Engine Installation
- Windshield
- Icing Detector
- Fenestron shroud if necessary
- Fixed wings if necessary (horizontal stabilizer, …)
- All external equipment

Full icing:

This is the subject of this paper. It is associated with the demonstration of the complete envelope CS29 / FAR29 Appendix C or AC29 reduced envelope at 10000ft [9], [10].

Substantiations require the same elements than for limited icing in addition with rotors deicing.

Restricted icing domain:

Operators strongly ask for reduced icing envelopes both with "cold blades" and "hot blades". For example, it could allow them to cross icing layer clouds without FIPS to get to a clear sky or to design a simpler FIPS by demonstrating a reduced envelope, sufficient enough for operations in some part of the world. No regulation exists yet and for the moment, both American and European authorities are hesitant to grant the request. Therefore, light or reduced icing is generally a military qualification associated with a letter of non-objection to the customer. The customer is then responsible for approval with national authority.

The Figure below gives an overview of Airbus helicopters and main competitors with civilian icing certifications.

	Limited Icing	Full Icing
AS 332 (*L2 only limited Icing)	1984	1983
H225	2005	2005
S92	Europe only	2006
AW139	2007	2010
AW189	2015	2016
H175	2016	Planned

Figure 6: Civilian Airbus Helicopters and main competitors icing certifications.

In addition to this list, among the Airbus Helicopters fleet, the NH90 is authorized for military operation on the same basis as civilian regulation.

6. H175B ICING SYSTEM

The optional rotor ice protection system of the H175B, called "Full Ice Protection System" (FIPS), is an automatic system which has two main functions:

- deicing of the main rotor: the system removes the ice that has formed on the blades.
- anti-icing of the tail rotor: the system prevents ice from forming on the blades.

The FIPS is composed of the following main items:

- rotors power distribution systems (ICB, MRD and TRD)
- 2 dual OAT probes
- main and tail rotor sliprings
- 5 main rotor harnesses
- 3 tail rotor harnesses
- 5 de-iced main rotor blades
- 3 anti-iced tail rotor blades
- a control panel

The two dual OAT probes are needed by the rotors power distribution and control system (ICB, MRD and TRD) in order to manage the automatic activation and heating cycles of the main blade deicers and tail blade anti-icers. The de-icing harnesses transfer the de-icing / anti-icing power from the sliprings to the blades.

In addition to the H175B basic type design definition, the following optional equipment required to fly in limited icing conditions are also needed in full icing domain:

- 2 heated cockpit windshields and Windshield Heater Controllers (WHC)

- An icing detector with severity indication (IDMS)
- A horizontal stabilizer ice lump impact protection
- A weather radar used to avoid penetrating large cumulus clouds with extensive vertical development
- A winter kit including Engine Air Intake Protection (EAIP)

In order to supply the FIPS, an AC Electrical generation and distribution system is added. It is based on:

- 2 x 20 kVA Alternators
- 2 x AC electrical Master Box (ACEMB)
- 2 High Voltage Transformer Rectifier Units (HVTRU)

To be able to install the 2x20 kVA Alternator, the existing emergency generator is dismounted and the emergency source for the electrical network is replaced by an emergency TRU connected on the 2x20 kVA AC electrical generation system.

The full ice protection system is set up as a kit so that the customer may partially remove the system in the summer season to reduce EEW impact. That allows for a decrease of more than 55% of the induced weight of the deicing system when it is not deemed necessary, without any heavy maintenance operation.

The main rotor blades are equipped with an electro-thermal deicer positioned under the leading edge. The deicer is divided in two rings in spanwise direction and 5 heater mats in chordwise direction as presented in Figure 7. The heating mats are powered in a ring-by-ring mode. When one ring heats, the other ring is in a cool down phase. The heating cycle duration depends on OAT. H175B integrates enhanced carbon heating mat technology, originally developed for application on a previous program [16]. It provides improved thermal efficiency allowing to reduce heating cycle duration and thus limits helicopter performance degradations in icing conditions by reducing residual ice accretion on rotor blades.

