EVALUATION OF THREE HELICOPTER PREFLIGHT DEICING TECHNIQUES

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ABSTRACT

Procedures for preflight deicing of helicopters have not been refined nor standardized. Parked helicopters are often exposed to weather, allowing freezing precipitation and snow to accumulate on airframe and blade surfaces. Unless removed, snow and ice may linger after precipitation ends, grounding aircraft for hours to days, depending upon temperature.

Newer helicopters with composite blades and fuselage components are susceptible to damage from deicing operations because thermal and mechanical damage can cause delamination. In addition, glycol-based deicing fluids may cause corrosion of critical rotor head components. Therefore, there is a need to develop different ground deicing techniques for helicopters.

This paper describes an experimental evaluation of the use of infrared radiation, hot water and hot air to deice helicopters before flight. The purpose of the experiment was to evaluate the effectiveness of each deicing method, and to assess the potential thermal effects of each on rotor blade composites. Our greatest interest was the potential for using infrared radiation as a deicing agent, a technique that has been used to deice fixed-wing aircraft, but not helicopters.

INTRODUCTION AND PROBLEM

Hangared helicopters are protected from weather. However, helicopters exposed to weather during military, search and rescue, medevac, and oil rig supply operations allow freezing precipitation and snow to accumulate on airframe and blade surfaces when parked. Adhering snow and ice may linger after a storm passes, grounding aircraft for hours to days, unless frozen precipitation is manually removed. Reports that manual deicing methods can require up to four hours to prepare a single aircraft for flight, and the inefficiency of manual methods, justifies the need for finding better methods.

Modern helicopters are more likely to be damaged by ice and snow removal techniques than are fixed-wing aircraft because large portions of rotor blades and fuselage surfaces are constructed of composites. Composites are susceptible to damage from physical impact, scraping, high temperatures, and rapid thermal cycling. In addition, glycol deicing fluids may corrode helicopter rotor heads and wash lubricants from bearings.

Boots and covers are occasionally used to protect helicopter components from ice and snow on the ground. For example, covers for blades, rotor heads, wind screens, tail rotors, engine inlets and, as on fixed-wing aircraft, pitot covers, are often used. However, reports of freezing of covers to aircraft surfaces make them less practical than desired. In addition, their use requires knowledge that freezing or frozen precipitation may occur when the aircraft is parked. Unless forecasts of freezing precipitation are very reliable and precipitation probabilities are high, aircraft are unlikely to be covered prior to a storm resulting in snow or ice-covered aircraft requiring deicing.

This paper describes an experimental evaluation of the use of infrared radiation, hot liquid, and hot air to deice Army Blackhawk helicopters before flight. It also describes the utility of a portable ice imager system for use in deicing procedures. The purpose of the experiment was to identify deicing techniques available for helicopters, to select and evaluate the effectiveness of several methods, and to assess the potential thermal effects of each on rotor blade composites.

BACKGROUND

A variety of techniques are used to deice helicopters in the field, but none are refined or standardized. Each operator finds a method that is as effective as possible using equipment available. The most common and effective method is to tow the aircraft into a heated hangar, if one is available. Otherwise, a tent, tarp, or parachute can be draped over the aircraft and the space beneath heated.

The U.S. Coast Guard has used blade, windscreen, engine inlet, rotorhead, and tail rotor covers to protect aircraft on the fantail of ships. Heated glycol from portable units has been used to deice these aircraft in areas unprotected by covers. However, blade covers are ineffective if they are not installed before ice and snow occur. Brushes, brooms, ropes, and gloved hands effectively remove dry snow. However, mechanical deicing techniques, reportedly using scrapers and ball peen hammers, are usually harmful to composite structures.

Composites that compose the blades and portions of the fuselage of Black Hawk helicopters are a matrix of polymer fibers embedded within a glass resin. Resins are formulated to have cure temperatures which, if exceeded, can cause weakening of bonds and delamination of polymer mats. Even at somewhat lower temperatures composites can soften and lose shear strength. High temperatures from deicing operations would first affect adhesive bonds, which are normally cured at about 70°C. Higher temperatures (>120°C) can severely damage the epoxy matrix of composites, irreversibly degrading their load capacity.[1]

In addition to the danger of reaching the transition and cure temperatures, lower temperature cycling has the potential to damage composite structures. Thermally induced stresses caused by rapid thermal gain, and differential heating of dry and ice-covered surfaces, have the potential for invisibly weakening multilayered, nonmetallic aircraft structures.[1] This may be a particular hazard to flight safety after many repetitions, especially for helicopter blades, which receive the most thorough deicing treatments, and thus potentially the greatest damage. Material damages can grow and accumulate.

