Aircraft Deicing Operations

Final Project

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1 Introduction and Motivation

Aircraft deicing is a crucial process of removing frost, ice or snow from the surface of the aircraft. Deicing is usually followed by anti-icing – process of preventing further buildup for a limited holdover time. In this paper, deicing refers to deicing/anti-icing combination. Without proper treatment of an aircraft during snowy and icy conditions, the accumulation of frost, ice or snow changes the airflow over the aircraft wings, reducing the lift and increasing the drag. Ice and snow also adds to the total weight of an aircraft, increasing its required lift for takeoff. The combination of these effects can bring about significant consequences. A few notable accidents include a 1982 crash of Air Florida flight out of Washington-National Airport, DC, and a more recent 2004 crash of China Eastern Airlines flight from Baotou, China to Shanghai; both crashes occurred moments after takeoff due to improper deicing procedures [1][2].

In order to comply with aircraft deicing regulations, airports and airlines have been devoting considerable resources to the entire deicing process. There are many factors to consider before investing in a particular system – cost of various deicing methods, environmental restrictions, location and available space, type of aircraft demand, etc.

This paper aims to review some of the current deicing practices, their regulatory considerations and their costs. Consideration is also given to some of the environmental concerns and policies regarding deicing, the future of aircraft deicing technology and how it can change current systems and procedures.

2 Deicing Regulatory Guidelines

In the US, the Federal Aviation Administration (FAA) provides regulations for airports and airlines that operate during icy conditions. The following is a list of some applicable regulations:

- Code of Federal Regulations (CFR) Sec. 121.629 dictates operating requirements in icing conditions, including the fact that takeoff of an aircraft that has frost, ice or snow adhering to critical surface is not permitted – clean aircraft concept – and gives information on holdover time procedures [3].

  - Advisory Circular (AC) 120-60B in accordance with CFR provides an "industry-wide standard means for obtaining approval of a Ground Deicing/Anti-Icing Program" [4]. It also provides means for contractors or a certificate holder using other certificate holder's personnel to deice.
- AC 135-16 provides ground deicing training requirements for training programs of certain air carries. It also provides requirements for pre-takeoff contamination checks for certain air carries [5].
- AC 120-58 provides guidelines for developing large aircraft deicing procedures aimed at personnel responsible for ground deicing [6].
- AC 135-17 provides recommendations for pilots of small aircrafts for ground deicing [7].
- AC 150/5300-14B provides standards for aircraft deicing facilities. Aircraft deicing facilities can be located, per FAA standards, at terminal gates/apron areas, near departure runway ends or along taxiways [8].

Similar deicing requirements and guidelines can be found within the International Civil Aviation Organization (ICAO) documents. Particularly, Annex 6 – *Operation of Aircraft*, Part I, and the *Manual of Aircraft Ground De-icing/Anti-icing Operations* (Doc 9640) Second Edition 2000 [9].

3 Current Deicing Practices

3.1 Aircraft Deicing Fluids

Aircraft deicing fluids (ADFs) are organized into four classes: Type I, Type II, Type III, Type IV. The two freezing-point depressants that can be found in them are either propylene glycol or ethylene glycol. The Society of Automotive Engineers (SAE) sets the technical standards for ADFs. The fluids are categorized based on their properties [10]:

- Type I fluids are mainly of low viscosity and are used for the removal of frost, ice, and snow from the surface of the aircraft.
- Type II fluids are non-Newtonian fluids and are applied for anti-icing purposes on a clean surface.

- Type III fluids are developed for anti-icing purposes for aircrafts with lower rotation speed at liftoff.
- Type IV fluids are similar in function to Type II fluids but allow for longer holdover times – time for which ground anti-icing fluid will provide protection from frost, ice or snow.

Type I and Type IV are the most commonly used fluids today. According to the US Environmental Protection Agency (EPA), propylene glycol-based ADFs are more popular than ethylene glycol-based ADFs based on survey responses they collected for the 2002-2003, 2003-2004, and 2004-2005 deicing seasons [11].

Chemical	Average Total Airport Use/Purchase (million gallons/year)	Percentage of ADF Use/Purchase
Type I Propylene Glycol Aircraft Deicing Fluid	19.305	77.1
Type IV Propylene Glycol Aircraft Anti-Icing Fluid	2.856	11.4
Type I Ethylene Glycol Aircraft Deicing Fluid	2.575	10.3
Type IV Ethylene Glycol Aircraft Anti-Icing Fluid	0.306	1.2

Source: US EPA Airline Deicing Questionnaire (2006b).