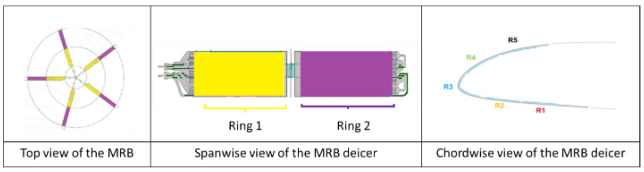

Figure 7: Different views of the MRB deicer

The tail rotor blades are equipped with an electro-thermal anti-icer positioned under the leading edge. The anti-icer is divided in 4 heater mats in chordwise direction. The heating mats have also a power regulation as function of the OAT.

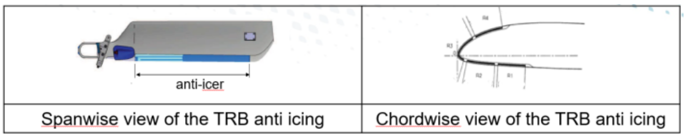

Figure 8: Different views of the TRB anti icing

7. FLIGHT TEST CAMPAIGNS OBJECTIVES

The flight test program for the FIPS validation is composed of two main parts:

- dry air flight tests
- flight tests in natural icing conditions

The main objectives of the dry air points are:

- validation of margin regarding overheat
- loads assessment by comparison to the standard non-heated blades

The targeted dry air flight test envelope is at an altitude near the helicopter ceiling, as it is the worst condition for convective heat transfer. Indeed, the higher the helicopter is, the lower is the air density. However, the tail rotor and main rotor FIPS heating cycles vary according to the OAT. It is expected that higher OAT will be found at lower altitude. Therefore, the OAT range required for these tests is [-23.3°C; +5°C]. As the OAT domain investigated in flight may not fully cover this desired OAT range, results can be extrapolated using °C/°C method and supplemented by analysis. Finally, alternator output voltage has been set to the highest value in order to get the highest possible power density on both the MRB and TRB. All these tunings are required to demonstrate that the blade material temperature limits are not exceeded, thanks to the temperature sensors installed on the main and tail rotor blades.

The main objectives of the icing condition points are:

- demonstrate the FIPS efficiency in nominal mode and failure modes
- evaluate the helicopter performance, vibrations and handling qualities
- assess the loads for the Service Life Limit (SLL) computation

These points may be affected by:

- the power consumed by the FIPS
- the increase of the necessary power due to the residual ice accretion on the fixed and rotating parts
- a partial clogging of the engine air intake

The icing flights should cover the whole OAT and altitude ranges that will be claimed down to -23.3°C and up to 10000 ft for nominal FIPS mode. Once the critical OAT range had been established, the FIPS failure modes have been tested inside that range.

Flights should also cover the whole LWC range required by the AC29 Appendix C envelope limited to 10,000ft. The LWC can be considered satisfactory if the average value during the point is between 80% to 100% of the LWC required by CS29 Appendix C or between 40% to 100% for temperature below -20°C since the presence of supercooled water droplets is rarer in these conditions.

Similarly, the complete range of the MVD mentioned in the CS29 Appendix C should be demonstrated, in particular, MVDs between 15µm and 25µm which leads to the highest LWC values.

For tests in natural icing conditions, alternator output voltage was set to the lowest practical value, leading to the lowest possible power density on both the MRB and TRB. That setting is the critical one for the FIPS efficiency demonstration.

8. FLIGHT TEST INSTRUMENTATION AND MEANS

In order to assess the efficiency of the FIPS system and to check the margins with material limits (overheating demonstration), several temperature sensors are positioned on the main and tail rotors' blades. There are two kinds of sensors: the internal sensors located between the heating mats and the blade and the surface sensors located between a heating mat and the metallic leading edge. Internal sensors are used to monitor margins with material limits in order to prevent an overheating of the blade whereas the surface sensors are used to assess the system's efficiency. The internal temperature sensors shall be available in real time monitoring for the flight test campaigns for the safety regarding the risk of overheating.

Moreover, for the compliance demonstration, loads on the rotors and the structure have to be assessed and recorded during the flights. For parameters associated with a flight limitation, real time monitoring must also be available.