The structure of helicopter blades makes them particularly susceptible to thermal damage. In addition to the thermal susceptibility of the composites, the substrates to which the composites are attached have differing thermal masses and thermal conductivities, which influence the ultimate temperature of the blade surface. Thus, uniform thermal flux applied to such a structure can result in differential heating of the blade surface, and perhaps damage.[1]

Methods of deicing may also have a large role in the amount of damage done to helicopter composites. For example, during hot air deicing some hot air hits dry or ice-free portions of the blade, which heat rapidly, whereas ice-covered areas may heat slowly, and only to 0°C. This may create a large temperature gradient between dry and ice-covered areas under the hot air stream. Poor thermal conductivity, plus high coefficients of thermal expansion, can cause "working" of the composite layers and may cause eventual, but perhaps not immediate, weakening and damage of the blade. This process can shorten blade life, increasing blade life-cycle costs.

DEICING EXPERIMENT

A research team consisting of participants from the Army, the Air Force, the FAA, and private industry was assembled to design an experiment to evaluate as many helicopter deicing methods as possible. Discussions among participants indicated that three deicing methods using hot air, hot liquid (glycol or water), and infrared energy could be practically evaluated. The hot air and hot liquid methods had early prototype hardware available, developed for the Army. The infrared system was commercial.

The Army hot air and hot liquid deicing prototypes (described in more detail later) were portable and could be easily shipped to any CONUS experiment site. The infrared system selected, however, was not portable, and consisted of a fixed, drive-through hangar. As a result, the experiment occurred at the location of the infrared system, Buffalo International Airport, in February 1998, a location that is typically cold and snowy during that time of year.

The research plan intended to utilize natural icing events if they occurred. Otherwise, ice would be created by spraying aircraft with water from the airport's fire trucks, a procedure used earlier by the FAA when evaluating the infrared system for fixed-wing aircraft.[2] This would allow a direct comparison of each method with regard to the time necessary to make each aircraft flight worthy, the thoroughness of each method, and the difficulty of using each. An ice imaging system would be used to evaluate the coverage of snow or ice on each aircraft, and to evaluate the thoroughness of each technique for removing ice and snow.

We acquired two Blackhawk (H-60) helicopters from the New York National Guard for the experiment. Both helicopters were flown to Buffalo and left, each with an NCO in charge, to be iced and deiced as needed.

Each helicopter was sprayed using fire truck fog nozzles, creating 1–2 mm of clear ice, with a density of near 0.91 g cm^{-3}. Experiments, but only with infrared deicing, were also conducted with natural, wet snow on each helicopter (two infrared deicings). Ice and snow thickness were measured at 23 locations on each helicopter. Snow thickness averaged ~1 cm, and snow density averaged about 0.14 g cm^{-3}.

Warmer than normal weather conditions limited the number of times that the two aircraft could be iced and deiced. Thus, though all fundamental goals of the project were accomplished, repeated evaluations of some of the deicing methods, especially for several different types and thicknesses of frozen deposits, were not possible.

INSTRUMENTATION AND PRE-EXPERIMENT ANALYSES

One of the goals of the experiment was to measure the thermal response of aircraft composite structures to the deicing techniques. Maximum allowable temperature of the blade surfaces was 66°C.[3] We were concerned about damaging the aircraft, especially the blades, by overheating the composites and causing delamination, thus making the aircraft unflyable. Therefore, noninvasive instrumentation was applied to each aircraft to measure temperature and ice thickness. We were also concerned about how to measure temperature of the aircraft surfaces unambiguously in the strong radiative environment created by the infrared deicing system.

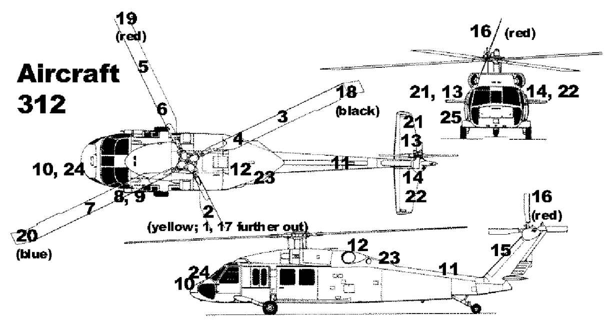

Figure 1. Numbers refer to ice thickness measurement stations. Thermocouples were located at 16 of these locations. Colors are blade identifiers.

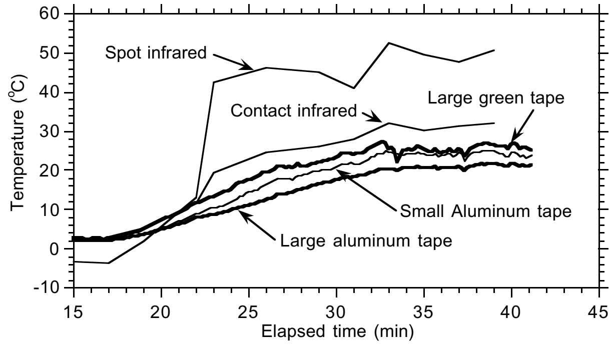

Figure 2. Temperatures of thermocouples under various tape configurations.