Table 1: Estimate of Aircraft Deicing Fluid Use/Purchase by US Commercial Airports

Deicing fluids can be used in various combinations and volume to serve specific deicing needs. For instance, the practice of applying aircraft anti-icing agents in advance of predicted icing can reduce the amount of deicing fluid (Type I) needed. Since anti-icing fluids are applied in smaller volumes than deicing fluids, proactive anti-icing can be a cost effective measure.

Reducing the volume required of deicing Type I fluid can also be achieved by optimizing its concentration relative to the outside air temperature. All ADFs have data for the lowest operational use temperature for a range of mixture. The blending of fluid to air temperature does require compliance to the SAE Aerospace Recommended Practice (ARP) 47274 specification that dictates that the residual Type I ADF on the surface of an aircraft must have a freezing point of at least 18ºF below the outside air temperature or aircraft skin temperature [12].

The choice of alternative fluids is constrained to the SAE certified products and the need to revise FAA approved plans.

3.2 Hot Water Aircraft Deicing

Hot water deicing helps reduce the amount of ADFs used for deicing operations. Hot water deicing requires to heat and distribute water over the aircraft surface with water temperature of at least 140ºF. The FAA allows for hot water deicing followed by an application of an anti-icing fluid when the ambient air temperature is above 27ºF [13]. The performance level of hot water deicing depends on the local weather during which deicing is implemented and can be a successful practice during relatively mild winters. Hot water deicing has fewer operating costs than using ADFs alone as the required volume of theses fluids, particularly of Type I, is reduced.

3.3 Forced Air Deicing System

Forced air deicing system delivers high-pressure air to the aircraft surface and is effective in removing dry, powder snow. In some cases, an aircraft deicing fluid can be added to the air stream to create a hybrid system that can be more effective in removing ice and wet snow.

Forced air deicing has been adopted by various airlines as part of their deicing operations. At the Nagano Airport in Japan, forced air deicing is used to remove snow from aircrafts that are parked overnight at the airport [13]. Aircraft operators who use this technology do so because:

- Under certain conditions, the time needed to clean the aircraft of snow can be significantly reduced.
- Under certain conditions, the ADF usage is reduced, thus also reducing the volume of fluid purchased and frequency of refilling deicer trucks.
- By reducing ADF usage, it is easier to comply with stormwater regulations and reduce the costs of wastewater disposal.

Overall, forced air deicing systems do not eliminate the need for ADFs and are not cost-effective in areas where icy conditions and heavy wet snow dominate.

3.4 Hangar Storage

Hangar storage prevents snow and ice from accumulating on the aircraft surface. By not exposing the aircraft to snow and ice until just prior to departure, less ADFs are used in the deicing process. Mainly, only Type IV fluid is needed to keep snow and ice build-up during taxiing from hanger parking to the runway. The effectiveness of hangar parking depends on size of aircraft, departure times and traffic, and the location and availability of hangar space. Due to the cost and space needs of hangar storage, smaller airports can implement this system more easily.

3.5 Airline/Airport Deicing Relationships

There are various ways in which airlines and airports handle deicing operations. Airlines may be responsible for deicing their own aircrafts, deicing other airlines' aircrafts, or use fixed-based operators (FBO).

Airports designate areas where deicing can take place. Most commonly, deicing is conducted at deicing pads, terminal gates, and apron areas. Airports also provide systems of collecting ADF contaminated stormwater.

Airports can concentrate deicing activities to one or more centralized locations. This practice minimizes deicing containment areas. In most cases, centralized deicing is a result of airport's compliance with stormwater discharge permits, which is further addressed in Section 4, Deicing and the Environment. Centralized deicing facilities have shown to have the highest performance of glycol collection practices due to the fact that deicing activities are consolidated into confined areas and that centralized deicing is commonly done near the head of runways, resulting in shorted holdover times and less use of Type IV ADF.

The largest centralized deicing facility is currently at Toronto Pearson International Airport. The complex is capable of deicing up to six ICAO code Class E aircrafts or twelve Class C aircrafts at any given time. The facility is also equipped to deice queued aircrafts to increase the throughput capacity of the facility [14]. Based on this example, it seems that high capital costs and required space for such a facility make centralized deicing more practical for larger airports.

4 Deicing and the Environment

4.1 Environmental Concerns

All airports in the US are required to obtain discharge permits for stormwater or for other industrial wastewaters through the National Pollutant Discharge Elimination System (NPDES) program. Permit requirements vary from airport to airport as local water quality issues are accounted for in the development of individual airport stormwater discharge permits.