Typical aircraft parameters also have to be recorded (weight, airspeed, OAT, altitude etc.) as well as specific icing parameters. The cloud droplet characterization is made with a probe developed by the "Droplet Measurement Technologies (DMT)" laboratory in Colorado (USA). Their probe is called Cloud Combination Probe (CCP). It includes:

- A Cloud Droplet Probe (CDP) for MVD measurement for small droplet diameters – from 2µm to 50µm. This probe is the main sensor to chase the adequate diameter droplets of the regulation.
- A Cloud Imaging Probe (CIP) for MVD measurement for large diameter droplets – from 15µm to 930µm.

The CCP provides Particle Size Distribution (PSD), MVD and complementary evaluation of LWC through integration of the PSD. Airbus Helicopters is relying on the "LaMP" Laboratory – "Laboratoire de Météorologie Physique" expertise for the processing of data. This research laboratory is located in France and is specialized in cloud processes, from nucleation to wet and dry precipitation.

In addition, a hot-wire sensor called LWC-300 probe (not presented on the Figure below) is also used for LWC measurement – from 0.005 to 3 g/m^3. That sensor confirms the LWC provided by the CCP as it uses a different technology. Indeed, optic sensors of the CCP are sensitive to all particles in the clouds and not only liquid water drops while hot-wire sensor type are mainly sensitive to liquid water.

Figure 9: Cloud Combination Probe – CCP – installed on H175B

Additionally, a "CEV Probe" was installed near the copilot window to visualize the ice accretion rate. A camera recorded this probe and pictures at regular intervals were taken during all flights.

Figure 10: CEV probe near the copilot window

A careful monitoring of the ice accretion on the CEV probe is required to confirm the LWC value. Indeed, a chart, called "LUCAS AEROSPACE abacus", allows to correlate the millimeter of ice per minute seen on the probe to the level of water contained in the cloud according to the airspeed (Figure 11). The probe can be deiced on demand. The LWC is derived based on the chart presented on Figure below. This simple device allows the crew to have a reliable indication of the overall accretion level on fixed parts as well as to confirm the validity of other LWC measurements means.

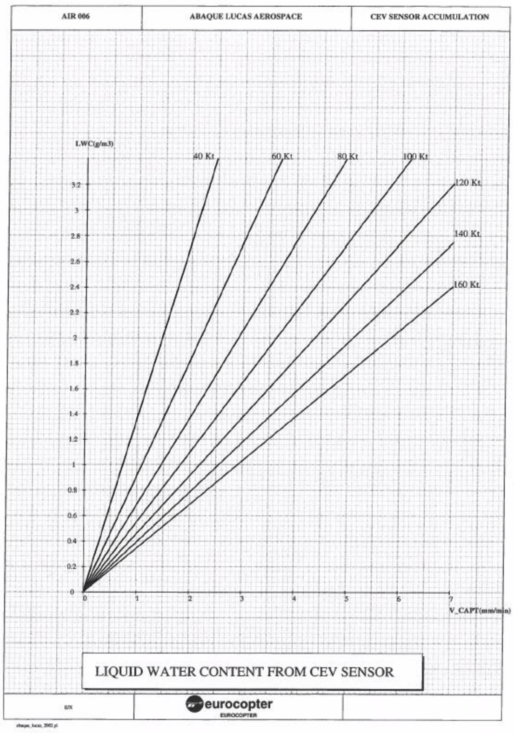

Figure 11: LUCAS AEROSPACE abacus used with CEV probe

Indicators are installed on the horizontal stabilizer and the tail boom for a qualitative assessment of the ice accretion observed in the cloud.

