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METHODOLOGY FOR CERTIFICATION/QUALIFICATION OF AN AIRCRAFT FOR FLIGHT IN KNOWN ICING CONDITIONS.

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Key words: Icing, Certification, ERF32, rotorcraft

Abstract: Twenty years after the first certifications of the PUMA (SA330J - 1978) and SUPER PUMA (AS332L/C - 1983) for flight in known icing conditions, EUROCOPTER started the development of an ice protection system for application on both the NH90 and the EC225/725 (last version of the SUPER PUMA/COUGAR family).

To comply with both civilian and military requirements of those two programs, a methodology involving the highest level of system safety demonstration, extensive flight tests in natural icing conditions, complete set of icing wind tunnel tests and numerous fatigue or damage tolerance tests has been defined and followed up.

Even if standard icing envelops present several differences, both programs' rotors protections bear a common dual duplex architecture centered on the same core equipment (PDU: Power Distribution Unit) while using the same ice protection techniques.

The efficiency of those protections and their effects on the aircraft performances, handling qualities, vibrations and loads in icing conditions have been demonstrated in flight during several icing campaigns and extended to the whole icing envelop with the help of icing wind tunnel tests and computational models.

Aircraft ice accretions have been analyzed using in flight measurement and code computations and the consequences of their shedding have been demonstrated trough trajectory analysis and dedicated impact and fatigue tests on blades.

The combination of all those demonstrations drove to the successful EASA certification of the EC225 for flight in known icing conditions without restrictions in August 2005 while the NH90 is on the track.

1. INTRODUCTION

The EC225/EC725 helicopter is the latest enhanced version of the PUMA/SUPER-PUMA/COUGAR family. It is a 11tons helicopter sustained by a 5 blades main rotor produced for both civilian and military applications. As its predecessors, it is intended to operate in an all weather environment.

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Figure 1 : EC225/EC725 Helicopter

The NH90 is a 10/11tons military helicopter produced in two main versions: the TTH version dedicated to terrestrial applications and the NFH dedicated to naval missions. It is a 4 blades main rotor with an automatic blade folding capability.

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Figure 2 : NH90 NFH/TTH Helicopter

A common Ice Protection System (IPS) has then been developed with the objective to cope with both civilian regulation and military requirements and to allow flight operations in the full icing envelops applicable to each program, ie JAR29 App. C for the EC225/EC725 and JAR29 App. C + DEF-STAN 00-970 (amdt1) for the NH90.

Taking advantage of the experience gained during icing certification of the PUMA (330J) and SUPER-PUMA (AS332 L/C), a common methodology has been followed to get the EASA icing certification of the EC225 and the NAHEMA qualification of the NH90 equipped with their ice protection systems. This methodology is mainly based on extensive flight trials in natural icing conditions, on tests campaign in icing wind tunnel of the rotors protections and on a high level of damage tolerance and system safety demonstrations.

After a brief recall of the icing envelops and requirements, the paper describes the main steps of this methodology.

2. ICING ENVELOPS

The EC225/EC725 ice protection system is designed to operate in the full JAR29 App. C icing envelop, means down to OAT -30°C and up to 22000ft of altitude (or aircraft ceiling), either in continuous maximum icing conditions (CMI, stratus clouds) or in intermittent maximum icing conditions (IMI, cumuliform clouds). The clouds Liquid Water Content (LWC) and droplets Median Volume Diameter (MVD) limits vary accordingly with the temperature as displayed in Fig. 3.

The NH90 ice protection system is designed to cope with both JAR29 App. C and DEF-STAN 00-970 (amdt1). In the DEF-STAN envelop the LWC limit values in CMI are higher than those of JAR 29 while the LWC limit values in IMI are lower (see Fig. 3). Thus for demonstrations a conservative envelop based on the maximum LWC limit values of the two standard envelops has been considered ie the DEF-STAN 00-970 (amdt1) LWC for CMI conditions and the JAR29 App.C LWC for IMI conditions.

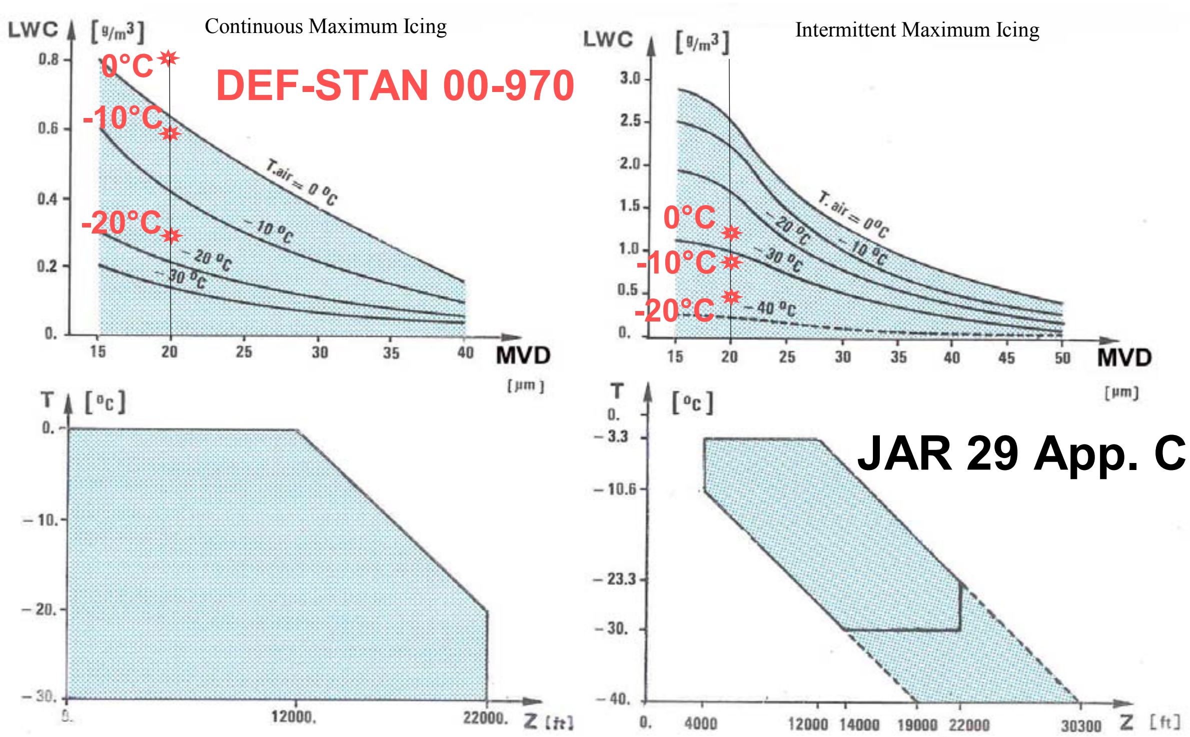

Figure 3 : JAR29 App. C + DEF-STAN 00-970 (Amdt1) icing envelops

In addition to the recommendation of AC 29-2C §1419:

> (i) The rotorcraft should be shown by analysis and confirmed by either simulated or natural icing tests to be capable of holding for 30 minutes in the design conditions <u>of the continuous maximum icing envelope</u> at the most critical weight, CG, and altitude with a fully functional ice protection system.

and for the purpose of a complete demonstration when performing the extension of in flight measurement to the icing envelops limits, CMI and IMI conditions have been mixed together using the conservative proportion of their standard horizontal extend defined in JAR29 App. C (standard horizontal extend of 17.4 Nm for CMI and 2.6 Nm for IMI).

For instance, when looking at the efficiency demonstration in wind tunnel, IMI conditions have been simulated as a cloud composed of both IMI clouds separated by CMI clouds (see Fig.4).

