Dedicated to innovation in aerospace

NLR-TP-2017-098 | March 2017

Icing Certification of Korean Utility Helicopter KUH-1

Artificial Icing Flight Test

CUSTOMER: Netherlands Aerospace Centre

NLR – Netherlands Aerospace Centre

Netherlands Aerospace Centre

NLR is a leading international research centre for aerospace. Bolstered by its multidisciplinary expertise and unrivalled research facilities, NLR provides innovative and integral solutions for the complex challenges in the aerospace sector.

NLR's activities span the full spectrum of Research Development Test & Evaluation (RDT & E). Given NLR's specialist knowledge and facilities, companies turn to NLR for validation, verification, qualification, simulation and evaluation. NLR thereby bridges the gap between research and practical applications, while working for both government and industry at home and abroad.

NLR stands for practical and innovative solutions, technical expertise and a long-term design vision. This allows NLR's cutting edge technology to find its way into successful aerospace programs of OEMs, including Airbus, Embraer and Pilatus. NLR contributes to (military) programs, such as ESA's IXV re-entry vehicle, the F-35, the Apache helicopter, and European programs, including SESAR and Clean Sky 2.

Founded in 1919, and employing some 650 people, NLR achieved a turnover of 71 million euros in 2016, of which three-quarters derived from contract research, and the remaining from government funds.

For more information visit: **www.nlr.nl**

Dedicated to innovation in aerospace

EXECUTIVE SUMMARY

UNCLASSIFIED

Icing Certification of Korean Utility Helicopter KUH-1

Artificial Icing Flight Test

REPORT NUMBER
NLR-TP-2017-098

AUTHOR(S)
S.C. van 't Hoff
J. van der Vorst
R.J. Flemming
D.C. Parkins

REPORT CLASSIFICATION
UNCLASSIFIED

DATE
March 2017

KNOWLEDGE AREA(S)
Helicopter Technology
Military Airworthiness

DESCRIPTOR(S)
Icing
Certification
HISS

Problem area

Artificial icing flight testing using the US Army Redstone Test Center (RTC) Helicopter Icing Spray System (HISS) to support the military qualification for flight into icing conditions of the Korean Utility Helicopter KUH-1 Surion.

Description of work

Flight testing took place out of Sawyer International Airport in Marquette, MI, over a period of four months in the 2015/2016 winter season. The artificial icing flight test campaign was aimed at opening up the icing flight envelope in a controlled and safe manner, prior to flight testing in natural icing conditions. The KUH-1 artificial icing flight test campaign was completed successfully in February of 2016.

Results and conclusions

The aircraft has been tested up to the limits of its certification icing envelope and beyond. In total 56 individual test points have been recorded, subjecting the aircraft to the full range of icing conditions for which operational approval is requested. Test points flown at temperatures colder than -20°C and with ambient relative humidity greater than 40% produced less ice accretion and a lower icing torque rise than expected.

Applicability

This report describes the test procedures used for helicopter artificial icing flight testing aimed at the qualification/certification for flight into icing conditions.

GENERAL NOTE

This report is based on a presentation held at the AIAA Aviation Forum, Denver, Colorado, 5-9 June 2017.

NLR
Anthony Fokkerweg 2
1059 CM Amsterdam
p) +31 88 511 3113 f) +31 88 511 3210
e) info@nlr.nl i) www.nlr.nl

Dedicated to innovation in aerospace

NLR-TP-2017-098 | March 2017

Icing Certification of Korean Utility Helicopter KUH-1

Artificial Icing Flight Test

CUSTOMER: Netherlands Aerospace Centre

AUTHOR(S):

S.C. van 't Hoff	NLR
J. van der Vorst	NLR
R.J. Flemming	Aviation Icing Consultant
D.C. Parkins	American Kestrel Co., LLC

NLR - Netherlands Aerospace Centre

This report is based on a presentation held at the AIAA Aviation Forum, Denver, Colorado, 5-9 June 2017.

The contents of this report may be cited on condition that full credit is given to NLR and the authors.
This publication has been refereed by the Advisory Committee AEROSPACE VEHICLES.