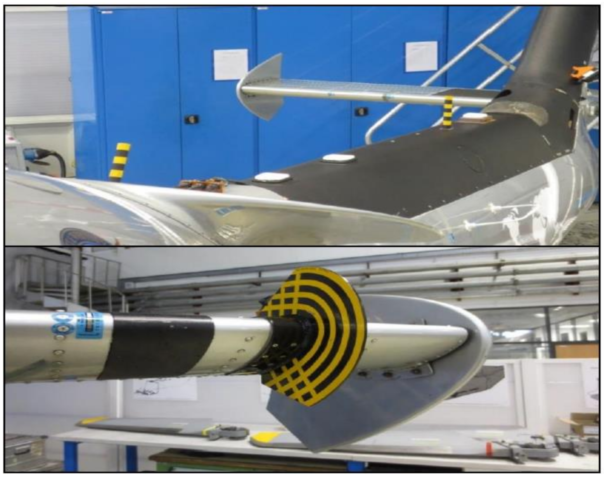

Figure 12: Tail boom and horizontal stabilizer witnesses

Generally speaking, for these type of flight tests, cameras are very useful for in-flight monitoring and post-test analysis. 11 were installed on H175 in order to visualize the main and tail rotor blades, the helicopter head and structure as well as the CCP and CEV's probes. The most interesting information on the tests could be analyzed from these recording as unusual icing location, run back, ice shedding and so on.

Figure 13: Example of main and tail rotor blades cameras

In addition to weather forecast of local organizations and available websites, a private meteorologist has been contracted for a better comprehension of local icing conditions both for flight schedule anticipation and real-time guidance in flight with a dedicated communication tool called "Planet" [13].

Even if the weather radar is not a specific flight test instrumentation but an equipment already available on the helicopter for icing certification, it is also an efficient tool to choose the clouds. Indeed, satisfactory clouds for these tests are at the initial stage of their formation so they have only a small proportion of red on the image and they are mainly yellow and green.

Finally, all these parameters are gathered and presented to the flight test engineer for the test conduct thanks to the monitoring station installed on the helicopter cabin.

Figure 14: FTE monitoring station installed inside the helicopter cabin

To summarize, The FTI is needed to measure the characteristic of the helicopter as well as to observe the ice buildup, while preserving the external configuration of the helicopter. Indeed, the FTI should not change the ice buildup and the helicopter's behavior. All these measured parameters shall be both recorded and available in real time for monitoring during the flight test campaigns.

9. FLIGHT TEST CAMPAIGN METHODOLOGY

The effects of the icing conditions will be demonstrated as follows:

- **Performance**: in-flight measurements have been used to characterize the required power increase and to substantiate any impact on the performance as published in the Rotorcraft Flight Manual.
- **Loads**: the stresses measured in flight have been post-processed and the service life limits determined according to the icing flight envelope limitations and taking into account the specific flight spectrum in icing conditions. Moreover, monitoring the load levels in flight gives a good indication of local icing on the helicopter.
- **Vibrations:** have been measured in flight both in nominal and failure FIPS modes to assess the behavior of the helicopter. Similarly, monitoring the vibration levels in flight gives a good indication of a local icing on the rotors and the structure.

In icing conditions, the Engine Air Intake (EAI) may collect ice that could adversely affect engine operation or cause serious loss of power. EAI are certified thanks to ice tunnel to justify the air intake in icing conditions. However, the proper behavior of engines is also monitored during all the tests by the FTE.

In addition, a crew member checks permanently the CEV probe in order to announce the total accumulated value of ice and compares it with the LUCAS AEROSPACE chart.

The best technique when looking for icing conditions is to enter in the clouds with a trajectory which allows turning within the yellow area of weather radar. The FTE carefully monitors the size of droplets and the LWC in order to help the pilot to stay in the area of interest. Usually, the top of the clouds is more likely to offer icing conditions with high LWC. Moreover, it is not unusual to have lightning strikes during these tests. It occurs generally in cumulous or IMI conditions. Fortunately, there are lightning forecasts which can be used to avoid that hazard.

The choice of flying speed should allow sufficient power margin, so the pilot maintains his collective fixed in a position corresponding to less than one division on the First Limit Indicator (FLI) in constant flight condition. This method simplifies the evaluation of power degradation in icing conditions. A maximum bank angle of 30° is also respected. Moreover, a maximum rate of descent following flight in icing condition of 1500 ft/min is applied to avoid ice shedding through the rotors. This limitation does not apply in an emergency.

Airbus Helicopters has a unique logic for the demonstration of the icing system's efficiency. Indeed, a complementary demonstration is made in icing wind tunnel in the worst icing conditions and power supply in order to have the lowest theoretical power densities for the demonstration.