Each helicopter was instrumented with 16 thermocouples, with two thermocouples located on the top of each of the four blades (Figure 1), and one on the bottom of one blade. Remaining thermocouples were located on the tail rotor, stabilator, and fuselage. Thermocouples were fastened with tape to prevent damage to the aircraft, as suggested by the FAA from evaluations of fixed-wing aircraft.[2] Radiant (or effective) temperature measurements were also made using an infrared spot radiometer, an infrared contact radiometer, and an Inframetrics Model 760 infrared imaging radiometer.

Before committing an entire helicopter to the system, experiments were conducted with blade sections from Huey, S-76, and Blackhawk helicopters to determine how warm they would become under the infrared heaters. In addition, we used this opportunity to evaluate temperature measurements from the three radiometer types and from the thermocouples, to determine how well each measurement method compared.

The FAA reported that thermocouples fastened with aluminum tape provided accurate temperatures of bare aluminum or white-painted aircraft surfaces.[2] However, Blackhawk blades are painted black, with potentially higher infrared absorptivity than bare or white-painted aluminum. We wished to fasten the thermocouples with a tape that resembled the radiative characteristics of the blade surface as closely as possible. We were concerned that the aluminum tape would reflect more infrared radiation than the blade surface and thus provide a temperature that was not representative of the actual blade temperature. In addition, the thermal conductivity of an aluminum aircraft skin is larger than that of composites. Thus, the composites could not conduct heat to the thermocouples from exposed areas around the tape as readily as could the aluminum.

We experimented by attaching thermocouples to the aircraft with small (~7 cm^2) and large (~25 cm^2) strips of aluminum tape and with green duct tape (~25 cm^2) and exposed them to the infrared deicing system. Figure 2 indicates that green duct-tape-covered thermocouples are only about 5°C cooler than the contact radiometer measurements. However, the green tape adhesive softened in the heat, allowing the thermocouples to loosen. Therefore, the small pieces of aluminum tape were finally used to attach the thermocouples, providing temperatures that were about 3°C cooler than the green tape temperatures.

The contact radiometer was placed directly on the surface of the aircraft to minimize effects of reflections. The contact radiometer temperature will be the same as the physical temperature if the emissivity of the surface is 1.0, but we were unable to verify whether this was true on the blades. Temperatures read by the spot radiometer and the infrared imager depend on the emissivity of the surface, infrared reflections from the surfaces, and also on viewing geometry. As a result, thermocouple, infrared radiometer, and infrared imager temperatures were not the same for the same point at the same time. Where temperatures are presented in this report, thermocouple and contact radiometer temperatures are provided.

Prior to evaluating the infrared deicing system on a helicopter, it was evaluated for its thermal effects on Black Hawk blade sections. The critical concern was the power level to operate the infrared system to maintain safe blade temperatures. The infrared deicing system could be operated at two power density levels, providing an average of about 945 W m^{-2} (300 BTU ft^{-2} hr^{-1}) at full power, and about 440–630 W m^{-2} (140-200 BTU ft^{-2} hr^{-1}) at half power. Thermocouples exposed to the infrared system at full power recorded maximum blade surface temperatures of 50 to 60°C on dry sections of blade, close to the 66°C maximum recommended.[3] One-half power maximum blade temperatures were about 30°C; all experiments on the actual helicopters therefore were conducted with the infrared system operating at one-half power.

INFRARED DEICING

Infrared deicing experiments were conducted using a system called InfraTek, developed by Process Technologies, Inc. (PTI), of Orchard Park, New York. At the time, the PTI system was the only infrared deicing system that had been thoroughly evaluated by the FAA and demonstrated as safe for fixed-wing aircraft. For that reason, we used the InfraTek system for the experiment to minimize any chance of damaging the helicopters. The PTI system is routinely used to deice turboprop commuter and private fixed-wing aircraft at Buffalo International Airport. The InfraTek system consists of a fabric-covered, space-frame, drive-through hangar with an asphalt floor. Gas-fired infrared heaters suspended from the roof are configured to match the shape of typical fixed-wing aircraft. As indicated earlier, the system can be operated at full or one-half power by firing selected banks of heaters. The shape of the infrared heating pattern can also be roughly tailored to the shape of the aircraft by the selection of appropriate heater banks. Infrared flux from the system was monitored at locations around the periphery of the helicopter during the experiment to obtain both its temporal and spatial variations.