CUSTOMER	**Netherlands Aerospace Centre**
CONTRACT NUMBER	**-----**
OWNER	**NLR**
DIVISION NLR	**Aerospace Vehicles**
DISTRIBUTION	**Unlimited**
CLASSIFICATION OF TITLE	**UNCLASSIFIED**

APPROVED BY :		
AUTHOR	**REVIEWER**	**MANAGING DEPARTMENT**
S.C. van 't Hoff Approved	J. van der Vorst Approved	J.F. Hakkaart Approved
DATE	DATE	DATE

Summary

In support of the military qualification for flight into icing conditions of the Korean Utility Helicopter KUH-1 Surion, Korea Aerospace Industries, Ltd. (KAI) and the Netherlands Aerospace Centre (NLR) have conducted artificial icing flight trials using the US Army Redstone Test Center (RTC) Helicopter Icing Spray System (HISS). Testing took place out of Sawyer International Airport in Marquette, MI, over a period of four months in the 2015/2016 winter season. The artificial icing flight test campaign was aimed at opening up the icing flight envelope in a controlled and safe manner, prior to flight testing in natural icing conditions. Despite unfavourably warm weather conditions, the KUH-1 artificial icing flight test campaign was completed successfully in February of 2016. The aircraft has been tested up to the limits of its certification icing envelope and beyond. In total 56 individual test points have been recorded, subjecting the aircraft to the full range of icing conditions for which operational approval is requested. Test points flown at temperatures colder than -20°C and with ambient relative humidity greater than 40% produced less ice accretion and a lower icing torque rise than expected.

Contents

1 Introduction

The Korean Utility Helicopter KUH-1 is being qualified for flight in icing conditions. The KUH-1 has been developed by Korea Aerospace Industries, Ltd. (KAI), with technical support from Airbus Helicopters, formerly Eurocopter. The Ice Protection System (IPS) is based largely on technologies and systems proven on other aircraft having civil certification or operational approval for flight in icing. Artificial and natural icing flight testing has been performed in the 2015/2016 winter season in the Great Lakes area of Michigan. KAI contracted with the Netherlands Aerospace Centre (NLR) for icing expertise and technical support throughout the test campaign. The multinational NLR-KAI test team included icing specialists employed by and under subcontract with NLR, as well as KAI flight test pilots, maintenance crew, engineering, and program management. Representatives of both the Korean military airworthiness authority and Ministry of National Defense were present on-site during the entire test campaign. The team also included US Army staff from Redstone Test Center (RTC) who operated the Helicopter Icing Spray System (HISS) tanker and RC-12G King Air chase plane.

2 Background

2.1 Design icing envelope

The KUH-1 has been designed to operate in icing conditions I and II as defined in Table I of DEF STAN 00-970 Part 7/3 Section 7 Leaflet 711/2, subject to a Periodic Maximum Icing (PMI) Liquid Water Content (LWC) limit of 1.0 g/m^3. DEF STAN specifies a single design drop size distribution that corresponds to a Median Volume Diameter (MVD) of 20 µm. The DEF STAN Continuous Maximum Icing (CMI) LWC envelope is identical to the 15 µm CMI envelope defined in 14 CFR Part 29 Appendix C.

To maximize the productivity of the flight trials, the test matrix included additional points for rotor testing in the 10,000 ft altitude-limited AC 29-2C Appendix C Intermittent Maximum Icing (IMI) envelope. Figure 1 presents the selected test envelope, as well as a summary of the test conditions that were achieved over the duration of the test campaign.

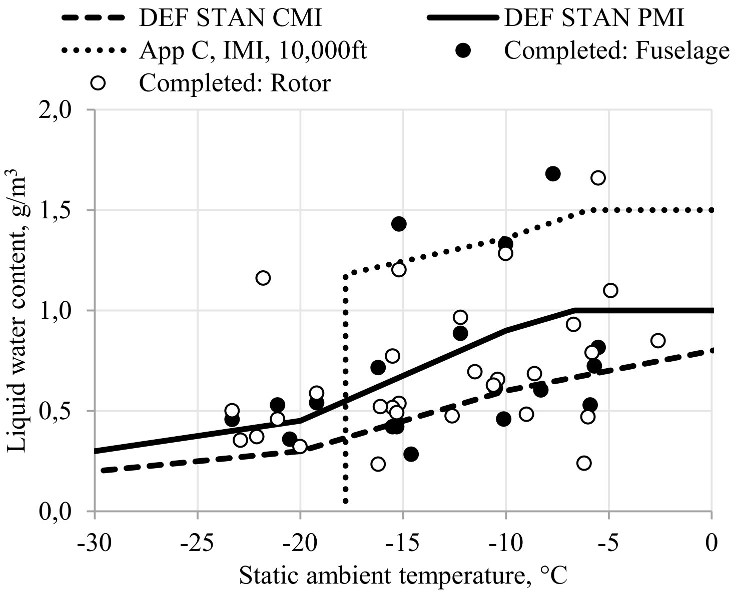

Figure 1. KUH-1 artificial icing test envelope. Test conditions as reported by RC-12G. Appendix C IMI envelope included for reference.