As the heating cycles vary according to the OAT, the efficiency of the FIPS system is validated to demonstrate satisfactory helicopter behavior for each range of these cycles. The heating cycles are previously developed in the icing tunnel in order to test all the conditions and study the different phenomena such as runback in the most severe conditions without the centrifugal force.

Usually, the critical flight domain for the structure and the Engine Air Intake is in the range [-5°C; 0 °C] due to the high LWC required by Appendix C. All the domain for rotors has to be demonstrated in flight even if the critical one is generally between [-15°C; -10 °C] as mentionned in reference [7] and confirmed in flight.

The performance impact is only measured in natural icing flights by firstly demonstrating the existence of a critical temperature domain, in which the performance degradation will be measured. This is once again, something that has been seen in the icing tunnel and then demonstrated in flight [6].

Finally, the effect of ice accretion that might occur as a result of a single system malfunction, should be considered for the certification. The applicant has to show that the helicopter can safely exit icing conditions by demonstrating 15 minutes level flight with FIPS failure. This demonstration has to be done in the [-15°C; -10°C] critical temperature envelope for rotors [12].

10. FLIGHT TEST CAMPAIGN RESULTS

Icing campaigns are challenging as they can be in stand-by for weeks waiting for adequate meteorological conditions and generally, several winters of flight testing are required to acquire a sufficient data base. The H175B might not have been an exception. It was one of the main reasons why Airbus Helicopters decided to fly in different locations to increase the chance to get a larger range of LWC, MVD, Zp and OAT during the same winter. Indeed, covering the requested points of the AC29 during only one winter was the challenge given to the flight test department. Among the various difficulties, being able to find conditions with sufficient LWC between – 80% to 100% of the LWC required by CS29 Appendix C – for H175B certification is the most crucial one. Usually, it is also difficult to fly inside sufficiently long clouds with supercoolded water droplets. Indeed, the AC29 asks for 30 minutes in the design conditions of the continuous maximum icing envelope at the most critical weight, CG, and altitude with the FIPS on. Indeed, even if the helicopter can turn inside the cloud, by doing so, it generally decreases the water content of the cloud. However, it has been observed that it was less the case in Canadian icing conditions, encountered during the campaign, near the great lakes area. Once a flight test point is done, it is studied by analysts and engineers from the design office to be claimed for the certification. Each phase is divided according the following constraints:

- collective level generally constant
- constant altitude
- MVD and LWC established
- constant OAT / constant deicing cycle

If the helicopter briefly exits from the cloud, the point is measured as a unique phase if there is no drop in torque before re-entry and if not, the flight datum is divided into two specific phases.

Dry air tests have led to the following main results:

- The heating cycles remain under the temperature limit of the materials used for the blade manufacturing. So, no risk of blade overheat has been observed.

Concerning the icing points, two prototypes have been flown simultaneously in both Canada and Norway, the Figures below present the impressive coverage of the continuous and intermittent icing envelope as defined in CS29 Appendix C and limited to 10.000 ft altitude domain according to AC29-2C §29.1419