Current deicing methods result in a number of adverse effects on the environment. ADFs are designed to adhere to the surface of an aircraft for a limited amount of time. According to an analysis done by the EPA, about 80% of Type I ADFs drip to the ground at the application site and about 10% of Type IV fluids fall to the ground during application. Type IV fluids are designed to remain on the aircraft surface longer so as to prevent new ice and snow from accumulating before takeoff; therefore, most of Type IV fluids fall from the aircraft during taxiing and takeoff. These fluids can then be swept by stormwater runoff and discharged into streams, lakes, or rivers. The EPA has identified the following environmental impacts of deicing discharges [11]:

- Dissolved oxygen levels in receiving waters of deicing stormwaters discharges are reduced.
- Nutrient concentrations in receiving waters of deicing stormwaters discharges are increased.
- Dead zones for aquatic life downstream of deicing stormwater outfalls.
- Overall impact to aquatic ecosystems such as drop in organism abundance and diversity.
- Groundwater and surface drinking water resources contamination.
- Foaming, noxious odors, and discolorations of surface waters.
- Deicing stormwater odors have brought on headaches and nausea complaints by people who are exposed to them.

The EPA has reported the following estimate of current national chemical oxygen demand (COD) – a primary environmental characteristic of aircraft deicing – discharges just from ADF application sites (table taken from [11]):

Airport Hub Size	ADF Application Site COD Discharge (pounds/year)
Large	70,287,571
Medium	28,433,086
Small	9,863,368
Nonhub	17,382,976
General Aviation/Cargo	2,412,898
Total	**128,379,900**

Table 2: COD Discharge for Various Type Airports in the US

4.2 ADF Collection and Containment Methods

Several practices have been implemented by airports to help meet environmental restrictions on stormwater discharges [13]:

- Stormwater Drainage System – designed to divert deicing stormwater from airfield operations and reduce the amount of stormwater contaminants before surface water discharge. Drainage systems are subject to significant amount of regulation. Aside from environmental regulations, FAA's AC-150/5320-5C provides guidance for airport drainage systems.
- Glycol Recovery Vehicles (GRVs) – provide the means of collecting aircraft deicing runoff from pavement surfaces using specialized vehicles that vacuum liquid from surfaces. The contaminated wastewater is then typically transported to an on-site storage facility. This method of collecting deicing runoff can be easily integrated with other collection and containment methods.
- Block and Pump Systems – work by intercepting deicing runoff near the source by using storm drain inserts or plugs to block drains and use existing storm sewers for temporary storage of the ADF contaminated stormwater. The stormwater can then be pumped out. This system can be used with GRVs to collect deicing runoff.
- Containment Ponds – provide storage for collected deicing stormwater prior to treatment or surface water discharge. During detention, solids are allowed to settle and pollutant concentrations are equalized. Ponds can also contain microscopic

bacteria that is used to biodegrade the deicing material. Ponds, however, require large areas for installation and uncovered ponds may present a hazard by attracting wildlife. As a result, the FAA put out AC 150/5200-33, Hazardous Wildlife Attractants on or Near Airports, to provide guidelines on installation of stormwater containment ponds.

- Storage Tanks – provide storage for deicing runoff in aboveground or underground storage tanks. Storing deicing stormwater in deicing tanks has the benefit of equalizing pollutant concentrations but do not attract wildlife like the containment ponds. There is also the option of portable tanks (Frac tanks) that provide temporary storage in a mobile storage tank that can be easily removed from the airport site.

The following table shows the type of ADF collection and containment methods currently employed in US airports.

Collection/Containment/Conveyance Method	Estimated Number of Airports	Percentage of Airports
Stormwater drainage system	211	63
Containment pond/basin	121	36
Aboveground/underground Tank	57	17
Glycol recovery vehicles/sweepers	54	16
Other (vegetated swales, snow melters, absorbant)	34	10
Plug and pump	29	9

Source: EPA airport questionnaire database (Scaled to national estimate) (USEPA, 2008c).

Table 3: ADF Collection and Containment Methods and Percentage of US Airports Using Them

4.3 Proposed New Regulations

The EPA has recently evaluated new regulatory measures on the collection and treatment requirements for deicing discharges. The four proposed options are [15]:

1) Airports that have 10,000 or more annual departures will be required to collect and treat at least 20% of deicing operation discharges from ADF application sites.
2) Airports that have 10,000 or more annual departures will be required to collect and treat at least 40% of deicing operation discharges from ADF application sites.

3) In addition to option 1) requirement, airports using more 460,000 or more gallons of propylene glycol/ethylene glycol annually will be required to collect and treat at least 60% of deicing operation discharges from ADF application sites.
4) Airports that have 1,000 or more annual jet departures will be required to collect and treat at least 20% of deicing operation discharges from ADF application sites. Airports using more 460,000 or more gallons of propylene glycol/ethylene glycol annually will be required to collect and treat at least 60% of deicing operation discharges from ADF application sites.