2.2 Aircraft description

Flight testing has been performed with prototype A/C #1, in the Republic of Korea Army (ROKA) Primary Mission Configuration. Test instrumentation included surface and embedded temperature sensors, High Definition video cameras and a Droplet Measurement Technologies (DMT) Cloud Combination Probe (CCP) for cloud characterization. High speed video camera images of the main and tail rotors were obtained from a camera mounted on the tail boom. An overview of the KUH-1 IPS is presented in Fig. 2.

Figure 2. KUH-1 ice protection system. Overview of ice protected systems installed on test aircraft.

A mock-up of the prospective rescue hoist intended for the Search and Rescue variant of the KUH-1 was mounted on the starboard side of the aircraft. Although not geometrically exact, the mock-up replicates the shape and location of the main accretion sites and can, therefore, be used to assess ice thicknesses, shed trajectories and the effects of drop sorting.

Since it is a part of the Primary Mission Configuration, most testing was performed with the Infrared Suppressor (IRS) installed. The IRS deflects the warm engine exhaust gasses upwards into the main rotor plane in order to reduce the infrared signature of the aircraft.

Part of the testing was performed with heater coils imbedded at the upper rim of the windshield (referred to as the windshield eyebrows). The heaters were installed prior to the start of the campaign as a risk reduction strategy, protecting against the formation of windshield runback ice that may pose a threat to the engines. Once it was determined that the runback ice accretion was well within engine limitations, the eyebrow ice protection was removed.

The Rotor Ice Protection System (RIPS) protects the leading edge of the main and tail rotor blades against the effects of icing. The RIPS power cycle schedule (on-time and off-time) is based on data obtained from the production aircraft static temperature probes and an accretion-based ice detector. The engine is protected by bleed-air anti-icing and electrothermal anti-icing of the air intakes. The deflector and support struts of the upper wire cutter are fully anti-iced. The static temperature probes and horizontal tail plane, including slat, are unprotected; ice shapes for the horizontal tail are shown in Fig. 4.

2.3 Prior testing

Whereas the artificial icing flight test marks the first aircraft-level test in icing conditions, multiple systems have been subjected to component-level testing in the earlier development stages. Full-scale non-rotating testing of the tail rotor IPS was performed in the Goodrich (now UTAS) icing wind tunnel in Ohio.

Icing testing of the engine air intakes with simulated engine mass flow was performed in the CIRA icing wind tunnel in Italy in 2012. The wind tunnel model consisted of production intake parts integrated with a mock-up of a substantial part of the forward fuselage, as shown in Fig. 3. Details of the test are provided in Ref. 1.

Figure 3. KUH-1 engine air intake wind tunnel model. Full-scale engine air intake wind tunnel model tested in the CIRA icing wind tunnel.

Figure 4. Computed horizontal stabilizer and slat ice shapes. Critical ice shapes used for simulated icing flight testing of the KUH-1.

The effect of ice accretion on the unprotected horizontal stabilizer was substantiated through simulated ice flight testing. Two critical ice shapes, computed in cooperation with ADSE using LEWICE, were manufactured using 3-D printing methods and bonded to the tail for dry air flight testing. No significant degradation in handling qualities due to the ice shapes in Fig. 4 was observed.

3 HISS testing

3.1 Helicopter Icing Spray System

The Helicopter Icing Spray System (HISS) is part of a modified CH-47D that is operated as a tanker aircraft to generate artificial icing conditions. The HISS can generate icing clouds with a liquid water content between 0.25 g/m^3 and 3.0 g/m^3. At the coldest conditions, the lower limit of LWC is increased in order to avoid freezing the spray nozzles.

The spray bar system is suspended beneath the tanker and is fed by a 1,800 gallon water tank. Two auxiliary power units prevent freezing of the spray boom and provide the hot air supply required to atomize the spray at the nozzles. Two horizontal nozzle arrays generate a spray of approximately 8 ft in height and 36 ft in width.

Figure 5. Helicopter Icing Spray System. RTC HISS tanker with spray boom deployed.