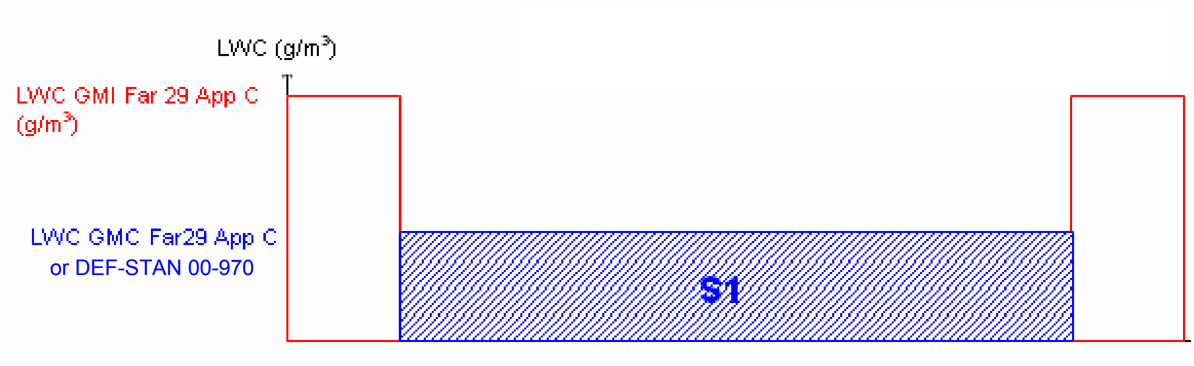

Figure 4 : Alternation IMI/CMI for icing wind tunnel tests

In a same way, for fatigue substantiation, maximum stresses associated to IMI conditions have been mixed with maximum stresses associated to CMI conditions with a respective proportion of 13% and 87% corresponding to the ratio of their standard horizontal extend by the sum of both IMI and CMI standard horizontal extend (see Fig.5).

	CMI	**IMI**
All flight configurations	87%	13%

Figure 5 : Ratio IMI/CMI for fatigue substantiations

This ratio has been checked to be conservative enough compared to the ratio estimated from the different icing campaigns of the EC225, Super Puma MK1 & MK2, cumulating more than 500h of flights in icing conditions.

3. IPS DESCRIPTION

Performing the Functional Hazard analysis of the system, the most critical event was set to CAT in case of any overheating leading to the complete debounding of the main rotor blades leading edge while the total loss of main rotor protection was set to MAJ for most of the flight operations and HAZ for few of them. This classification of those main feared events required to develop a DAL A (Design Assessment Level A) system.

To fulfill the latest requirements in safety demonstration for a DAL A system, a dual duplex architecture has been selected (see Fig.6).

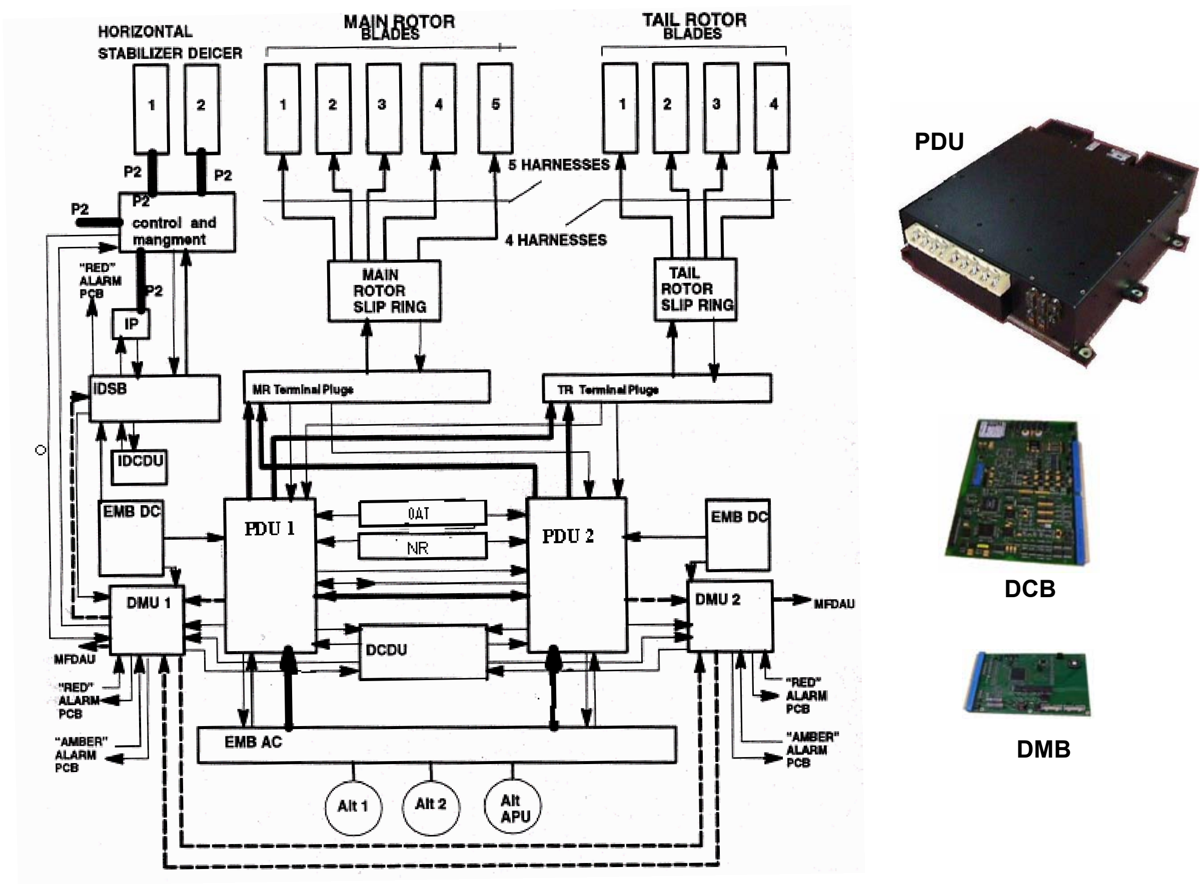

Photo ARTUS

Figure 6 : EC225 IPS architecture & PDU equipment

This architecture is based on core equipment called PDU (Power De-icing Unit, see Fig.6). Two of them are used to make the power transformation and distribution to the main and tail rotor blades heating mats.

Each PDU includes a monitoring board (DMB) and a controlling board (DCB). The DMB is centered on a PLD device and has been developed following the DO254 level B while the DCB is operating a microprocessor with C software developed under DO178 B level B. The maximum partitioning associated to dissimilarity and independence of DCB/DMB allows demonstration of a DAL A system in respect of ARP4754 as combined with a Common Cause Analysis performed down to the single component level.

The power is then delivered to the blades through a main and a tail rotor slip ring equipped with and enhanced brush ring technology (see Fig.7). They both includes a specific health monitoring to detect automatically they have reached the level of wear for which the overhaul is required. This monitoring permits to avoid a periodic overhaul and to wait until the real usage limit of the equipment is reached.

Photos Eurocopter

Figure 7 : Tail and Main slip rings and harnesses

The power then goes into the main and tail rotor harnesses (see Fig.7), specifically designed to meet high level of reliability. Both main and tail rotor harnesses have followed 2000h of endurance tests (based on the aircraft flight spectrum) on rotative test benches fully representative of the blades displacements and rotors speeds in a climatic chamber to apply a conservative low temperature spectrum. Those endurance tests have been applied to brand new harnesses, harnesses after humidity ageing and harnesses with seeded faults to check cracks propagation.

