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Development of an International Standard for Safe Winter Operation

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When analyzing accident scenarios in winter operation, wing contamination due to frost, ice, or snow was often found to be a contributing factor for accidents/incidents worldwide. A standardized procedure for safety enhancements in winter operation started in Europe in 1982. This activity within the Association of European Airlines (AEA) resulted in standardized requirements for 1) de-/anti-icing fluids including holdover times specifications; 2) de-/anti-icing procedures and respective pilots information; and 3) de-/anti-icing vehicles requirements. The next step after this joint industry approach of aircraft manufacturers, authorities, airlines, fluid, and vehicle manufacturers was the development from the AEA standard to an international specification in International Standards Organization (ISO). The performance requirements for nonNewtonian, pseudoplastic fluids are described including the hardware test setups for aerodynamic acceptance as well as anti-icing protection. Operational experiences using nonNewtonian fluids including an overview of the effects of Newtonian fluids on aircraft performance are presented.

Introduction

AIRCRAFT ground de-/anti-icing plays a vital role in cold weather environments to assure that an aircraft is free of ice, frost, or snow contamination at takeoff. Airworthiness Authorities requirements (see Table 1) like FAR 91.209 and FAR 121.629 clearly dictate the "clean wing concept." Rigorous adherence to this clean wing ground maintenance philosophy is required to assure safe winter operations, otherwise, climb and maneuvering capabilities are seriously reduced. Figure 1 is an estimate of the stall speed increase that would occur on small turbojet transports like the B737, and DC-9, etc. With such increases in stall speed, stall warning margins and margins to stall decrease markedly or disappear completely.

These significant increases in stall speed also occur at much lower than normal angles of attack as shown in Fig. 2, resulting in at least two adverse effects. First, many contemporary stall warning systems are actuated at a prescheduled α, if wing ice contamination causes a stall to occur before reaching this angle no warning of impending stall is there. Second, the reduced α increases the tendency to pitch-up during rotation with the increased risk of overshooting the stall α shortly after liftoff.

This analytical description of the adverse aerodynamic effects of wing contamination is reflected in Table 2, listing the icing-related accidents from 1968 to the present time. Looking at the accidents as a percentage, wing contamination accidents are about 1.1% of the total accidents. Small, but rather significant. Total accidents comprise 4.4% of the total, and fatalities 2.3% of the total.

Wing contamination is affecting all types of aircraft identically, straight wing propeller aircraft like the Nord 262, large turbojet aircraft with conventional airfoils like the F-28, DC-9, DC-8 as well as aircraft with leading-edge high-lift devices such as the B737.

The industry was and is concerned about icing related accidents. They are all (Table 2) avoidable accidents.

Compared to many other types of accidents where a pilot has to make immediate decisions to determine the cause of his problem and what action to take very quickly, this is not true for the scenario described here. There is time to determine accurately the condition of the aircraft on ground. What is missing? It is communication and education.

Definition of AEA Activities

Communication and education requirements on winter operation were highlighted in European Airlines after the 737 fatal accident in Washington, DC, on January 13, 1982. The Association of European Airlines (AEA)—representing 21 European airlines—decided in March 1982 to establish a task force activity. Scope for this task force was the definition of standards for 1) de-/anti-icing fluids materials specification; 2) de-/anti-icing procedures for maintenance and cockpit crews; and 3) de-/anti-icing fluids vehicles requirements.

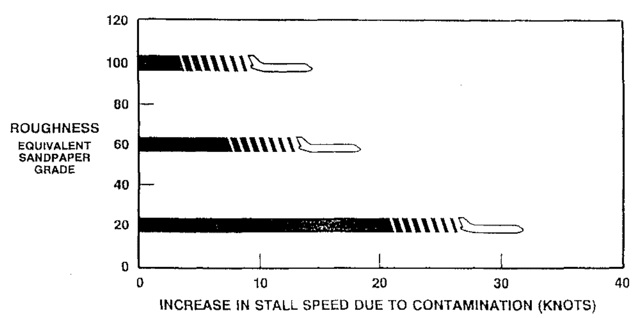

Fig. 1 Approximate effect of wing upper surface ice contamination on the stall speed of a typical small turbojet transport.