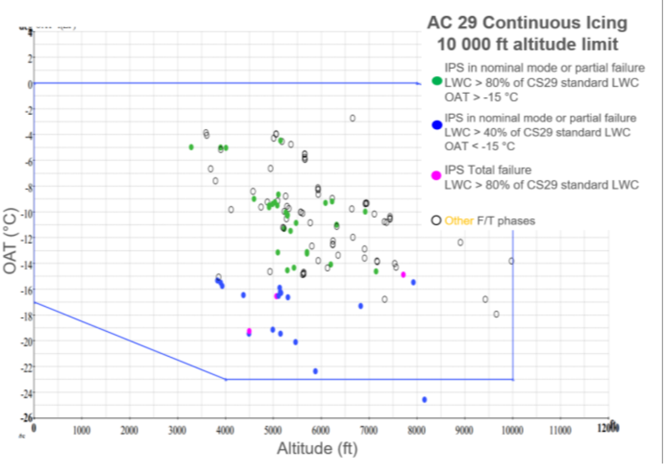

Figure 15: Continuous icing domain tested – OAT according to Pressure altitude

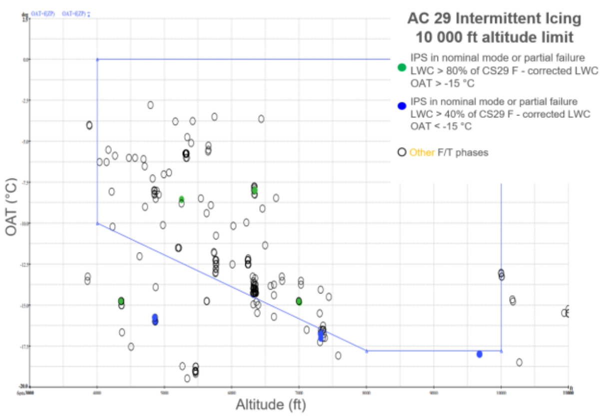

Figure 16: Intermittent icing domain tested – OAT according to Pressure altitude

At the end of the campaign, the accumulated amount of ice collected on the CEV probe was about 2.5 meters during almost 190 flight hours – 65h flight hours in icing conditions.

The Figure below gives an overview of icing test points performed in the continuous icing domain with the system ON or in partial failure.

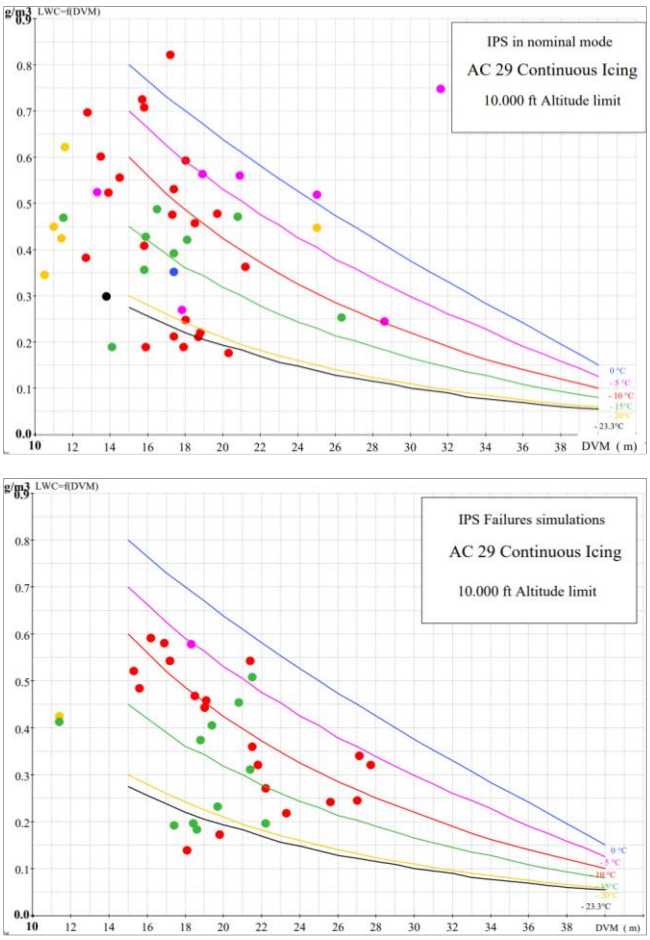

Figure 17: Continuous icing test points – LWC according to OAT – FIPS ON or in partial failure mode

Some preliminary results are listed below:

- The assessment of loads and SLL are under study but the real time load limitations in flight have never been reached.
- No significant impact on handling qualities have been noticed by the crew.
- No unacceptable vibration level has been reached.
- No critical ice shedding has been observed
- The FIPS efficiency has been validated with the correct heating cycles applied. The adequacy of the heating cycles determined during the icing wind tunnel tests, has been confirmed. This outcome has avoided in-flight re-adjustment of heating cycles on the blades.

The Figure below is an example of an icing point in nominal FIPS mode. No significant increase of the torque is observed thanks to the proper functioning and efficiency of the MR de-icing and TR anti-icing system.