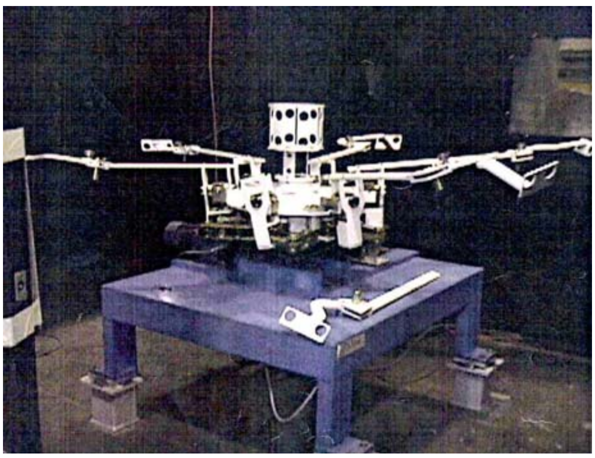

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Figure 8 : Main rotor harness test bench

Eventually, the power enters the main rotor blades de-icers and the tail rotor blades anti-icers (see Fig.9). The main blades incorporate 7 heating mats around the leading edge that are dual connected and powered cyclically with an activation and rest sequence based on OAT. The tail rotor blades incorporate 4 heating mats around the leading edge that are series connected and powered continuously through a pseudo periodic sequence also dependent on OAT.

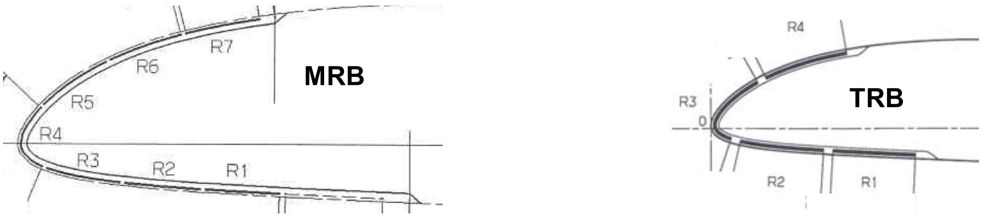

Figure 9: EC225 Main and Tail Rotor Blades heating mats

The de-icers/anti-icers are then substantiated as critical parts within the blades substantiations. They have both followed series of thermo-mechanical fatigue tests (see Fig. 10) in order to adapt the blades resistance coefficient when fitted with their ice protection and to rework the fatigue and static substantiations. Thermo mechanical tests have been performed either on samples or on real blade sections with thermal cycling and stress cycling representative of the maximum flight levels. As a result the calculations based on the different aircraft flight spectrum have led to service life compatible with the high level of reliability required for the main and tail rotor blades.

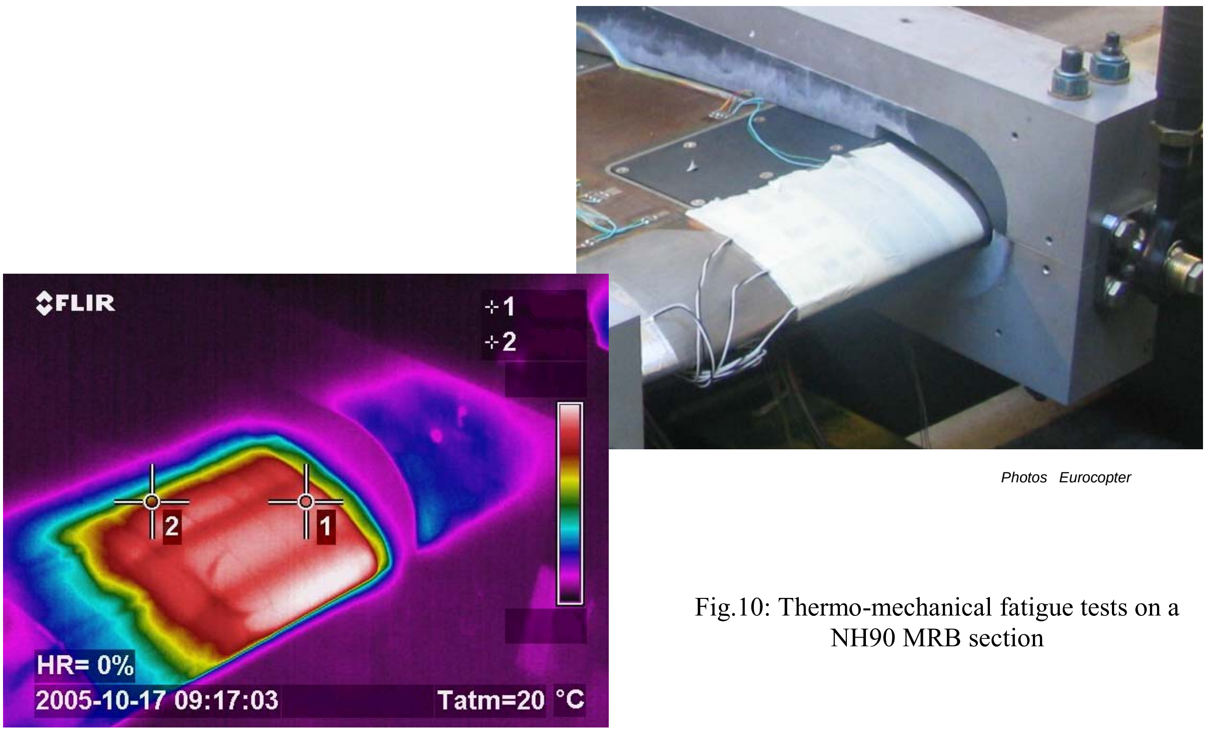

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Fig.10: Thermo-mechanical fatigue tests on a NH90 MRB section

4. ICING FLIGHTS

Flights in icing conditions are of major importance regarding aircraft and system substantiations. Among the several objectives of the flights, the most difficult is to find and collect as much different icing conditions as possible and as near as possible to icing envelops limits. Such type of tests require very accurate meteorological forecasts but also flight areas where the aircraft can fly around with as less air traffic constraints as possible. In addition, flight tests profiles may be quite different when looking for system efficiency, aircraft performances, handling qualities or loads, while icing conditions may be very unstable.

For that purpose, 3 icing tests campaigns have been found necessary on very different places such as Orléans/FRANCE, Bergen/NORWAY or Manching/GERMANY for both aircrafts.

During those flights the aircraft were fitted with the following icing instruments (see Fig. 11) in order to perform the characterization of the encountered icing conditions:

- a Johnson-Williams (JW) probe for LWC measurement
- a CSIRO-KING probe for LWC measurement
- a Forward Scattering Spectrometer Probe (FSSP) with Extended Range (ER) from 1.0 to 95.0 µm for MVD measurement (and LWC indirect calculation).
- A fixed probe for ice accretion thickness measurement (and LWC indirect approximation).

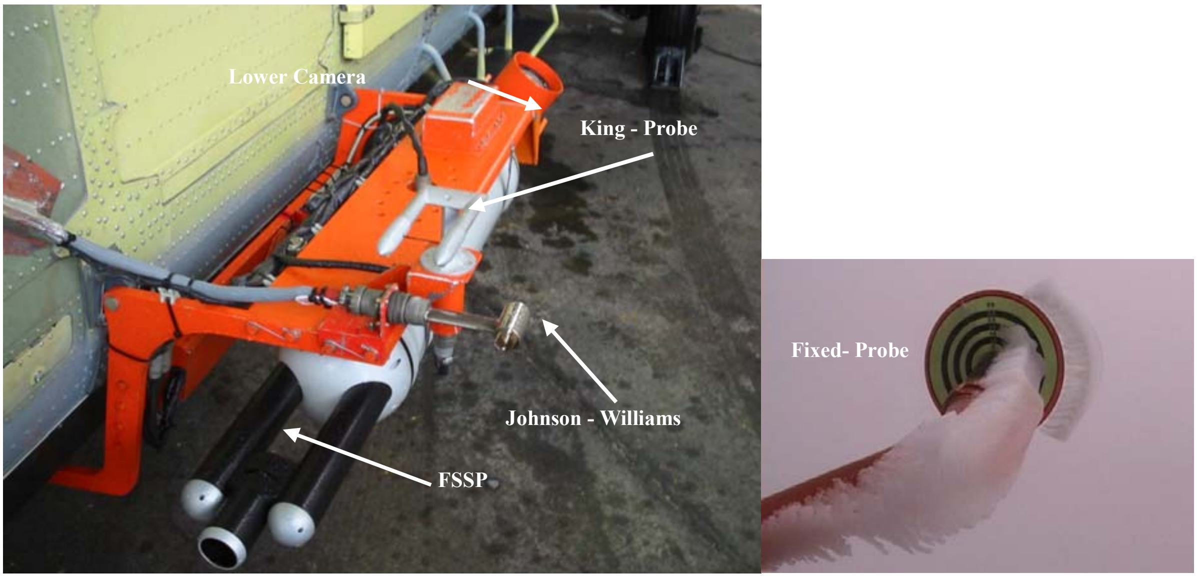

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Figure 11: Icing instruments on EC225 and NH90 aircrafts