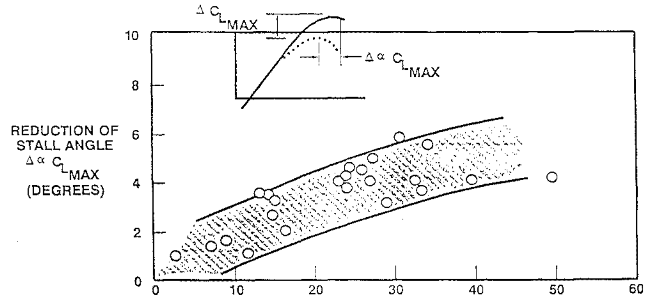

Fig. 2 Reduction of the angle of attack at stall due to wing surface roughness.

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Table 1 Federal air regulations applicable to ice, frost, or snow accumulations prior to takeoff

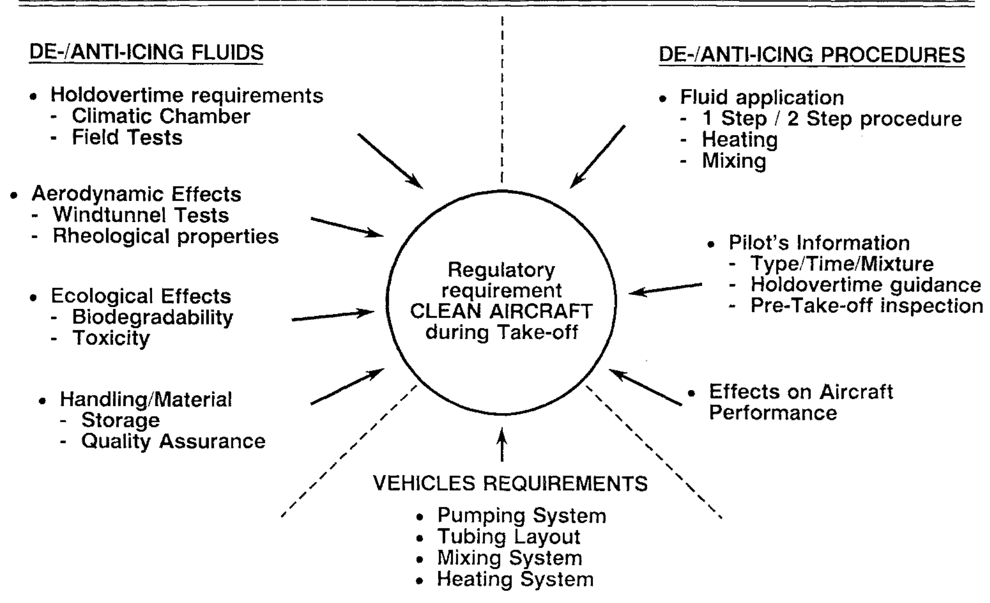
Part 91—General operating and flight rules
 91.209 Operating in icing conditions
  a) No pilot may takeoff an airplane that has the following:
   1) Frost, snow, or ice adhering to any propeller, windshield, or power plant installation, or to an airspeed, altimeter, rate of climb, or flight attitude instrument system
   2) Snow or ice adhering to the wings, or stabilizing or control surfaces
   3) Any frost adhering to the wings, or stabilizing or control surfaces, unless that frost has been polished to make it smooth

Part 121—Certification and operations
 121.629 Operation in icing conditions
  a) No person may dispatch or release an aircraft, continue to operate an aircraft en route, or land an aircraft when in the opinion of the pilot in command or aircraft dispatcher (domestic and flag air carriers only) icing conditions are expected or met that might adversely affect the safety of the flight.
  b) No person may takeoff an aircraft when frost, snow, or ice is adhering to the wings, control surfaces, or propellers of the aircraft.

Table 2 Takeoff accidents where wing upper surface ice contamination is considered to be a contributing factor