Infrared deicing was evaluated four times, twice with clear ice, and twice with wet snow. PTI recommends preheating the InfraTek facility prior to deicing an aircraft, which heats the hangar floor and thus, through reradiation from the floor, encourages more thorough deicing. We deiced with and without preheating for both clear ice and wet snow.

During infrared deicing of thin, clear ice on 23 February, temperatures increased at differing rates at each thermocouple, with each reaching a different maximum temperature. This is likely a result of variations in the absorption of infrared energy by materials on the helicopter, exposure geometry, and the presence of residual ice or water on some surfaces. The highest thermocouple temperature, about 28°C, was reached on the upper surface of one of the blades directly under one of the lower banks of heater elements. Contact radiometer temperatures were higher, near 42°C. These lower, horizontal heater elements are intended to deice the wings of fixed-wing aircraft, which are typically farther from the heater elements than are helicopter blades. The thermocouple with the smallest increase in temperature was on the aircraft nose and did not directly face any of the heating elements.

During deicing the condition of ice or snow was recorded as the ice or snow melted, and the blades eventually dried. For clear ice, the blades were visually observed and successively recorded as ice-covered, melting, wet, damp, or dry at certain ice measurement sites. These qualitative estimates of blade surface condition were related to thermocouple temperature at nearby locations to try to explain the thermal time series during deicing (Figure 3).

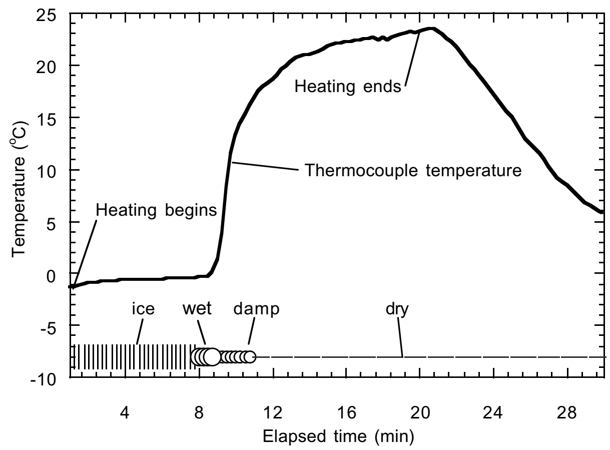

Figure 3. Relationship between blade thermocouple temperature and blade ice condition.

Observations during deicing of clear ice indicate that until ice begins to melt, blade temperature rises to and remains at 0ºC (Figure 3). This is followed by a rapid increase in temperature after ice melts and the blade becomes wet. Finally, after the blade dries, temperatures increase as a function of direct radiant heating of the surface, though often at a slower rate than when covered with water. Temperatures continued to climb after the blade was dry until surfaces lost heat through reradiation and convection at a larger rate.

The experiment was stopped soon after substantial portions of blades were dry, typically after 20–25 min of infrared heating had elapsed, to prevent overheating of dry surfaces. Though temperatures were not dangerously high when the experiment was stopped, our temperature measurements were not unambiguous. Thus, the experiment was stopped as soon as the aircraft was nearly free of ice as a conservative measure. Small amounts of ice resided yet on shadowed portions of the stabilator and on the sides of the fuselage where infrared energy, originating primarily from above the aircraft, could not reach with great intensity. There was no significant difference in deicing rate when the hangar was preheated, so results are not shown here. However, ice cleared from fuselage sides somewhat better when the hangar was preheated.

A wet snow fell over the evening of 23–24 February, accumulating ~1 cm of snow on each aircraft. As with the thin, clear ice, both aircraft were deiced with the infrared system. Wet snow infrared deicing thermal signatures were similar to those of clear ice deicing, though infrared energy may have been able to penetrate to the blade surface more rapidly in snow than in ice because of density differences of the ice versus the snow. Similar blade thermal signatures are also apparent in the snow thermal time series as for clear ice as the surface transitioned from snow, to slush, to wet, damp, and dry. Snow deicing differed from ice deicing when the snow began to melt. Ice melted directly to water, whereas when snow began to melt, water was often absorbed by snow remaining on the blade, which formed a slush that persisted until all of the frozen material melted.

Blade thermocouple temperatures were largest after a snow deicing of 25 min. Two surfaces-the top of a main rotor blade and a tail rotor blade-reached a maximum temperature of about 44°C. There was no significant relationship between deicing event duration and the maximum temperature reached on the aircraft. Maximum temperatures on blades surfaces measured with the contact radiometer ranged from about 41°C to about 56°C.

There appeared to be no significant difference in the rate of removal of snow versus clear ice in the infrared system, considering the amount of ice and water on the aircraft. However, the similar liquid equivalents of the 1–2 mm of ice cover at a density of about 0.91 g cm^{-3}, and the ~1 cm of snow cover at a density of about 0.14 g cm^{-3}, suggest that the amount of energy required to remove either the ice or snow should be similar. Any small differences could be attributed to snow versus ice physical properties, and wind flow through the hangar and air temperature changes.