In addition, to provide complementary analysis of ice accretion and protections efficiency, a series of video camera were installed on several locations onto the aircrafts (see Fig.12). One of them was installed on top of the main rotor head on a rotating and ice protected bracket to overlook at the upper side of the main rotor blade. Two other ones were located on the aircraft fuselage but synchronized on the main and tail rotors speeds in order to get the inner face of the main rotor blade and the outer face of the tail rotor blades. Then, several others were fitted onto the aircraft at places where it was of interest to follow up the ice accretion or any ice shedding phenomenon.

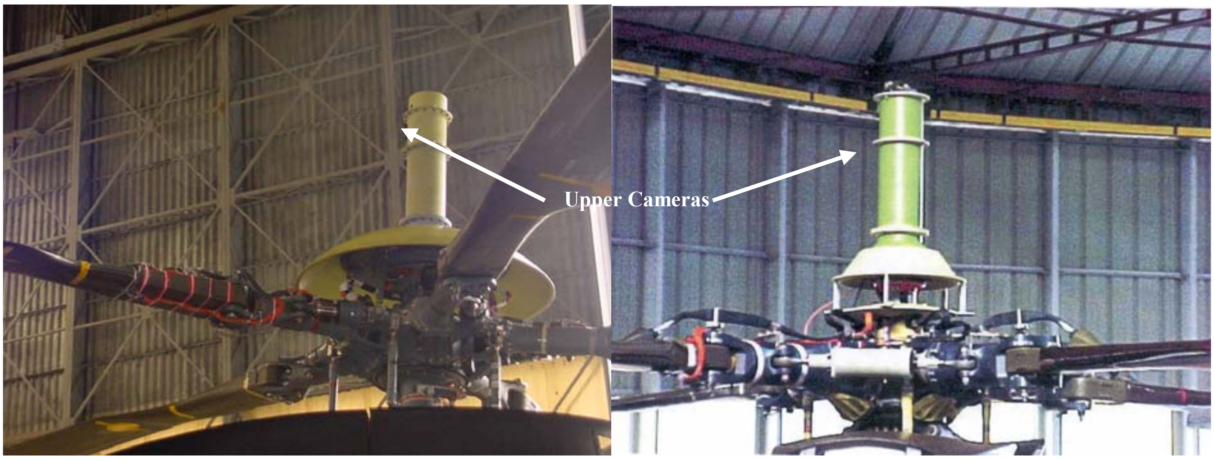

Figure 12: Vidéo-Cameras on EC225 and NH90 aircrafts

Main and Tail rotor blades were fitted with thermo sensors on all heating mats at several span wise location and strain gages at locations where the maximum efforts apply.

Temperature and stresses were monitored in conjunction with all aircraft and engines flight parameters in order to differentiate all flight phases and to separate the effects of aircraft parameters such as attitude or speeds from the effects of icing conditions.

First, flights in dry air were performed at different aircraft altitudes (including aircraft ceiling) and speeds with blades inner temperature measurement to check that limit temperature of the blades materials were not reachable for all de-icing or anti-icing sequences and within the whole atmospheric and aircraft flight envelops (see Fig.13).

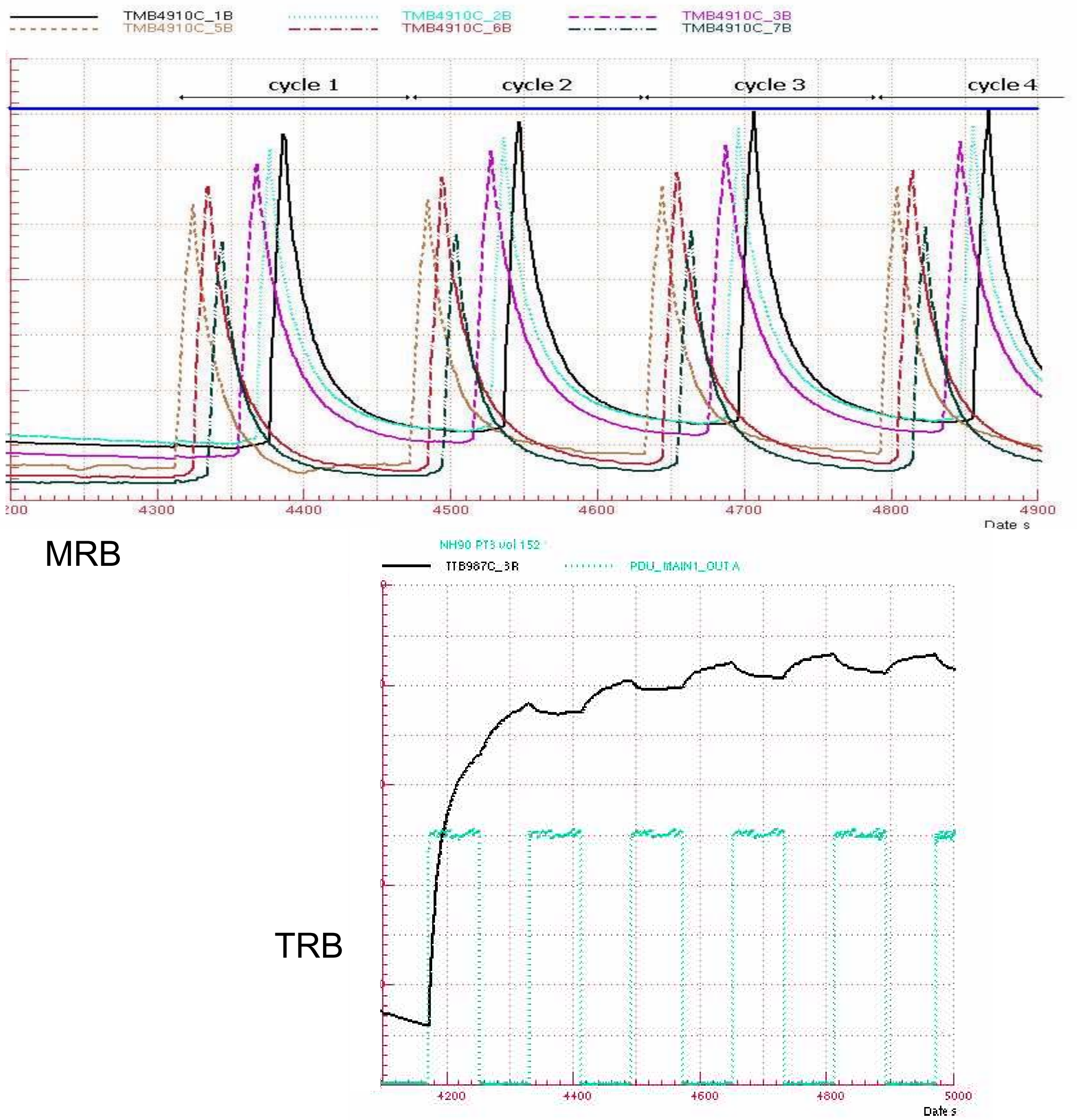

Figure 13: Blades temperature measurements during flights in dry air

Then, flights in natural icing conditions were started in order to check the efficiency on the blades protections and the effects of icing conditions on the aircrafts. All the tests measurements were samples by flight phases where icing conditions and aircraft parameters were stable enough and of interest regarding the icing envelop in order to progress into deeper analysis.