The liquid water content of the spray is controlled by the flow rate supplied to the spray bar. The exact flow rate required to achieve a target LWC depends on the test airspeed and the prevailing ambient condition at the test altitude, most notably on the relative humidity. Icing spray calibration is, therefore, required before each test point. The longitudinal position in the spray needs to be tightly controlled in order to limit the effect of evaporation on LWC and MVD.

The drop size is not directly controlled and depends predominantly on the LWC, ambient relative humidity and temperature. At low humidity, the rate of evaporation of the smaller drops is increased, resulting in higher MVDs. There is also a small drop sorting effect due to gravity. Although it is not an advertised capability of the system, the drop size can increased by running on a single auxiliary power unit. In this case, drop sizes within the range of a Supercooled Large Drop (SLD) encounter can be achieved when the relative humidity is low.

3.2 Test procedure

The artificial icing flights were performed under VFR conditions in close formation between the HISS tanker, the RC-12G chase plane and the KUH-1 test aircraft. The test altitude is established to match the target static temperature and the altitude can vary from 3,000 to 10,000 ft above mean sea level. The selection of the test altitude also takes into account the ambient humidity and turbulence levels. No flights are performed over water, overcast cloud cover or in the presence of precipitation.

Once the HISS tanker has achieved a stable spray at the test airspeed, the chase plane characterizes the icing spray for calibration using wing mounted optical and hotwire probes. The spray calibration includes a vertical sweep, followed by one or more 1-2 minute steady samples. Typically, no more than two samples are required to achieve the desired icing conditions within acceptable tolerances.

When so directed, the test aircraft enters the spray from below and establishes a steady vertical position behind the tanker. The longitudinal position is maintained using station keeping (traffic) lights located at the bottom of the HISS tanker. The spray nozzles form the visual reference for lateral positioning. Cloud immersion is verified by the observers on the chase plane and on the HISS ramp.

Throughout the immersion, the HISS tanker attempts to keep the static ambient temperature within tolerance, executing a slow descent or climb, as required, When changing heading (e.g., to avoid clouds or maintain proximity to the airfield), turn rates are minimized to enable the test aircraft to maintain a steady relative position.

Figure 6. HISS icing spray calibration. RC-12G on station behind the tanker to sample the spray for calibration.

At the end of the immersion, the test aircraft exits the spray and may establish coordinated flight with the chase airplane for photo documentation. In case of rotor test points, the test aircraft may also proceed with the execution of a set of basic mission maneuvers. Accreted ice on the rotors is expected to begin to shed or to sublimate soon after the end of the immersion in the HISS cloud. Therefore, any chance to obtain valid performance or maneuver data can only be obtained if acquired soon after the end of the exposure. The need to expedite the acquisition of post immersion data is even more critical if the ambient temperature is near freezing.

In some cases, large variations in ambient relative humidity are observed along the direction of flight. The effect on cloud density is clearly distinguishable visually and is recognized by the pilots in the test aircraft as a substantial change in outside visibility. Where deemed appropriate, the RC-12G chase plane may take an additional post-immersion data record to quantify the change in icing conditions.

Further details on the standard RTC test procedure are provided in Ref. 2.

3.3 Icing spray characterization

The properties of the artificial icing cloud are not perfectly uniform. In the fore/aft direction the evaporation of small drops directly affects the local LWC and MVD. In the vertical direction the acceleration of gravity causes larger drops to descend faster, resulting in an increase in MVD towards the bottom of the cloud. The cloud is most uniform in lateral direction. The position of the test aircraft in the cloud is presumed sufficiently periodic to average out most of the non-uniformity of the cloud. The statistical mean and standard deviation of the vertical HISS spray profile, as measured by the RC-12G throughout test campaign, is summarized in Fig. 8.

The MVD of the icing spray is heavily influenced by the ambient relative humidity. In dry conditions, the high rate of evaporation results in a spectrum that is biased towards larger drops. However, in conditions where an MVD of around 20 µm has been achieved, the drop size distribution was fairly close to the theoretical DEF STAN spectrum, as shown in Fig. 7. In drier conditions, the higher concentration of larger drops is considered to be conservative as it produces higher water catch and more penalizing impingement limits.

The evaporation of the drops inside the artificial icing cloud also causes a net reduction in the temperature measured inside the HISS spray. This temperature decrement is not taken into consideration when defining the reference test conditions. In fact, the static temperature probe of the RC-12G is not immersed in the icing cloud during cloud calibration. The result is a conservative bias that can be expected to affect the ice accretions observed, particularly near the onset of icing at the warm end of the test envelope.