Date	Airline	Location	Aircraft type	Precipitation/Observations	De-Icing
December 27, 1968	Ozark	Sioux City	DC-9-10	Light freezing drizzle	No
January 26, 1974	THY	Cumaovas, Turkey	F28	Probable cause: frost accretion on the wings	No
January 3, 1977	JAL	Anchorage	DC-8-62	Fog	No
November 27, 1978	TWA	Newark	DC-9-10	Blowing rain and snow	?
February 12, 1979	Allegheny	Clarksburg	Nord 262	Light snow, frozen snow photographed on empenage after accident	No
February 18, 1980	Redcote	Boston	Bristol 253	Light snow	30% Type 1 mix 60 min before takeoff
January 13, 1982	Air Florida	Washington, D.C.	737	Moderate-to-heavy snowfall	Type 1 45 min before takeoff
February 5, 1985	Airborne	Philadelphia	DC-9-10	Light freezing rain, ice, and snow pellets, fog	No
December 12, 1985	Arrow Air	Gander	DC-8-63	Light freezing drizzle, snow grains	No
November 15, 1987	Continental	Denver	DC-9-10	Moderate snow, fog	Type 1 20 min before takeoff
March 3, 1989	Air Ontario	Dryden	F28	Steady snow	No

Table 3 De-/anti-icing disciplines



The principle understanding for defining these three disciplines was that only a close link between materials, vehicles, and communication/procedural requirements was guaranteeing safe winter operation. In addition this safety enhancement should also positively influence the cost effectiveness of de-/anti-icing tasks as well as assure—to the highest degree possible—a scheduled operation in terms of passenger convenience and aircraft turnarounds.

The requirements for safety, cost effectiveness, and scheduled operation determine a multidiscipline approach between 1) regulatory agencies, 2) aircraft manufacturers, 3) airport authorities, 4) local communities, 5) fluid manufacturers, 6) equipment manufacturers, and 7) meteorological services, with the airline as the focal point in between. Before the start of this activity, the airlines were faced with various, very often contradicting and inconclusive requirements of the above-mentioned parties.

Therefore, the AEA task force (see Table 3) decided to put the airworthiness authority's requirement of the "clean wing" into the center of its activities and completed the first version of the "AEA recommendations for de-/anti-icing of aircraft on ground" within 6 months in October 1982.[1]

AEA Recommendations for De-/Anti-Icing

Materials Specification for De-/Anti-Icing Fluids

Water-glycol solutions (containing a minimum of 80% glycols) had been used successfully for years as a freezing point depressant for performing the ice and snow removal operation. However, such fluids, including the so-called Mil-Spec. fluids, can only provide a limited protective against refreezing when freezing precipitation exists.

It is evident, however, that protection against refreezing under freezing precipitation is vital since delays between wing contamination removal and actual takeoff are unavoidable.

Therefore, a new-generation fluid, containing a thickening agent with special viscosity qualities and nonNewtonian rheological properties was required to assure an anti-icing barrier on the wing surface. The estimated time this anti-icing fluid takes in preventing frost, ice, or snow from forming or accumulating on the protected surfaces on an aircraft is called holdover time.

Material Specification AEA Type I Fluid

AEA Type I fluid is an unthickened Newtonian fluid containing a minimum of 80% glycols, providing protection against refreezing when no precipitation conditions occur (inferior holdover time performance).

Material Specification AEA Type II Fluid

This is a thickened nonNewtonian fluid containing a minimum of 50% glycols, providing protection against refreezing under precipitation conditions.

The specification is covering materials requirements/physical properties like the following: flash point, specific gravity, storage stability, pH-value, freezing point, surface tension, material compatibility, exposure to dry air, thermal stability, toxicity, biodegradability, slipperiness, qualification requirements, and two performance requirements 1) anti-icing performance, and 2) aerodynamic acceptance.

Test Method for Anti-Icing Performance

The test fluids to be evaluated are applied to a test plate exposed to two types of freezing conditions, and their anti-icing performance is evaluated by measuring the minimum exposure time before a specified degree of freezing occurs.

Water Spray Endurance Test

This involves subjecting the AEA Type II fluid when applied to an inclined test plate at $-5°C$ to a supercooled water spray in air at $-5°C$. The water spray endurance is recorded as the time for ice formation to reach the first 25-mm mark at the top of the test plate under these conditions, when the water spray intensity corresponds to 5-g dm^2h^{-1}; this is equivalent to an average precipitation rate of 0.5 mm h^{-1}. It is a fundamental requirement of this test that the spray impinges onto the surface of the test plate as water droplets which freeze on impact.

High-Humidity Endurance Test

The high-humidity endurance test involves subjecting a candidate AEA Type II fluid, when applied to an inclined test plate at $-5°C$, to air at 0°C having a relative humidity of 96%. The high-humidity endurance test is recorded as the time for ice formation to reach the first 25-mm mark at the top of the test plate under these conditions, when the ice formation after 4 h corresponds to 1.2 dm^{-2}; this is equivalent to a water accumulation rate (in the form of frost) of 0.03-mm h^{-1}. It is a fundamental requirement of this test that the RH value is maintained to an accuracy of $\pm 2\%$ RH in the absence of any visible precipitation (such as mist, fog, or rain).