The number of airports affected by these proposed changes and the annual pollutant discharge reductions depends on the selected option (data taken from [15]):

Proposed Regulatory Option	Number of Airports Subject to Option	ADF COD reduction (million pounds)
Option 1	110	9.0
Option 2	110	18.8
Option 3	110 (14 to 60% requirement, 96 to 20% requirement)	27.2
Option4	218 (14 to 60% requirement, 204 to 20% requirement)	29.3

Table 4: Number of Airports subject to Proposed Regulations and the COD Reduction for Each Option

As a note, Options 3 and 4 would require some of the US major airports – New York JFK, Chicago O’Hare, Cleveland-Hopkins International, Newark Liberty International, Boston Logan International and New York LaGuardia – to contain 60% of their applied ADFs [16]. These airports will need to make heavy investments in new ADF collection and containment technologies.

5 Future of Deicing Technology and Policy

5.1 Infrared Deicing Systems

Infrared (IR) deicing technology involves melting frost, ice, and snow from aircraft surface with infrared energy. IR energy systems are based on natural gas- or propane-fired emitters that are used to melt frost, ice, and snow. Infrared energy does not heat up the surrounding air and tests have shown that it has negligible effect on the aircraft cabin temperature [13].

Two main manufacturers are leading the way in developing infrared-based deicing systems: Radiant Energy Corporation with the InfraTek™ system and Infra-Red Technologies with the Ice Cat™ system. The Ice Cat™ system uses IR emitters fueled by natural gas or propane mounted on booms that are fitted to specially designed trucks. The booms are then positioned above the aircraft surface and the IR emitters are used to remove frost, ice, and snow. Currently there is no commercial application of this system.

The InfraTek™ system consists of infrared generators, called Energy Processing Units (EPUs), located in an open-ended, hangar-type structure. The EPUs are fueled by natural gas and generate IR energy waves to melt and evaporate frost, ice, and snow. If the aircraft surface is dry, the IR waves are reflected away. A diagram of this process is shown below (figure taken from [17]):

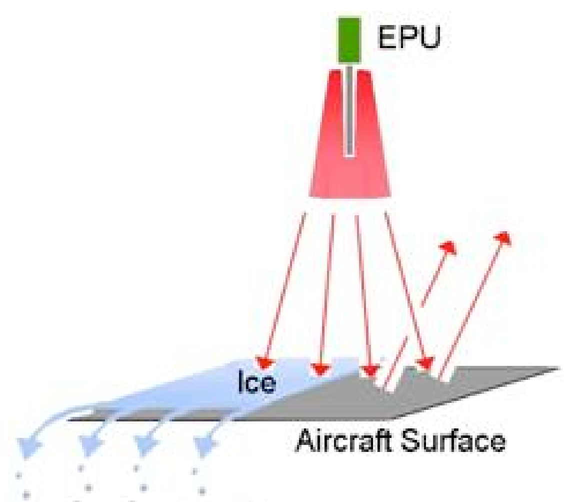

Figure 1: Diagram of How InfraTek™ Deicing System Works

The InfraTek™ system is designed to be operated by only one person and is mainly controlled by a computer. Before deicing can begin, the floor of the InfraTek™ system facility is heated in order to facilitate the deicing process of aircraft lower parts such as the landing gear. Depending on the type of aircraft and the severity of ice and snow build up, the energy and wavelength generated by the EPUs are adjusted. In March of 1996, InfraTek™ technology was shown to deice a Boeing 727 in six minutes, which is about the same amount of time it would take to achieve deicing results using conventional ADFs [13].

There are currently three InfraTek™ Deicing System facilities in the US and one in Oslo, Norway. The largest by volume is the one installed at JFK International Airport in March 2006. The facility was operating during the 2006-2007 deicing season. The system is designed to provide deicing services for up to a 747-300 size aircraft [18]. The following performance benefits have been documented:

- Approximately 90% reduction of glycol use per aircraft under snow and ice conditions.
- No glycol use for defrosting operations.

Furthermore, in terms of budget management, using the InfraTek™ system allows more accurate winter operations budgets for customers since the system charges a fixed fee based on the size of the aircraft. Conventional deicing methods are priced based on the volume of fluid applied, which varies based on the severity of winter weather conditions. However, cost data is currently limited by the number and scale of facilities using the InfraTek™ system.