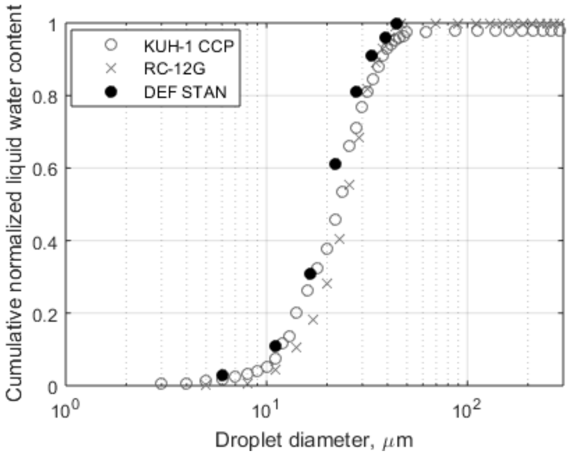

Figure 7. HISS spray drop size distribution. Drop size distribution measured by RC-12G and KUH-1 CCP compared with DEF STAN requirement (LWC = 0.53 g/m^3, MVD = 24.6 µm, RH = 58%).

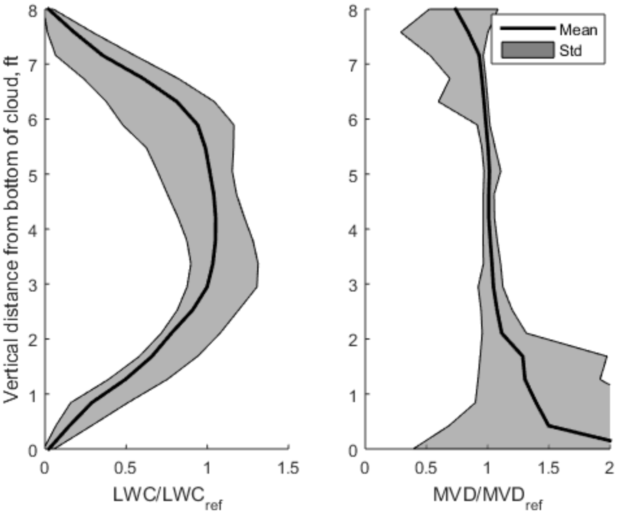

Figure 8. HISS spray vertical profile. Mean and standard deviation of vertical LWC and MVD profiles measured throughout the test campaign, normalized by the reference test conditions reported by the RC-12G.

3.4 Immersion position

Three separate immersion positions have been tested, as shown in Fig. 9. The rotor position effectively immersed the main and tail rotor, as well as the horizontal stabilizer and vertical fin. Dedicated testing of the tail rotor, as well as the installation of the horizontal stabilizer simulated ice shapes was, therefore, deemed unnecessary.

The lower fuselage position resulted in effective icing of the air data probes, windshield, upper wire cutter, and ice detector. Once there was sufficient confidence in the ability of the air data probes to maintain performance in icing, subsequent fuselage test points were flown at the upper immersion position, emphasizing the exposure of the windshield and engine intakes.

The lateral dimension of the icing spray is less than the width of the rotor. To account for this, a centered position is maintained and the LWC is scaled according to

Figure 9. HISS spray immersion position. Relative vertical positions selected for rotor, upper fuselage and lower fuselage icing.

the ratio of the iced radial extent in natural and artificial icing conditions. Due to the kinetic heating of the rotor blade, the iced radial extent and the LWC correction factor are functions of ambient temperature. Effectively, there is no correction in conditions warmer than approximately -8°C, when the iced extent is less than the width of the spray.

4 Test results

4.1 Onset of rotor icing

A single rotor test point was defined at a target static ambient temperature of -2°C. This test was intended to demonstrate a trend towards zero icing torque rise as the kinetic heating of the blades grows large enough to raise the recovery temperature of the leading-edge above freezing. The test was performed at the following conditions:

- Static Ambient Temperature = -2.6°C
- Liquid Water Content = 0.85 g/m^3
- Median Volume Diameter = 34.9 µm
- Ambient Relative Humidity = 43.2 %
- Pressure Altitude = 6400 ft
- True Airspeed = 117 kt

Contrary to expectation, the icing torque rise was found to be comparable to that observed around -5°C. Ice accreted on the main rotor blade up to approximately 60% radius, where an icing extent of around 30% would have been expected[3]. It is believed that, at 43.2% relative humidity, the evaporative cooling inside the artificial icing spray contributed to the increased ice extent and associated torque rise. The test has not been repeated in natural icing conditions to confirm the torque rise observed behind the HISS tanker.