All the raw data of icing measurements corresponding to the selected flight phases were transferred to a laboratory specialised in the analysis of icing measurement and in the microphysics of ice formation within the clouds. This independent laboratory called LAMP (Laboratoire Associé de Météorologie Physique) performed the in depth analysis of the different probes measurements in order to filter those measurements that might have been affected by the icing conditions themselves (ie icing of the sensing element, intrusion of ice crystal within the measurement, etc…). Once filtered from those instrument anomalies or clouds unexpected characteristics, the different phases with their corrected icing measurements were transferred back to Eurocopter specialists in order to proceed into the in depth analysis of their effects on the aircraft. Some of the most interesting icing conditions are presented in the Fig.14.

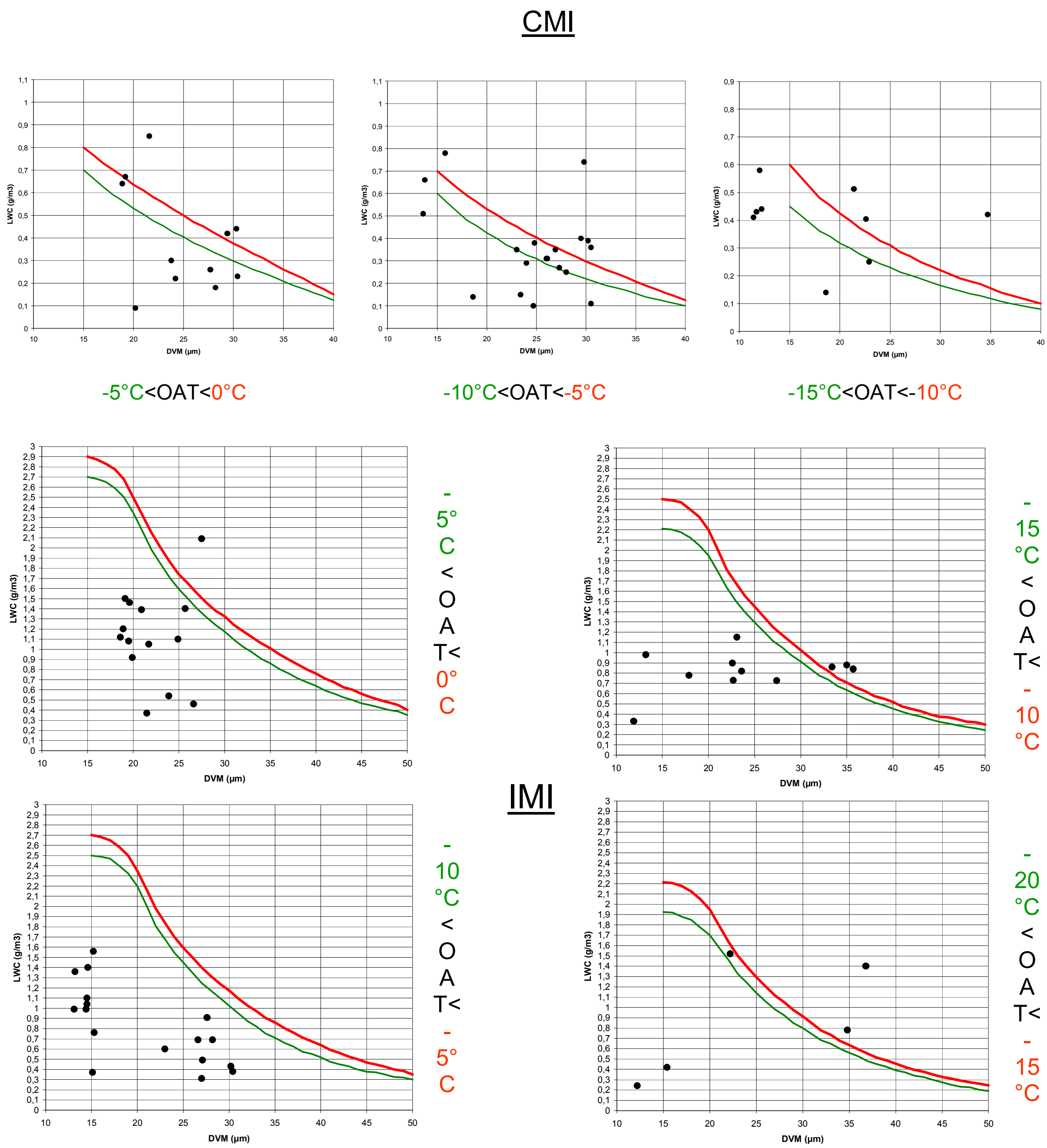

Figure 14: Natural Icing conditions compared to icing envelops CMI/IMI per OAT ranges.

All those measurements are then analysed back into raw data in order to perform the efficiency analysis of the blades protections, the aircraft performance analysis, the loads and the ice shedding analysis. For instance, in the frame of the efficiency analysis, corrected icing conditions are then compared with their effects on the aircraft main rotor torque and with the main rotor blade de-icers temperatures in order to confirm the ice has been shed off the blade during power on sequences (see Fig.15). The other aircraft parameters are also used in order to differentiate their effect from the icing effect on the main rotor torque.