The minimum requirements for the environmental test chamber and associated test equipment (i.e., test plate and spray equipment), have been developed to assure correlation and comparability.

Table 4 shows the differences in anti-icing performance between Newtonian (Type I) and nonNewtonian (Type II) fluids.

Test Method for De-/Anti-Icing Fluids Aerodynamic Acceptance

The effects of de-/anti-icing fluids on the aerodynamic characteristics of transport category aircraft has been in discussion since 1982 (i.e., the first publication of the AEA specifications).

Although European winter-operations has been successful for many years (operational-wise), one U.S. aircraft manufacturer, based on limited testing, argued about the flow-off behavior of Type II fluids with the indication that fluids residues may adversely affect the aircraft lift capability. Since there was no scientific investigation to either support the AEA approach or to quantify the possible adverse aerodynamic effects, the AEA decided in 1984 to start a research program with two main guidelines: 1) wind-tunnel model dimensions and tunnel speeds comparable to full sale; and 2) use of real fluids and tests at subfreezing temperatures. The aim was the investigation of a possible influence of a residual fluid film on the aerodynamic performance of a typical aircraft wing. Two phases have been implemented, sponsored by AEA and performed by the Van Karman Institute (VKI).

Phase 1 is the study of the rheological properties of anti-icing fluids at ambient and low temperatures exposed to an airflow of 2–60 m/s.

Phase 2 is the full-scale wind-tunnel tests of an actual wing section at ambient and low temperatures. Lift, drag, and pitching moment are continuously measured and compared to the "dry" wing. Airstream acceleration to 60 m/s within 30 s and pitchup with 3 deg/s to 12 deg.

Results of phase 2 in 1987 showed that both unthickened as well as thickened fluids affect the lift capability. Due to a variety of test limitations, however, the industry (AEA, Boeing, and McDonnell Douglas) finally agreed that only a full-scale flight test campaign would provide conclusive and substantiated results. A specific article will cover this issue at a later date.

Previous research at VKI supported by flight test results and subsequent NASA wind-tunnel testing, have shown that the possible deterioration of aerodynamic performances of aircraft during takeoff due to residues of de-/anti-icing fluids on wing surfaces can be related to measurements carried out on a flat plate covered with a fluid layer and subjected to an accelerating airflow. This methodology has been applied for the "aerodynamic acceptance" test. The quantity measured is the "displacement thickness" δ^* of the airflow boundary layer and fluid residue over the test flat plate.[2]

By implementing this criteria into the material specification, acceptable aerodynamic interference of the de-/anti-icing fluids as they flow off aircraft lifting surfaces during the takeoff ground acceleration and takeoff climb is assured. The acceptability criteria itself is (taking into account the transitory effects) guaranteeing adequate stall margins, adequate maneuvering capabilities, and sufficient ground clearance during takeoff rotation.

Standardization of De-/Anti-Icing Procedures

The procedures establish the minimum requirements for deicing and especially anti-icing of aircraft on ground. They have been established not only from the ground handling point of view, but highly important is a clear and precise communication means between cockpit crews and ground mechanics.

Therefore, a so-called common anti-icing code is defined, which indicates the quality of protection against refreezing the aircraft has received. The type of fluid as well as the mixture ratio and the start-time of the de-/anti-icing process is transmitted to the flight crew. Based on these inputs the holdover time determination can be performed using specific holdover time tables (Table 5).

Table 4 Comparison in holdover times

	Weather conditions					Holdover times, h	
°C	Frost	Freezing fog	Steady snow	Freezing rain	Rain on cold soaked wing	Type II	Type I
+0 and above	*					12	$\frac{3}{4}$
		*				3	$\frac{1}{2}$
			*		*	1	15 min
				*		20 min	5 min
−0– −7	*					8	$\frac{3}{4}$
		*				$1\frac{1}{2}$	15 min
			*			$\frac{3}{4}$	15 min
				*		20 min	3 min
−8– −14	*					8	$\frac{1}{2}$
		*				$1\frac{1}{2}$	15 min