Infrared imagery of the blades indicates that the blade heated most, after drying, on the portion of the chord aft of the spar, over the Nomex core (Figure 4). This portion of blade, with least thermal mass, may have the greatest opportunity to overheat should infrared heating continue after the blade is dry.

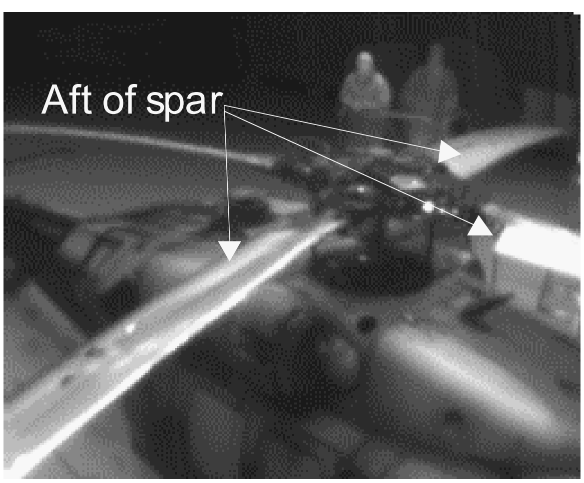

Figure 4. Infrared image showing Nomex core aft of spar as warmest (lightest in color).

The infrared system did not completely clear the aircraft of ice and snow, though all critical areas were clean. In addition, portions of the aircraft were also not dry and would benefit from manual drying and the application of an anti-icing fluid to prevent refreezing of water.

HOT WATER DEICING

Hot liquid deicing was accomplished with a prototype Aircraft Cleaning and Deicing System (ACDS) developed for the Army. The ACDS consists of a heated pump system that allows fluids to be sprayed on an aircraft, and a portable containment mat that allows fluids to be captured and recovered. We used an ACDS system that had been developed by Aviation Environmental, Inc., to demonstrate its feasibility to the Army. The portable 6.1-m by 18.3-m containment mat, manufactured from a puncture and abrasion resistant tripolymer material, collected and contained fluids draining from the aircraft. The mat was surrounded by a flexible berm that does not impede aircraft being towed onto and off the mat. A trailer towed behind a small truck contained a heated pressure washing system that included tanks to hold fresh deicing or washing fluids, and tanks for holding recovered fluids that drained to the mat. A vacuum system removed fluid from the mat to the holding tanks.

Two wands were used to manually direct hot liquid onto iced surfaces. One wand was similar to those used in manual car washes. The second, a specialized wand, allowed the top of a helicopter blade to be sprayed from the ground. The thermostat of the pump system was set to about 66°C. The temperature of water exiting the nozzles was estimated from a thermocouple attached to a wand to be about 45°C, and by spraying water onto thermocouples attached to the Blackhawk blade segment used in the first infrared system experiments.

The FAA allows the use of hot water to deice fixed-wing aircraft to temperatures of −3°C.[4] However, the FAA also requires that an anti-icing fluid be used after deicing to prevent the refreezing of water, especially in areas containing control linkages. Though we desired to use glycol in the ACDS, the Army does not allow glycol use on most parts of the Blackhawk helicopter. The Army permits glycol to be wiped with a moistened cloth on blade tops, but glycol is not allowed on other portions of the aircraft. Because of the difficulty of controlling overspray, and a need to deice the rotor head, tail rotor, and engine inlets to make the aircraft flyable, only hot water was used in the ACDS. Because of the prohibition of glycol, we did not follow our deicing procedures with an anti-icing fluid.

Experiments with the ACDS occurred only with the 1- to 2 -mm film of clear ice, and only on one aircraft. The

ACDS was shipped back to California the night that wet snow occurred, preventing its use for removing snow.

The containment mat was readily deployed in the near-0°C temperatures of the experiment, and the aircraft was towed onto the containment mat. Deicing was accomplished with the two wands described earlier, and personnel used stepladders to access the rotor head and tail rotor. Though those areas are accessible using foot pegs on the aircraft, they were considered too slippery for use in the experiment. The rotor head was rotated during deicing to position each blade near the spray rig. In addition, because the containment mat was narrower than the aircraft's blade span, the blades were rotated to allow water to fall onto the mat.

It was immediately apparent during hot water deicing that the ice imager was necessary to direct the work. The ice imager, described below, indicates where ice occurs on the aircraft, and can distinguish ice from water. To the unaided eye, hot water from the ACDS appeared identical to the thin, clear ice on the aircraft. As a result, once wet, it was not possible to determine where the aircraft had been deiced, especially on the blade tops. Therefore, the ice imager was used to guide the ACDS deicing operation.