4.2 HISS minimum ambient temperature

The practical minimum ambient temperature for artificial icing testing with the HISS tanker lies around -23°C. At this temperature, the anti-icing capability of the HISS spray boom is marginal and the freezing of one or more of the nozzles becomes a frequent occurrence. In combination with the generally modest liquid water content requirement, these cold conditions tend to produce comparatively small drops, as confirmed by Fig. 10. This trend was exacerbated on this test campaign, because the cold target temperatures were typically only available at an altitude with relatively humid air, close to developing cloud layers. As a result, the HISS spray was often very dense, with the lowest reported MVD as small as 17.7 µm.

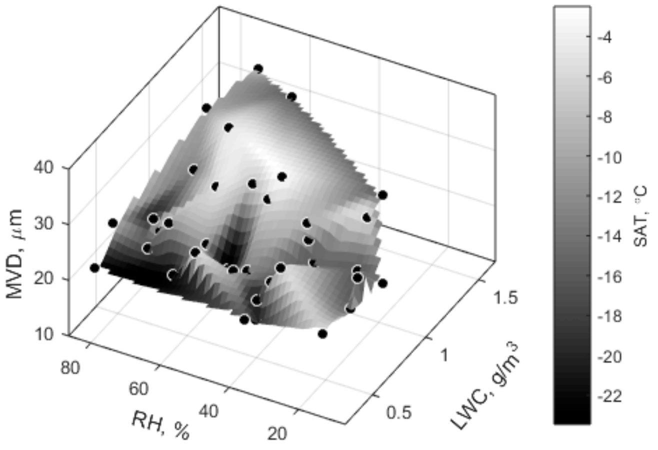

Figure 10. HISS spray dependency on ambient conditions. LWC and MVD achieved throughout the test campaign at different combinations of ambient temperature and relative humidity.

Commensurate with the smaller drop sizes, there was comparatively little ice accretion on unprotected surfaces and a notably reduced icing torque rise. Two 15-minute RIPS OFF rotor tests were performed at these cold conditions, one of which did not produce any noticeable icing torque rise.

For the purpose of illustration, Fig. 11 shows the ice accreted on a thin cylinder, acting as an icing blade, installed on the starboard side of the test aircraft. The ice accretion was documented on the ground after a 100 km HISS spray exposure at -21.1°C ambient temperature, 0.53 g/m^3 liquid water content and 19.3 µm median volume diameter The uniform ice thickness measures less than 1 cm, where a stagnation thickness closer to 5 cm would be expected based on a presumed collection efficiency of 0.9. Not accounting for second order effects such as sublimation and mass loss due to melting, the ice accretion observed is clearly smaller than would be expected. The same is true for the ice accretions seen on other parts of the aircraft.

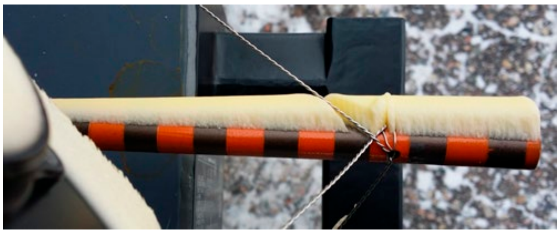

Figure 11. Ice thickness distribution on fuselage-mounted icing blade. Ice thickness documented on the ground after a 100 km HISS spray exposure at -21.1°C ambient temperature, 0.53 g/m^3 liquid water content and 19.3 µm median volume diameter. Marker width = 1 cm.

Eventhough there was no significant concentration of ice crystals apparent in the images recorded by the OAPX probe installed on the RC-12G, there may have been some measure of spontaneous freeze-out of the smaller drops in the spray.

In view of the questionable results obtained with the HISS tanker at conditions colder than -20°C, there has been increased emphasis on this temperature range during subsequent natural icing flight testing. Three extended natural icing encounters colder than -23°C have since produced ice accretions and performance penalties that are in line with the trends observed at warmer conditions.