Table 5 Guideline for holdover times in hours and minutes (hours:minutes) achieved by ISO Type II fluid mixtures as a function of weather conditions and outside air temperature

OAT, °C	ISO Type II fluid mixture concentration neat-fluid/water, % Volume/% Volume	Weather conditions: Frost[a]	Freezing fog	Snow	Freezing rain	Rain on cold soaked wing
0 and above	100/0	12:00	1:15–3:00	0:25–1:00	0:08–0:20	0:24–1:00
	75/25	6:00	0:50–2:00	0:20–0:45	0:04–0:10	0:18–0:45
	50/50	4:00	0:35–1:30	0:15–0:30	0:02–0:05	0:12–0:30
Below 0 to −7	100/0	8:00	0:35–1:30	0:20–0:45	0:08–0:20	
	75/25	5:00	0:25–1:00	0:15–0:30	0:04–0:10	
	50/50	3:00	0:20–0:45	0:05–0:15	0:01–0:03	
Below −7 to −14	100/0	8:00	0:35–1:30	0:20–0:45		
	75/25	5:00	0:25–1:00	0:15–0:30		
Below −14 to −25	100/0	8:00	0:35–1:30	0:20–0:45		
Below −25	100/0 if 7°C Buffer is maintained	Use of ISO Type II fluid recommended below −25°C only if freeze point buffer of 7°C is maintained. Consider use of ISO Type I fluid where ISO Type II fluid cannot be used (see Table 3).				

List of symbols
°C = Celsius
Vol. = Volume
OAT = Outside air temperature

[a]For maintenance purposes.

In addition, definitions of de-/anti-icing, holdover times, fluid mixtures, responsibilities, limitations, precautions, and final check requirements after aircraft treatment are provided.

Specification of De-/Anti-Icing Vehicles

The specification outlines the detailed requirement for a highly maneuverable self-propelled vehicle, primarily for deicing or anti-deicing aircraft, but with two secondary functions of providing an aircraft washing facility and a high access maintenance facility. The maintenance facility shall provide access to the center engine of trijet aircraft, and for aircraft windscreen cleaning. The design shall be suitable for both day and night operations.

The vehicle shall be capable of positioning ground crew personnel in a safe and stable manner so that ADF (anti-icing/de-icing fluid) can be applied to all areas of an aircraft while the vehicle is traversing the aircraft perimeter. For this purpose the vehicle shall have a minimum turning circle. The range of aircraft to be treated is from the BAC 1-11, Fokker F28 to the B747 size aircraft.

The vehicle should be of a size to suit the total fluid capacity chosen by the purchase from the following alternatives: 1) "A" size—2000–4000 l, and 2) "B" size—7000 l.

The B size is primarily for use on wide-body aircraft and the A size for all smaller sizes of aircraft.

The fluid-dispensing systems will consist of pumps, heaters, and a separate storage tank for water and ADF so that fluids can be dispensed as follows: 1) hot water for snow or ice clearance; 2) variable mix from 10 to 75% ADF for conventional deicing; and 3) ADF at ambient temperature for anti-icing.

The specification covers following requirements: equipment description, interface requirements, performance, operating feature, technical requirements, options, environmental and quality assurance provisions, design qualification test, maintenance manuals, and product support.

International Standards Organization

The AEA approach has successfully proven the safety enhancements due to adequate fluids and procedures. AEA Type II fluids were largely available in Europe; outside Europe, however, European airlines were facing still the limited Type I fluids and inadequate communication procedures. Due to this, the AEA recognized the need for a truly international standard, not one that is only limited to European operators.[3] It is with this objective in mind that the International Standards Organization (ISO) was invited to participate.

The ISO became actively associated with deicing/anti-icing in 1985. Essentially, the ISO does not create new standards from scratch, but adapts existing specifications to ISO format.

The AEA document on deicing/anti-icing formed the basis for ISO participation. Nations represented within the ISO are:

Participating members	Observer members
Brazil	China
France	Columbia
Germany	Czechoslovakia
Italy	Hungary
Japan	India
The Netherlands	Israel
Norway	Mexico
Spain	South Africa
USSR	Yugoslavia
United Kingdom	
United States	

Basically, each member nation's standards institute supports ISO. The pertinent ISO group for ground deicing is ISO TC20/SC9. All administrative aspects of the ISO are handled by the Society of Automotive Engineers (SAE).