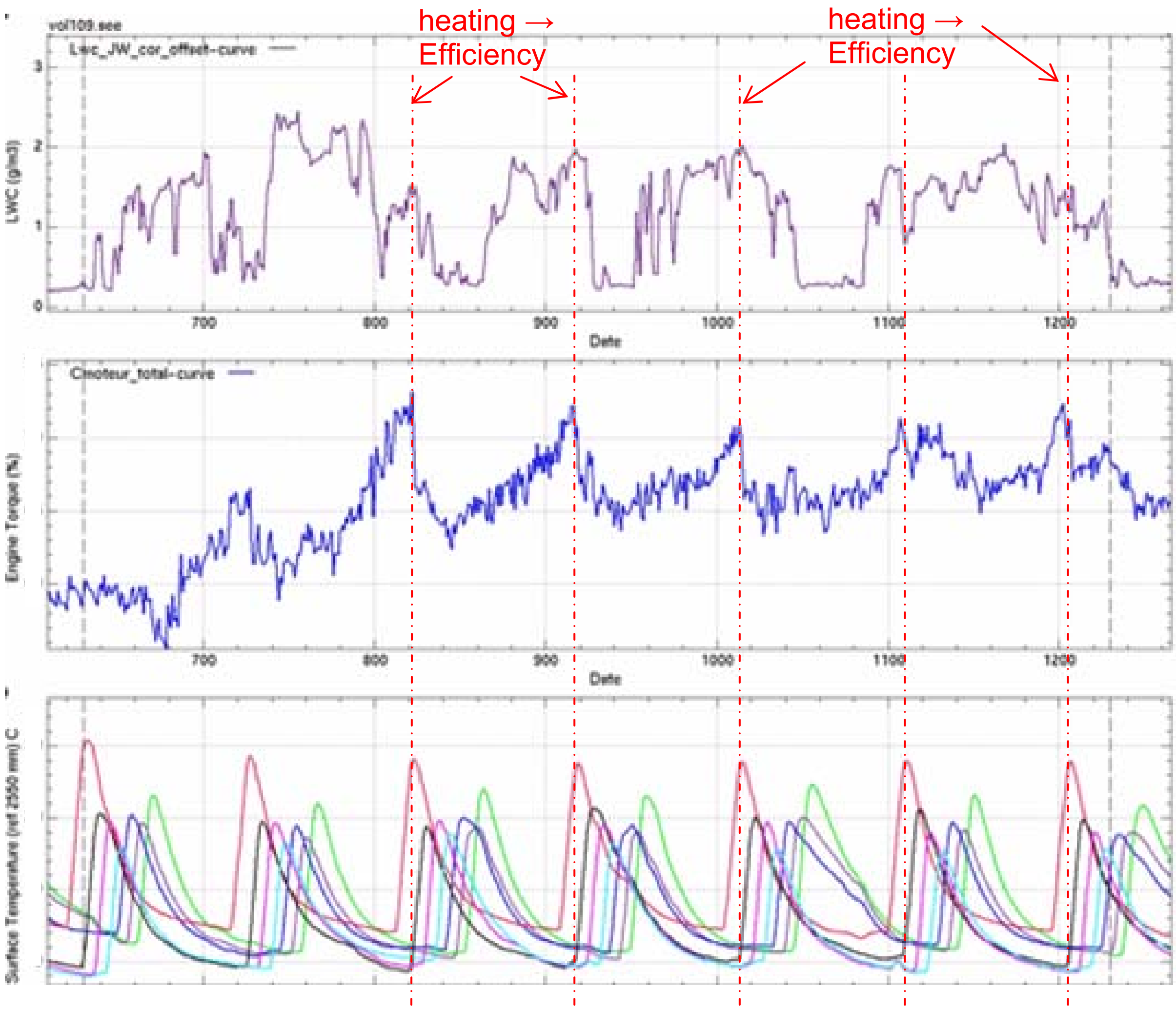

Figure 15: Analysis of main rotor de-icing efficiency during one flight phase.

In addition, raw data measurements are compared with video camera acquisitions for a visual assessment of blades deicing (see Fig.16).

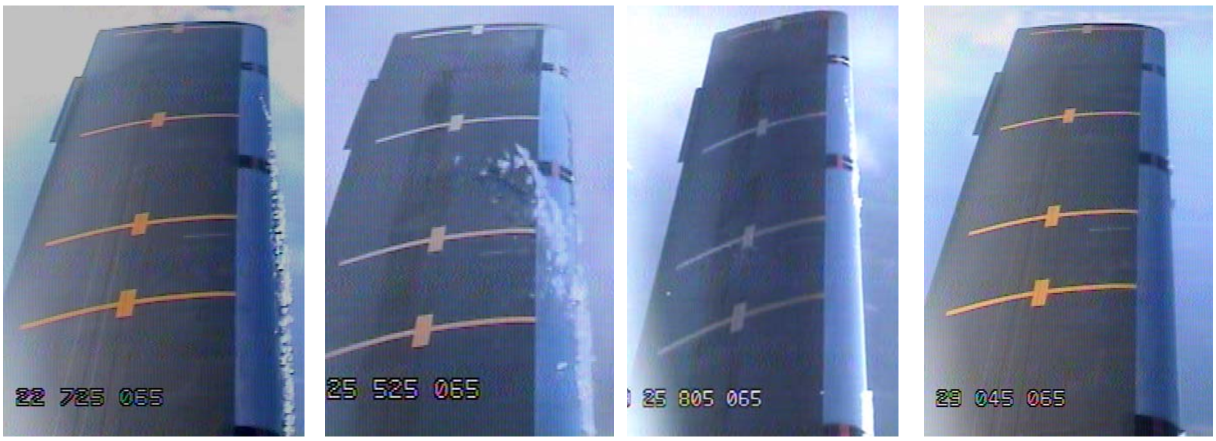

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Figure 16: De-icing sequence viewed from Upper Blade Camera.

On the other hands, for instance within the loads analysis, the raw data are reworked differently to get the measurements of stresses in stabilized aircraft flight sequences and select the maximum values associated to icing conditions.

All those analysis allowed to assess the aircraft flight into known icing conditions within the icing conditions encountered in flights. In order to extend those icing conditions to the limits of the icing envelops required, series of icing tests in wind tunnel have been performed.

5. ICING TESTS IN WIND TUNNELS

Extensive campaigns of tests in icing wind tunnels have been performed on main and tail rotor blade models made of different span wise section (including tip) of each blade at scale one.

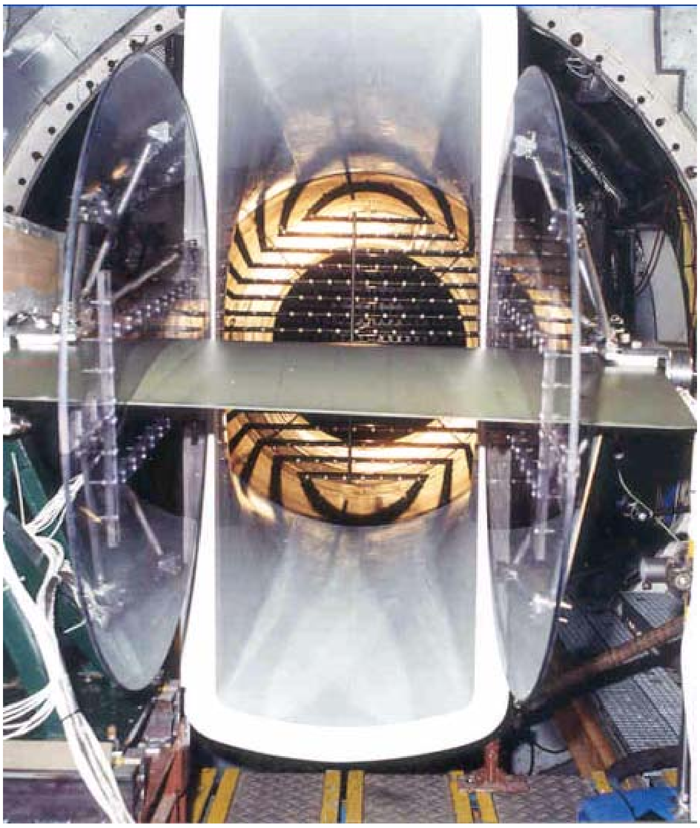

Photo CEPr

Figure 17: EC225 MRB Specimen in icing wind tunnel at CEPr (DGA Aero-engine Testing)

Icing wind tunnel tests have been selected for the following reasons:

- Calibration of each facility can be achieved accurately (SAE ARP5905 criteria + spatial uniformity) within the complete range of icing parameters (OAT, LWC, MVD, Humidity, droplets T°, airspeed, altitude) and then well stabilized/monitored during tests

- Adding an aerodynamic balance system associated to an aerodynamic calibration of the tested blade airfoil within the icing chamber allows to estimate aerodynamic performance degradation of the airfoil due to ice accretion (IPS ON, failure cases or IPS OFF) and then to classify conditions in between together.

- Lack of centrifugal effort leads to a conservative approach with regards to all effects (efficiency, performance, ice shedding, …)

Hundreds of tests have been performed:

- to cover the full icing envelops and to identify the effects of the influencing parameters (OAT, LWC, MVD, Alt),

- at several speeds necessary to rebuild the complete blade profile performance degradation

- in different conditions of protection behavior such as IPS OFF, IPS ON or simulated failure of some heating mats to compare their effects on the protection efficiency, the performance degradation and the ice accumulation or shedding.

During those tests, blade inner materials and surface temperature were recorded from temperature probes located inside the heating mats or on the leading edge, ice accretion on the inner and outer faces of the blades models were monitored trough video-cameras located at different view angles, allowing the confirm the efficiency of the de-icing or anti-icing sequence (see Fig.18).