5.1.1 Implementation Issues

Although IR energy systems have been in development since the mid-1990s, their use is not yet widespread. A few things to consider over their implementation are:

- The physical size of systems such as InfraTek™ make planning and design for such a system quite complex. Certain airports might not be able to accommodate such a facility as the structure needs to conform to FAA part 77 – Objects Affecting Navigable Airspace.
- Due to the aircraft processing capacity of an InfraTek™ type system, an IR facility can present a bottleneck during peak traffic hours. Traffic analysis is crucial for airports looking to adopt an IR system.
- While IR systems reduce the need for ADFs, thus limiting the environmental impact from these fluids, the system cannot provide anti-icing protection. Some

anti-icing fluid use is still required to provide holdover times and so is the collection and containment of these fluids.

- The JFK InfraTek™ facility is reported to have cost $9.5 million [18]. With such infrastructure costs, there needs to be a commitment by airlines to make use of the facility.

5.1.2 Regulatory Issues

The FAA has put out several guidelines and recommendations for ground deicing using IR energy. In particular, AC 120-89 allows IR energy use to deice aircrafts to be part of certificate holder's deicing program [19]. The FAA also published AC 150/5300-14, Change 2 to the Design of Aircraft Deicing Facilities to include IR facility guidelines [8].

As IR energy deicing technology continues to develop and spread, environmental concerns over this new system will need to be considered. For instance, what is the necessary power generation used by the IR emitters and do they have possible adverse effects. Also considered should be the air emissions by aircrafts moving to and from the IR deicing facility. Answers to these questions should be answered though studies performed at the local airport level [18].

5.2 Tempered Steam Technology

Tempered Steam Technology (TST) uses a mix of air and water vapor steam-infused air to melt ice on aircraft surface and then plain hot air to dry the surface. The system also includes an inflated blanket type device that is affixed to a vehicle boom to ensure that the heat is contained. Several tests have been conducted during the 2006-2007 deicing season. The new device demonstrated the ability to deice and dry up to 6 cm of snow and up to 2 cm of ice in about 10 minutes [20]. TST can thus prove to be useful for frost removal and pre-deicing applications, potentially reducing the volume of Type I ADF needed to deice an aircraft.

5.3 Under Development Technology

There are a few deicing technology that is currently under development [13].

- Polaris Thermal Energy Systems, Inc has been evaluating warm fuel as a deicing method. If the wing fuel tanks are infuse with heated fuel, frost, ice, and snow will not form on the aircraft wing surface. This will reduce the amount of ADF needed to deice the aircraft.
- At the Dartmouth's Thayer School of Engineering, Dr. Victor Petrenko is working on pulse electro-thermal deicing. This method uses short pulses of electricity to break up the ice.
- Foster-Miller, Inc. is trying to develop technology that will provide anti-icing protection by coating the aircraft surface. This surface treatment will not require ADF usage.

5.4 Improved Weather Forecasting

Weather forecasting plays a crucial role in optimizing aircraft deicing operations. Real-time forecasting assists airport operators in making accurate decisions on deicing applications. Manpower and money is wasted if more resources than necessary are devoted to deicing operations due to inaccurate forecasts.

Improved technology in weather forecasting has been in development. One such system is the Weather Support to De-icing Decision Making (WSDDM) developed at the National Center for Atmospheric Research (NCAR). The WSDDM system includes sensors that measure temperature, atmospheric pressure, dew point, and wind speed and direction as well as snow gauge that measures the liquid equivalent of snowfall. The data is outputted by an integrated display system that requires minimal training to operate [21]. The use of WSDDM system is also beneficial in determining accurate holdover times as it is able to determine the type of precipitation occurring at any moment and its liquid equivalent value. The system can calculate the time it will take before a particular ADF will fail in real-time under existing conditions.

The WSDDM system was developed with the support of the FAA. In AC 150/5200-30C, Airport Winter Safety and Operations, the FAA recommends airport operators to adopt WSDDM type systems [22]. The system complies with equipment performance and installation requirements provided by the SAE Aerospace Standard AS #5537.

6 Conclusions

The process of aircraft deicing is a vital part in not just aircraft safety but in airport design and management as well. To draw from the design of Denver International Airport (DIA), the facility manager there for Inland Technologies' glycol recovery and recycling plant once said, "They built the deicing system first, and then basically build the airport around it" [23]. This is to show that deciding on and installing a new deicing system is quite complex, especially with the expansion of various new technologies and environmental regulations. At this stage, it looks like no technology can escape at least some ADF usage, meaning that airports will always need to contain the environmental impact of these fluids. Does it make more sense for airports to invest and change their systems to accommodate new deicing technology that uses less ADFs or to invest in advancing new glycol collection and recycling systems? It seems that particularly major airports will not be able to avoid large capital expenditure associated with deicing operations.

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