Deicing/Anti-Icing Activity

The ISO TC20/SC9 meets annually at various member delegation locations. At the June 1986 meeting in Rome, Italy, it opted to provide international coverage on the same three elements studied by the AEA.

In an additional seven meetings, with the last one held in April 1990 in Hamburg, Germany, four documents have been finally established: 1) aircraft deicing/anti-icing fluids, Newtonian, ISO Type I; 2) aircraft deicing/anti-icing fluids, nonNewtonian, ISO Type II; 3) deicing/anti-icing self-propeller vehicle, functional requirements; and 4) aircraft deicing/anti-icing methods with fluids.

Having taken the AEA document as the baseline, the four ISO documents do include all fundamental AEA requirements and those specific formal items on top to assure international acceptance. There is no major difference concerning procedures and materials, i.e., AEA Type II fluid = ISO Type II fluid.

At the 21st Planetary Meeting of ISO TC20/SC9, May 22–25, 1990 in Sao Paulo, the subcommittee unanimously agreed to the documents and approved them for preparation of the draft international standard ballot.

Other International Activities

Society of Automotive Engineers

The Society of Automotive Engineers (SAE) is involved in two continuing aspects of de-/anti-icing and one temporary activity (in partnership with the Air Transport Association). The permanent activities include 1) the production of aerospace standards (AS), aerospace information reports (AIR), and aerospace recommend practices (ARP); and 2) specification of fluids such as aerospace material specifications (AMS).

The particular SAE committee for ground support equipment is the aerospace ground equipment (AGE-2). AIR 1335 ramp deicing, was released in Jan. 1976. Although this information is still useful, it lacks coverage of the new Type II fluids. AGE-2 has two ground equipment specifications that are current: 1) ARP 1971, aircraft deicing vehicle—self propelled, large capacity; and 2) ARP 4047, aircraft deicing vehicle—self propelled, small capacity.

Both of these SAE specifications note that the pumping system, if required, must handle both Types I and II fluids. The SAE ARPs on ground equipment form the basis for the equipment ISO specifications.

The temporary activity is conducted by the recently formed SAE/ATA ad hoc committee which will focus on all of the associated activities. Presently this group has defined an overall procedure, similar to the ISO, as being the main ingredient that is lacking on the North American scene.

Aerospace Industry Association

The Aerospace Industry Association (AIA) has supported ISO activities by developing suitable aerodynamic testing standards for fluids.

Federal Aviation Administration

The Federal Aviation Administration (FAA) advisory circular AC20-117 provides an overview of its subject: "Hazards Following Ground De-icing and Ground Operations in Conditions Conductive to Aircraft Icing." Appendix I of this AC lists many other FAA publications related to cold weather operations. Released in December 1982, AC20-117 does not specifically address Type II fluids. Therefore, the industry asked the FAA to reissue this document to assure complete coverage of existing and proven methodologies.

Summary of Operational Experience

Since 1982, 21 European airlines operating 1191 aircraft have followed the AEA recommendations. The safety enhancement due to this approach is evident because in Europe no accident was recorded on jet transport category aircraft in which de-/anti-icing was a contributing factor.

An average of 11.5 Mill. ltr. = 12,300 tons of AEA Type II fluid is used in Europe each winter. Four European airlines set up in JFK in 1984 a pool for AEA Type II usage, per annum about 20,000 USG are used.

Due to the ongoing discussions finalization of specification activities and industry support from the ATA, AIA, and the FAA, the major US-airlines have started or are starting Type II fluid application and procedure implementation. On more than 20 North American airports in the winter of 1990–91 these products are available.

Implementation of this new fluid generation is an investment in safety, and it is not free of charge because 1) the equipment must be modified; 2) storage facilities must be changed; 3) maintenance people have to be specifically trained; and 4) a learning curve must be established, but any investment in safety will pay off.

References

[1]"Recommendations for De-/Anti-Icing of Aircraft on Ground," AEA, Brussels, Feb. 1991.

[2]Hill, E. G., "Aerodynamic Acceptance Test for Aircraft Ground De-Icing/Anti-Icing Fluids," Boeing Commercial Airplane Co., D6-55573, Seattle, WA, Oct. 1990.

[3]"Aircraft Ground De-Icing Conference Proceedings," Society of Automotive Engineers, Warrendale, PA, July 1989, p. 217.