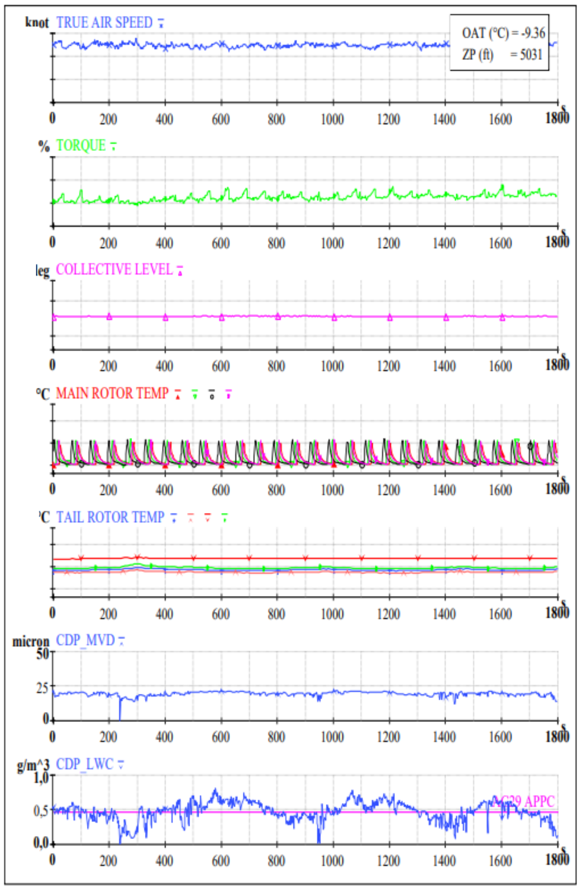

Figure 18: Example of an icing test point in nominal FIPS mode

On the contrary, the Figure below describes an icing test point in FIPS failure mode. An increase of the torque is observed during the test.

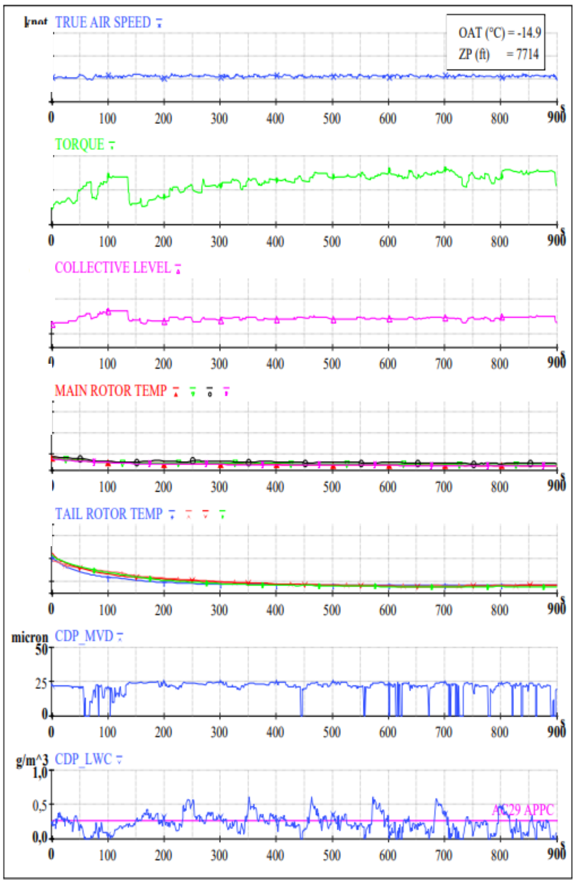

Figure 19: Example of an icing test point in FIPS failure mode

11. CONCLUSION

In the end, this icing campaign has not merely offered very promising results. It has also shifted a paradigm. Firstly, thanks to the H175B heating mat technology, performance degradations in icing conditions were reduced, minimizing the risk on the flight test campaign at the preliminary design stage phase.

Secondly, the H175 icing flight test campaign has shown the adequacy of the heating cycles defined through numerical analysis and validated in icing wind tunnel tests, avoiding in-flight re-adjustment of these cycles.