4.3 Supercooled Large Drop (SLD) cueing

Part 29 aircraft are not certificated for flight in Supercooled Large Drop (SLD) conditions such as freezing drizzle or freezing rain. Instead, it must be demonstrated that the crew can identify an SLD encounter and safely exit the condition. The KUH-1 is not fitted with a dedicated SLD marker. Therefore, the crew is reliant on the ice accretion that forms on standard aircraft features. Typically, SLD cues form due to direct impingement on parts of the aircraft where it normally does not, due to the high inertia of SLD drops and the correspondingly more ballistic trajectory of these larger drops.

The primary requirement for the SLD test condition was to obtain adequate LWC in drops larger than 100 µm, because this allows differentiating between 14 CFR 29 Appendix C drops and the SLD environment. LWC and ambient temperature were not considered critical parameters for this test. The drop size distribution that has been achieved on the SLD test is presented in Fig. 13, which also shows the freezing drizzle spectrum defined in 14 CFR Part 25 Appendix O. Whereas there is no exact agreement with the Appendix O distribution, there is a substantial amount of liquid water in the SLD range, as per the test objective.

Figure 12 presents the ice accretion observed on the windshield and upper windows of the KUH-1 during the SLD test. Although the curved part of the windshield is expected to be a suitable location for the development of a visual SLD cue, the runback ice observed in this area at the high test LWC obscures any direct impingement. Conversely, the ice accretion on the upper window consists entirely of direct impingement and is distinguishable from flights at DEF STAN CMI/PMI conditions by its density and lateral extent. The test pilots have commented that the SLD cue on the upper window is suitable for the operational pilot.

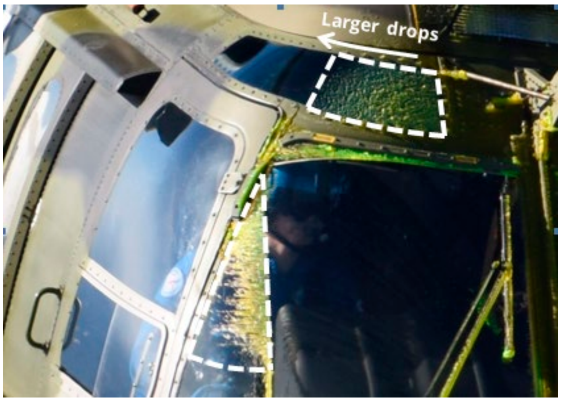

Figure 12. SLD ice accretion. Windshield ice accretion observed in-flight during SLD testing behind the HISS tanker.

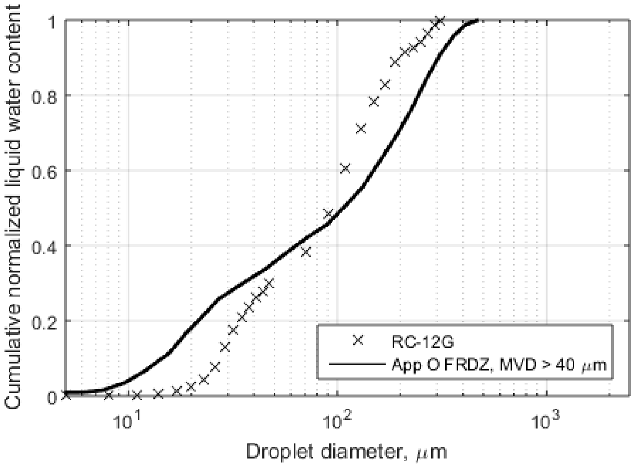

Figure 13. SLD drop size distribution. Drop size distribution measured by RC-12G during SLD test and the 14 CFR Part 25 Appendix O Freezing Drizzle MVD>40µm spectrum.

4.4 Effect of IRS

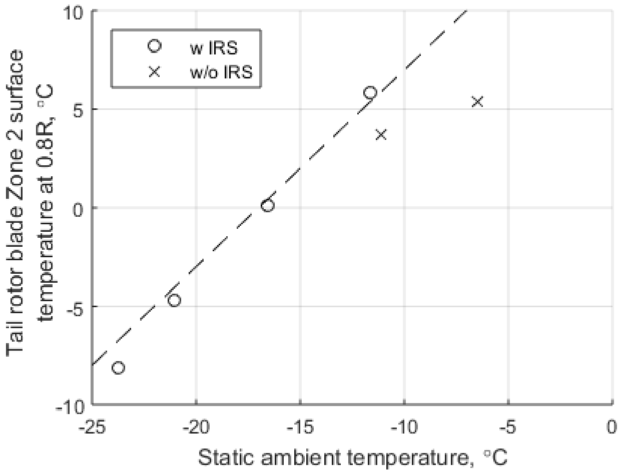

Figure 14 IRS effect on RIPS OFF tail rotor surface temperature. Effect of exhaust gasses deflected by the IRS on the Zone 2 tail rotor blade surface temperature with RIPS OFF.