Aircraft surface temperatures were measured only with the thermocouples during the ACDS operation, though

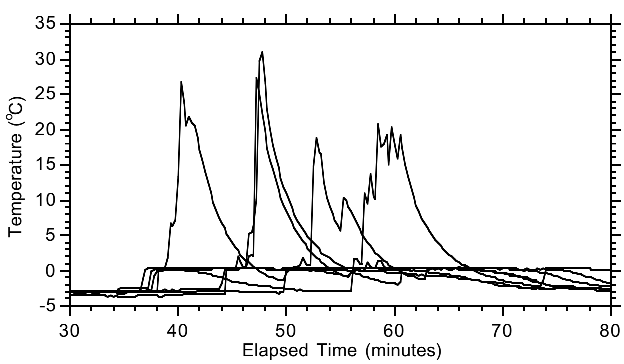

Figure 5. Temperatures of six thermocouples during hot water deicing.

thermal imagery was also taken. During deicing, blade temperatures rose quickly as hot water passed over thermocouples, and then cooled over a 10-min period (Figure 5). The thermal signature of the hot water passing over the thermocouples was very sharp compared to the infrared system's thermal signature. Maximum temperature at the thermocouple locations was about 31ºC. Unlike the infrared system, there was no danger of overheating the composites because they could never warm to a temperature greater than that of the hot water exiting the wands. However, the sharp thermal rise caused by the hot water does raise questions about thermal shock to the blade composites.

As the aircraft cooled to ambient temperature, a pause occurred at about 0°C, indicative of residual water freezing on the blade surfaces. This residual ice was observed at many locations on the blades and fuselage after deicing was completed, and occurred because the FAA-recommended anti-icing procedure was not used after the hot-water deicing. This refreezing occurred rapidly even though air temperatures were only –2°C, causing ice to reform where it had been removed. In addition, hot water ran under the blades causing some ice to form on blade bottoms where none had existed prior to deicing. This refreezing was detected by eye, but principally with the ice imaging system.

The ACDS successfully removed ice from critical areas of the aircraft, especially when operators were aided by the ice imager. However, refreezing of the hot water still caused the aircraft to be declared not airworthy. In addition, the containment mat became slippery as water (and subsequently ice) accumulated, creating a hazard for personnel.

HOT AIR DEICING

Hot air deicing was accomplished with the use of an accessory deicing nozzle for the Buddy Start System, a system utilizing electrical power and auxiliary power unit (APU) bleed air from a powered aircraft to start aircraft with dead batteries. The Buddy Start Hose Deicing Kit (BSHDK) is a prototype system developed by Kaiser Electro-Precision with cooperation of the Army's Aviation Applied Technology Directorate at Fort Eustis, Virginia. It was first demonstrated in the climatic chamber at Eglin Air Force Base, Florida, in 1997.[5] The hot air deicing system uses bleed air from the helicopter APU and a manually operated hose and nozzle to melt ice. Buddy Start systems are usable on Blackhawk and Apache helicopters and certain fixed-wing aircraft, such as the C-130.

The kit consists of a 0.5-m-long handheld aluminum nozzle with a 6.4-cm-diameter nozzle. A ball valve controls air flow and serves as one of the two nozzle handles. Hot air is fed to the nozzle through an 18-m-long flexible hose connected to the APU bleed air port, located on the port side of the Blackhawk. The system operates with at least three personnel: one operating the APU from inside the cockpit, one maneuvering the hose, and a third using the nozzle. The system is also usable with the Auxiliary Ground Power Unit (AGPU), available at air stations.

The Buddy Start Deicing Nozzle had previously been studied by the Test and Evaluation Command (TECO) of Fort Rucker, Alabama, to evaluate the temperature of air exiting the nozzle. TECO evaluations indicated that when used with 18 m of hose in temperatures of 10°C and wind speeds gusting to 7 m s^{-1}, air temperatures at the nozzle were about 167°C. At a distance of 0.4 m, temperature decreased to about 133°C, and at 0.6 m about 100°C.[4] The highest safe temperature for Blackhawk blades is about 66°C. We operated the BSHDK at an air temperature of about −2°C, suggesting that the nozzle should be kept at least 0.8 to 0.9 m from the aircraft surface when deicing. We could not successfully measure air temperature exiting the nozzle in the field. Air pressure and velocity at the nozzle, though very high, were also not measured.

We deiced only two blades, and a portion of the rotor head of one aircraft covered with 1–2 mm of clear ice, with hot air. The hot air experiment was terminated after only 16 min of operation because a pin holding a quick-connect coupling between the deice nozzle and air supply hose disengaged, allowing the hose to rapidly separate from the nozzle. The cause of separation could not be determined, so the experiment was terminated.