Lower side view of main blade profile specimen

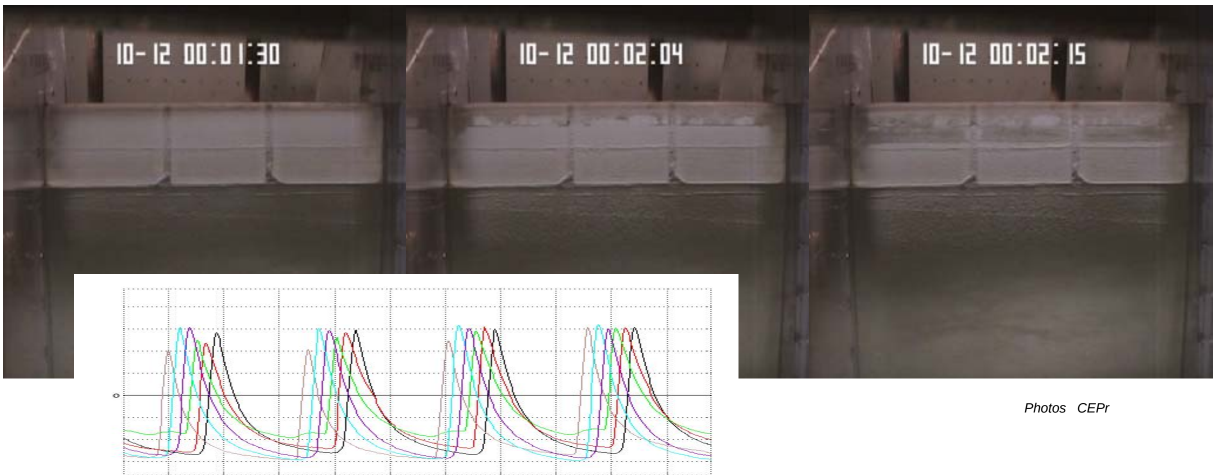

Figure 18: Efficiency substantiation down to -30°C: visual check and surface T° control.

Performance classification for IPS ON, failure cases as well as IPS OFF was done using an iced rotor “blade element” model (HOST [1]), built by substituting the polar curves of the iced blade measured in wind tunnel tests to the ones of the dry air airfoils in the EC225 isolated main rotor reference model (see Fig.19).

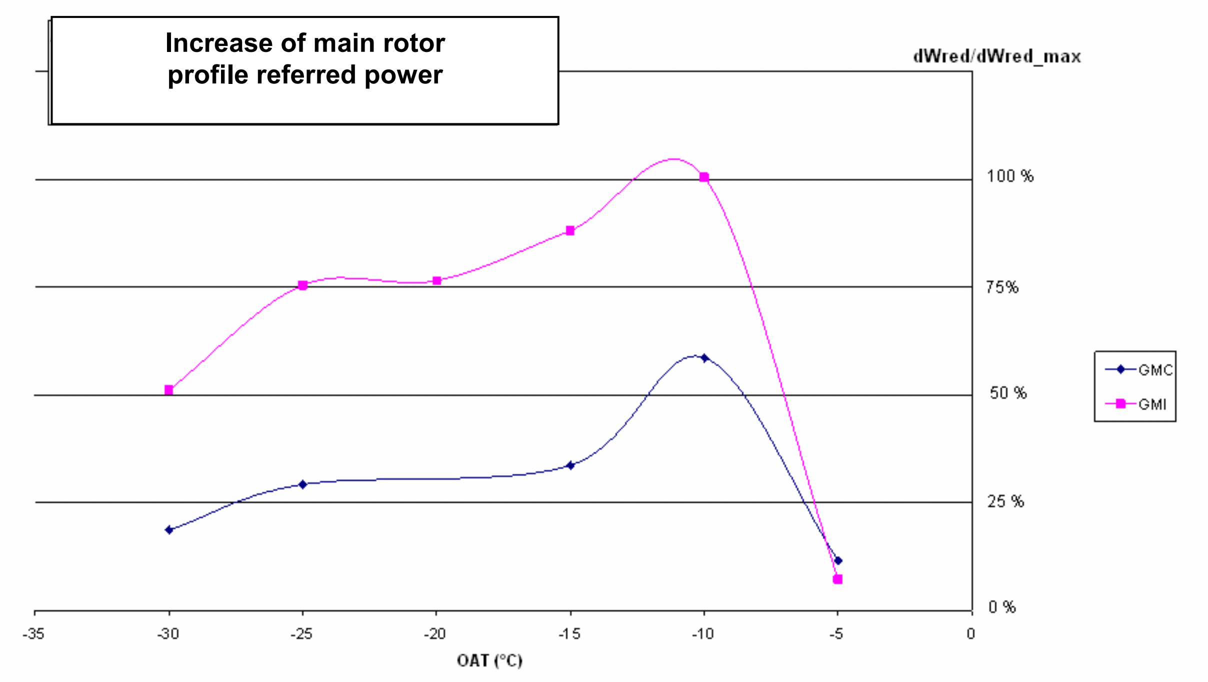

Figure 19: Performance comparison between CMI and IMI conditions.

This classification allowed to extend (when necessary) the flight measurements of performances and dynamic loads to the icing conditions that have not been encountered in flights.

During all the tests ice shapes were video monitored and at the end of them during cold stops the remaining ice shapes where measured and weighted (see Fig.20). From those measurements and with the help of strength analysis of the ice, conservative values of maximum ice shedding have been estimated in order to make the assessment of the maximum unbalance level within the vibration substantiation. This maximum unbalance level was also considered for the establishment of the limits loads within the static stress substantiation.

Figure 20: Ice shapes recording.

6. ICE SHEDDING HAZARD ANALYSIS

The ice shedding substantiations is performed in 3 phases:

- Evaluation of ice accretion on all protuberant helicopter parts
- Trajectory analysis of ice lumps
- Blades tolerance to ice lump impacts

The evaluation of ice accretion is done either by means of 2D computations using ONERA codes or with the help of ice accretions recorded from flights in natural icing conditions (see Fig.21).

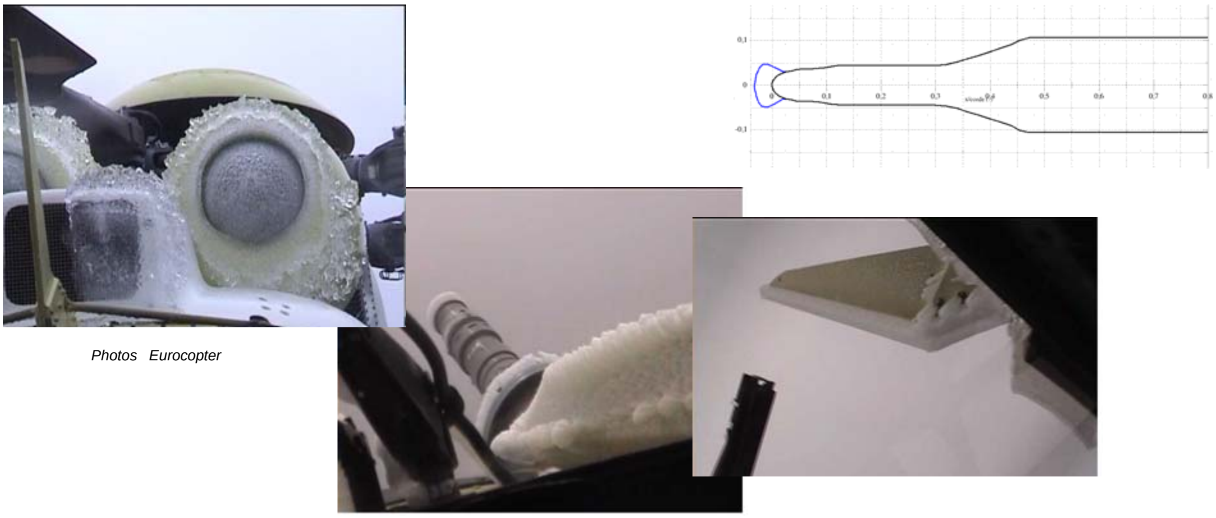

Figure 21: Ice accretions on protuberant parts.