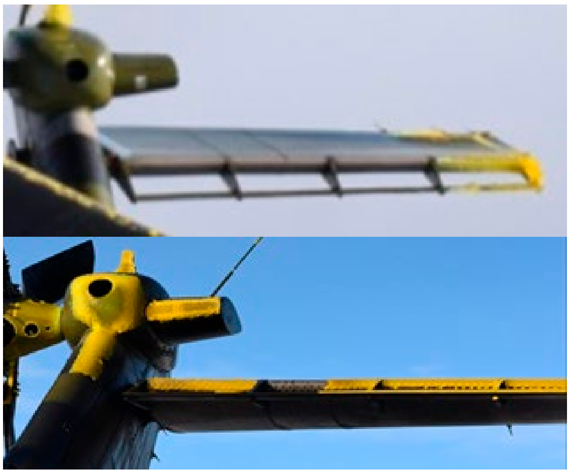

Figure 15 Horizontal stabilizer icing with (top) and without (bottom) IRS. Effect of exhaust gasses deflected by the IRS on the ice accreted on the horizontal stabilizer at -5°C ambient temperature.

The IRS deflects the warm engine exhaust gasses into the plane of the rotor disk in order to reduce the infrared signature of the aircraft. Additionally, the increased frontal area of the IRS introduces a shadowing effect on downstream parts of the aircraft. Prior to testing, there was some debate as to the magnitude of these effects in terms of the icing of the main rotor and tail. Multiple rotor test points were, therefore, duplicated without the IRS installed.

Initial testing with the IRS installed indicated that full span icing of the horizontal stabilizer does not occur until the ambient temperature is colder than -15°C. In contrast, without the IRS, ice accreted over the full span of the stabilizer at the warmest tested condition of -5°C. Because the unprotected horizontal stabilizer was not instrumented with temperature sensors, the temperature increment could not be quantified exactly. An example of the stabilizer ice accretion observed with and without IRS is presented in Fig. 15.

The effect of the IRS on the icing of the tail rotor proved immaterial, since there was no noticeable ice accretion on the rotor blades in either configuration. However, reviewing the average RIPS OFF tail rotor blade surface temperature data presented in Fig. 14, it is clear that the temperature increment at 80% radius may be as high as 5°C.

No noticeable effect of the IRS on the main rotor ice accretion or the icing torque rise has been observed.

5 Conclusion

Despite the record breaking warm temperatures of the 2015/2016 winter season, the integrated test team has executed no less than 42 productive artificial icing flights with the KUH-1 and HISS tanker.

The artificial icing flight tests have been a valuable tool for opening up the icing envelope and demonstrating the capabilities of the KUH-1 ice protection system at the edge of the certification envelope. The HISS tanker tests have also successfully enabled testing of various IPS failures, as well as SLD cueing in a controlled and safe environment.

Figure 16. Test team KUH-1 2015/2016 HISS test campaign. Members of KAI, NLR and RTC test team at Sawyer International Airport, MI.

The HISS test results obtained at -20°C and colder suggest that future testing at these temperatures should take care to avoid conditions with ambient relative humidity greater than 40%. For the KUH-1, the required substantiation in the cold end of the icing envelope has since been successfully obtained through natural icing flight testing.

The authors would like to thank the test team members of KAI, ADD, DAPA and RTC for their dedication to the test program, as well as their company in between testing.

6 References

1. De Bruin, A. C., Fatigani, G. and Shin, H. B., “KAI Surion Helicopter Full-Scale Air Intake Testing at CIRA Icing Wind Tunnel,” 30th Congress of International Council of the Aeronautical Sciences, Daejeon, Korea, September 25-30, 2016.
2. “Test Operations Procedure: Aircraft Natural/Artificial Icing”, US Army Aviation Technical Test Center, TOP 7-3-537, 2009.
3. Flemming, R. J. and Lednicer, D. A., “Correlation of Icing Relationships with Airfoil and Rotorcraft Icing Data,” Journal of Aircraft, Vol. 23, No. 10, 1986, pp. 737-743.

NLR

Anthony Fokkerweg 2
1059 CM Amsterdam, The Netherlands
p) +31 88 511 3113 f) +31 88 511 3210
e) info@nlr.nl i) www.nlr.nl