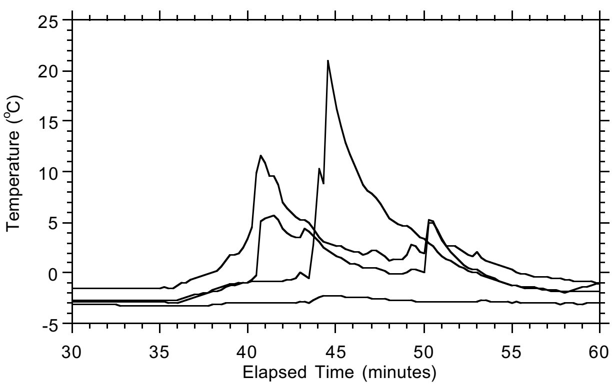

Figure 6. Thermocouple temperatures during hot air deicing.

Time series of temperature changes at five thermocouples as the deicing nozzle moved over them during the period that the Buddy Start system was used show a gradual increase in temperature followed by a rapid increase (Figure 6). The initial increase is probably associated with an increase in the temperature of the ice from the hot air, followed by a phase change from ice to water and the subsequent evaporation of the water. After the area is dry the operator moved on to another section of the blade and the blade temperature decreased to ambient exponentially. The secondary peaks in the temperature curves may be due to the operator revisiting certain locations during the deicing process. Because of careful application of hot air to the rotor blades, despite occasional use of the nozzle within 0.5 m of the blade surface, rotor blade temperatures never warmed above about 22°C in the −2ºC air temperatures of the experiment.

Temporal and spatial profiles of effective temperatures taken using an infrared scanning system demonstrate fluctuations in temperature along the blade being deiced caused by inconsistencies in operator usage. This is consistent with the deicing operation, which progressed along the blade in small increments from the rotor head to the blade tip. During this process, the hot air system not only melts the ice but also dries the surface so ice cannot reform.

As indicated in Figure 6, hot air did not warm blade thermocouples to high temperatures. This may be because the thin ice could be removed rapidly, allowing the nozzle to be moved rapidly, not lingering for long at any one location. Though blade discoloration did occur, no damage was judged to have occurred. Thicker ice or colder air temperatures may cause lingering at locations for longer periods of time, thus creating a greater potential for heating the blades.

ICE IMAGING

An ice imaging system was provided by Robotic Vision Systems Inc. (RVSI) to assess the system's effectiveness for helicopter deicing. The system, being used commercially for fixed-wing aircraft and by Air Force One, operates by scanning the aircraft surface with an infrared diode laser. Backscatter is digitized, and areas of ice are displayed in white, clean areas in green, and areas out-of-range in black.[6] Scanning occurs with a compact, hand-held gun through which an operator views the aircraft on a flat matrix display. The type of aircraft surface being viewed is selected by the operator, and areas that are ice covered or clean are indicated in real time. Post processing allows the surface type to be changed experimentally to assess the effectiveness of different processing algorithms on different aircraft surface types.

The ice imager allowed identification and location of areas of the aircraft covered with ice and snow prior to deicing. And, it allowed assessment of the progress of deicing during the deicing process with each technology. The system allowed deicing to occur with the hot water

Figure 7. Upper image, from ice imager, shows deiced portion of blade in gray; light areas are ice covered. Lower image, in natural light, is of same blade surface

system in a much more effective manner than could have occurred if the system were not available. As indicated earlier, the lack of visual contrast between the thin clear ice on the helicopter and the sprayed hot water made visual guidance of deicing progress ineffective. Figure 7 shows the top of a blade during hot water deicing with the special blade wand described earlier. The top image clearly illustrates where the blade has been deiced, compared to the natural light image beneath. Finally, the ice imager allowed assessment of the effectiveness of each deicing system after each technology had completed deicing. This is a necessary task for all pilots when preparing their aircraft for flight, currently conducted by naked eye. The ice imaging system makes operations in reduced light, and with clear ice, more effective than the naked eye.

Evaluations of the minimum ice thickness the ice imaging system could visualize have not yet been performed. However, we have detected only a few minor situations where reflections occurred off of curved or complex metallic surfaces under clear ice, making analysis difficult. The system appeared to work equally well with thin, 1- to 2-mm-thick clear ice, as with ~1-cm-thick wet snow.

DISCUSSION AND CONCLUSIONS

All three deicing technologies-infrared, hot water and hot air-are viable, with qualifications, for deicing helicopters. Infrared deicing has the potential to be a rapid deicing technique. However, methods are needed for unambiguously, and noninvasively determining composite temperatures to prevent overheating. Methods are also needed for drying the entire aircraft without overheating—perhaps by supplementing with manually operated hot air dryers, towels, or an anti-icing fluid that is compatible with composites and helicopter rotor heads. Though the system we used was not portable, smaller portable systems are commercially available. Infrared deicing has the potential for rapidly and inexpensively deicing helicopters with only one or two personnel as operators, and without the potential for environmental and material damage that can be caused by glycols.