Finally, the decision to take into flight two prototypes simultaneously, in two carefully selected locations, along with an optimized weather forecasting process and overall test coordination, allowed completing the icing testing within one winter. It provided a very effective methodology in experiencing icing conditions and flying in most varying conditions in the single winter of 2024. This led to an exceptionally successful flight test campaign, involving more than 200 people across 4 countries – France, Canada, USA and Norway – and 8 time zone areas.

The flight test methodology ensures that the most rigorous levels of safety are not only attained, but are exceeded. Through this campaign, Airbus Helicopters did not merely tick the requested certification boxes. It also offered our certification authorities feedback and insight on the most severe icing conditions. This has the potential to help maintain the highest level of safety, for the benefit of helicopter crews and passengers flying in the harshest possible conditions. It also ensures the greatest performance, availability and robustness for the FIPS.

And last but not least, this test campaign was also a once-in-a-lifetime, exciting human adventure across rarely traveled icy fields, that all Airbus team members will remember.

12. REFERENCES

[1] "Rotorcraft Icing - Status and Prospects," AGARD Advisory Report No. 166, August 1981.

[2] Lecoutre, J.C., “Protection systems against icing on the PUMA”, Icing Symposium, London (England), 1978.

[3] Trivier, D., Avedissian, G., “Aerospatiale's experience on helicopter flight in icing conditions”, 9th European Rotorcraft Forum, Stresa (Italy), September, 1983.

[4] Silvani, J-P., “The deiced Super Puma”, 11th European Rotorcraft Forum, London (England), September, 1985.

[5] Flemming, R.J., Bond, T.H., and Britton, R.K., “Results of a Sub-Scale Model Rotor Icing Test”, NASA Technical Memorandum 103709, AIAA-91-0660, 29th Aerospace Sciences Meeting, Reno, Nevada, January, 1991

[6] Britton, R.K., Bond, T.H., and Flemming, R.J.,

“An Overview of a Model Rotor Icing Test in the NASA Lewis Icing Research Tunnel”, NASA Technical Memorandum 106471, AIAA-94-0716, 32th Aerospace Sciences Meeting, Reno, Nevada, January, 1994

[7] Flemming, R.J., Britton, R.K., and Bond, T.H., “Role of Wind Tunnels and Computer Codes in the Certification and Qualification of Rotorcraft for Flight in Forecast Icing”, 20th European Rotorcraft Forum, Amsterdam (The Netherlands), October, 1994

[8] Alun, R. J., Lewis W., “Recommended values for meteorological factors to be considered in the design of aircraft prevention equipment”, Technical Note NACA n°1855, March, 1949

[9] Certification Specifications, Acceptable Means of Compliance and Guidance Material for Large Rotorcraft CS-29, European Union Aviation Safety Agency, Amdt. 10, 2022.

[10] AC 29-2C - Certification of Transport Category Rotorcraft (Changes 1 - 9 incorporated). 09, 2008.

[11] Special Condition (SC) - Certification Review Item, for limited Icing Clearances Applicable to Large Rotorcraft, CS 29 or equivalent, European Union Aviation Safety Agency, April, 2015

[12] Special Condition (SC) - Certification Review Item, Loss of Rotor Icing Protection System, CS 29 or equivalent, European Union Aviation Safety Agency, April, 2015

[13] Turner, S., Gaubert, J-M., Gallois, R., Dacla, Mullie, I., Bourdon, A., Dezitter, F., Grandin A., Protat, A., Potts, R., Schwarzenboeck, A., Strapp, J.W., "Improvements of the PLANET System for Real-Time Satellite Data Transmission During the HAIC-HIWC Darwin Field Campaign" SAE Technical Paper 2015-01-2147, 2015, https://doi.org/10.4271/2015-01-2147.

[14] Aircraft Accident Report, ‘’In-flight icing encounter and loss of control Simmons Airlines, d.b.a. American Eagle flight 4184 avions de transport regional (ATR) model 72-212, N401AM Roselawn, Indiana, October 31,1994

[15] NASA Aircraft Training https://aircrafticing.grc.nasa.gov/1_1_2_5.html

[16] P.Rauch, C.Quillien, "Advanced technologies for High Performance NH90 Blades", American Helicopter Society 59th forum, 2003

[17] H175B Flight Manual, European Aviation Safety Agency, 2022.