A complete zoning of the aircraft is thus provided regarding the potential ice accretion with respect to their ice collection characteristics and possible mask effects from forward helicopter parts.

This zoning is then analysed in terms of potential shedding of ice and risk of impact with the critical parts of the aircraft such as blades. For those locations where ice shedding may impact the main and tail rotor blades, a series of trajectory computation within the full range of aircraft speeds and attitudes allows to determine possible area of impact with the blades as well as maximum weight of the ice lumps (see Fig.22).

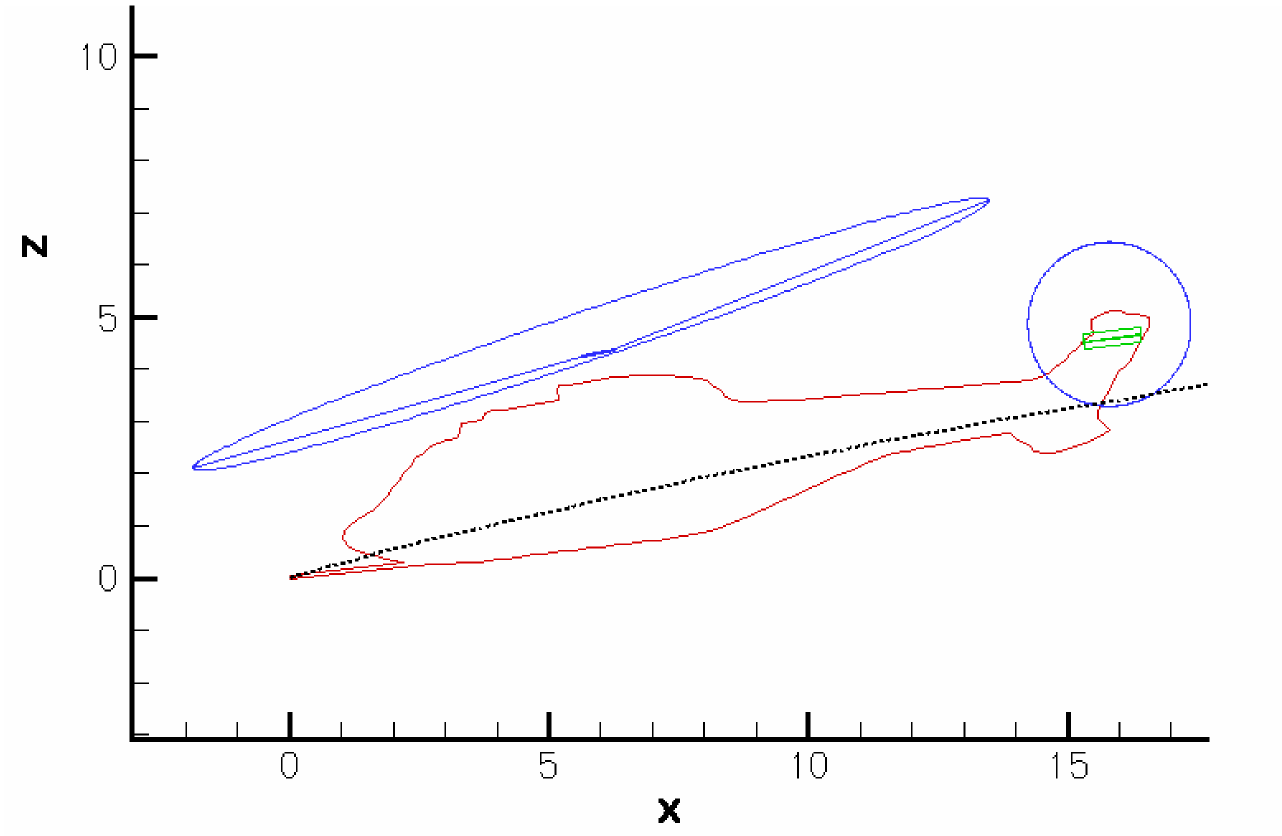

Figure 22: Example of ice lump trajectory.

On another hand, the blades tolerance to ice lump impacts is established by experience of different impacts in service on similar blades and by additional tests of impact. For instance, an EC225 main rotor blade has been tested with impact of conservative ice lump of a cubic shape (sides of 7cm, impact on a sharp angle) at the maximum ice density, with the most penalising speed and angle of attack (see Fig.23). The blade model has then be tested in fatigue at the maximum level of the aircraft flight spectrum to check that there was no damage propagation in order to substantiate that any flight can be ended safely.

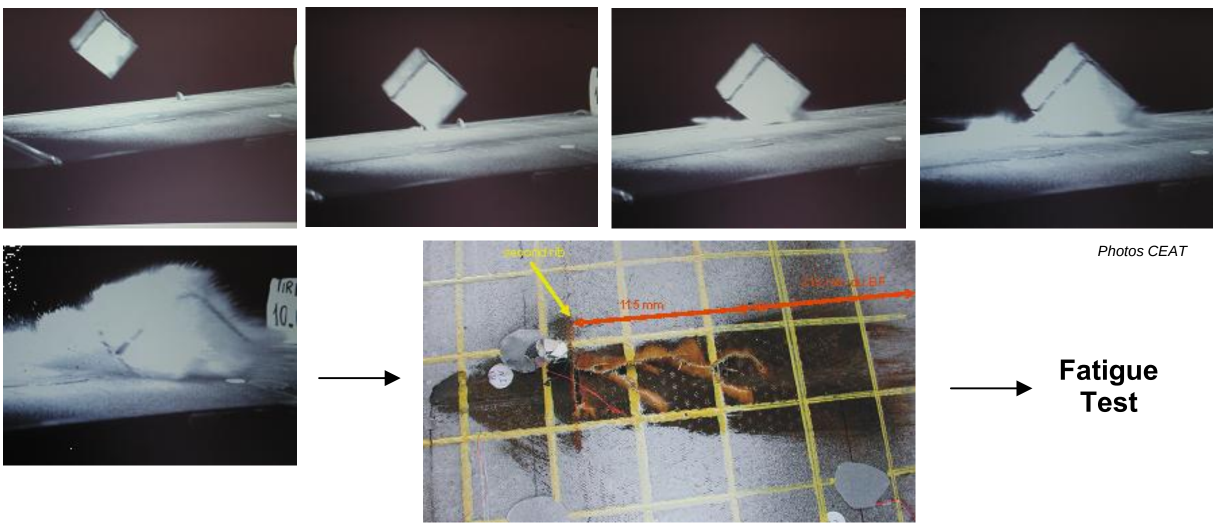

Figure 23: .Ice impact on the EC225 main rotor blade

Thus by showing that the blade damage tolerance always cover all possible impact resulting from the trajectory analysis, the ice shedding hazard substantiation is then fulfilled.

7. CONCLUSIONS

Thanks to all substantiations provided, the EC225 has been successfully certified by EASA for flight in known icing conditions without restrictions on the 24/08/2005 (R.C.01136) while NH90 qualification is on the track.

Thanks to the huge amount of data collected from either:

- hundreds of flight hours in natural icing conditions
- several campaigns of icing wind tunnel tests
- numerous fatigue and thermal tests

several research programs are then in progress or in preparation looking for modelling tools improvement (airfoil 2D/3D modelling of ice accretion, aerodynamic performance, de-icing/anti-icing efficiency, air duct and grid 3D icing models, finite element models combining thermal effect and stresses, …) with the objective of reducing the cost of testing activities.

8. REFERENCES

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