Hot water is a viable technology, in warmer temperatures, if an anti-icing fluid can be applied after deicing. However, an ice imaging system is also useful because of the optical similarities between water and clear ice in natural light. The ACDS technology used to apply hot water in the Buffalo experiment would be much more useful if an environmentally benign and helicopter-material-benign deicing fluid could be substituted for water. However, to date no such fluid is commercially available. Though the prototype fluid containment mat was too small for a Blackhawk helicopter, that shortcoming could be easily remedied. The Army ACDS must be transportable by helicopter to airfields; a larger mat may make it less transportable. Thermal damage to composites appeared unlikely with the ACDS, unless water temperatures were pushed to an unsafe temperature, a capability not possible with the prototype we used. Only one or two personnel are needed to operate the system.

Hot air was quite effective at deicing the aircraft and drying the surface. However, the danger of overheating blades by overzealous operators is a clear hazard, as is the danger to personnel and materiel by the high-pressure, high-velocity air from the aircraft APU. A method is needed to prevent operators from overheating composites. Hot air is an effective and extremely portable deicing technology for aircraft equipped with APUs and an appropriate bleed air port. It is also useful at airfields with AGPUs, though air temperatures from AGPUs are even greater than from APUs. The system requires at least three personnel to operate, with at least one certified to operate the aircraft APU.

Deicing performance of the three systems differed. The hot air system was evaluated only against 1- to 2-mm-thick clear ice because a system failure prevented its use on snow. Two blades and a portion of the rotor head were deiced. Extrapolating to all portions of the aircraft required to be clear of ice prior to flight (rotor head, blades, tail rotor, engine inlet areas), hot air would have required about 90 minutes to remove 1 to 2 mm of ice. Hot water required approximately 35–45 minutes to deice the aircraft if freezing of residual water and the time necessary to apply an anti-icing fluid was ignored. The aircraft was judged not ready for flight with the frozen residual water, rendering hot water deicing unacceptable at temperatures below 0ºC. However, hot water may be useful for removing wet snow. Infrared deicing required about 15–25 minutes to remove clear ice and wet snow. Shadowed areas were often wet or retained some slush after this time.

None of the systems heated blade composite surfaces dangerously. However, careless use of the hot air and infrared systems has the potential to cause thermal damage. The integrity of rotor blade composites after many thermal deicing events remains under investigation. Our evaluation suggests that infrared systems are most useful at established airfields unless an extremely lightweight and portable system is developed. Hot water/hot glycol systems are similar to fixed-wing deicing technologies widely available. However, the need to use glycol on helicopters limits its use to the Army, though perhaps not to other organizations. Hot air appears to be extremely useful for aircraft with compatible APU bleed air ports because of its portability if safety and thermal hazards can be reduced.

ACKNOWLEDGMENTS

P. Dutta, J. Bouzoun, S. Ketcham, G. Pedrick, B. Harrington, P. Keene, and A. Clifford of USACRREL assisted with planning, execution, and analysis of the Buffalo field program. L. Peck, A. Greatorex, and LTC Loven at CRREL provided critical reviews of the paper. P. Pantelis and M. French of the Army Aviation Applied Technology Directorate at Fort Eustis, Virginia, assisted with planning and funding of the Buffalo field program. T. Foster, Directorate of Combat Developments at Fort Rucker, Alabama, assisted with project planning. J. White and A. Gatano of the FAA William J. Hughes Technical Center, Atlantic City, NJ, assisted greatly with planning the Buffalo field project. Personnel from the 160th Aviation Group, Fort Campbell, Kentucky, and the New York National Guard, Albany, assisted with aircraft operations at Buffalo. D. Schoeffler and J. Merlino of Robotic Vision Systems Inc., and T. Seal of Process Technologies, Inc., generously provided ice imaging equipment and personnel, and the InfraTek System and technical advice, respectively, through CRDAs. D. Whitman of Aviation Environmental, Inc, Corona, CA, provided and operated the ACDS prototype. Col A. Clune, of the Air Force National Guard, Niagara Falls, NY, provided logistics support at Buffalo. R. Wilcox of Prior Aviation Services, Buffalo International Airport, provided local logistics support, and the Buffalo International Airport Fire Department produced ice. NASA Lewis Research Center Icing Branch and the Icing Research Tunnel, Cleveland, OH, provided technical assistance. The projected was supported by the U.S. Army Corps of Engineers, CRREL AT42 Work Item "Helicopter Deicing."

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