COPY 1

DOT/FAA/CT-85/21
FAA Technical Center
Atlantic City Airport
N.J. 08405

Ground Aircraft Deicing Technology Review

Deborah Mayer
Joseph Michitsch
Rosie Yu

ARINC Research Corporation
2551 Riva Road
Annapolis, Maryland 21401

FEDERAL AVIATION ADMINISTRATION
NOV 21 1986
TECHNICAL CENTER LIBRARY
ATLANTIC CITY, N.J. 08405

March 1986

Final Report

This document is available to the U.S. public through the National Technical Information Service, Springfield, Virginia 22161.

U.S. Department of Transportation
Federal Aviation Administration

NOTICE

This document is disseminated under the sponsorship of the Department of Transportation in the interest of information exchange. The United States Government assumes no liability for the contents or use thereof.

The United States Government does not endorse products or manufacturers. Trade or manufacturer's names appear herein solely because they are considered essential to the object of this report.

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
DOT/FAA/CT-85-21		

4. Title and Subtitle	5. Report Date
Ground Aircraft Deicing Technology Review	March 1986
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
D. Mayer, J. Michitsch, R. Yu	3038-01-1-3985
9. Performing Organization Name and Address	10. Work Unit No. (TRAIS)
ARINC Research Corporation 2551 Riva Road Annapolis, MD 21401	11. Contract or Grant No. DTFA03-84-C-00086
12. Sponsoring Agency Name and Address	13. Type of Report and Period Covered
U.S. Department of Transportation Federal Aviation Administration Technical Center Atlantic City Airport, NJ 08405	Final Report September 1984 - March 1986
	14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

This report provides a review and update of operational, procedural, and system information regarding on-ground deicing of aircraft prior to flight. It reflects current practices of the different segments of aviation with the preponderance of information addressing the ground deicing operations and procedures employed by the airlines. Survey results presented in this report reflect the airlines' adherence to the "clean aircraft concept" as presented in Advisory Circular 20-117, and also indicates the need for a better understanding of the different types of deicing fluids and facilities currently available.

17. Key Words	18. Distribution Statement
Deicing; anti-icing; ground icing; freezing point depressants; aircraft deicing fluids	This document is available to the U.S. public through the National Technical Information Service, Springfield, VA 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified		

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

ACKNOWLEDGEMENTS

The Federal Aviation Administration (FAA) provided the overall guidance to ARINC Research during this study. Special appreciation is extended to the FAA's Project Engineer, Mr. Larry W. Hackler, of the Aircraft Icing Engineering and Development Program at the FAA Technical Center. Also, a listing of manufacturers. Agencies, and groups that contributed to our understanding of aircraft deicing technology.

CONTENTS

	Page
EXECUTIVE SUMMARY	ix
CHAPTER ONE: INTRODUCTION	1-1
1.1 Background	1-1
1.2 Purpose	1-2
CHAPTER TWO: AIRCRAFT DEICING/ANTI-ICING FLUIDS	2-1
2.1 General Characteristics	2-1
2.1.1 ADF Properties	2-1
2.2 North American Commercial Fluids	2-4
2.2.1 North American ADFs: Types and Manufacturers	2-4
2.2.2 North American ADFs: Usage	2-4
2.3 European Commercial Fluids	2-5
2.3.1 European ADFs: Types and Manufacturers	2-6
2.3.2 European ADFs: Usage	2-8
2.4 Comparison of North American and European Commercial Fluids	2-11
2.4.1 Properties	2-12
2.4.2 Environmental Effects	2-13
2.4.3 Health Effects	2-16
2.5 United States Military Aircraft Deicing Fluids	2-17
2.6 Summary	2-17

CONTENTS (continued)

	Page
CHAPTER THREE: ON-GROUND AIRCRAFT DEICING EQUIPMENT	3-1
3.1 General Description	3-1
3.2 Specific Manufacturers	3-2
3.2.1 The Ted Trump Company	3-2
3.2.2 FMC Corporation Airline Equipment Division	3-9
3.3 Other Manufacturers	3-15
CHAPTER FOUR: DEICING/ANTI-ICING PROCEDURES	4-1
4.1 General Procedures	4-1
4.1.1 Training	4-1
4.1.2 Aircraft Surfaces	4-2
4.1.3 Types of Accumulation	4-5
4.2 Procedures Recommended by Aircraft Manufacturers	4-6
4.3 Procedures Recommended by Commercial Airlines	4-6
4.4 Procedures Employed by the General Aviation Community	4-10
4.5 Procedures recommended by the Association of European Airlines	4-11
CHAPTER FIVE: CENTRAL AND REMOTE DEICING FACILITIES	5-1
5.1 Central Deicing Facilities	5-1
5.1.1 Charles de Gaulle Roissy Airport	5-2
5.1.2 Dorval Airport	5-3
5.1.3 Mirabel International Airport	5-4
5.1.4 Kallax Airport	5-6
5.1.5 Pros and Cons of the Centralized Deicing Facility	5-6
5.2 Remote Deicing Facilities	5-8
5.2.1 Pros and Cons of Remote Deicing	5-9
5.3 Comparison of Deicing at Various Locations	5-9

CONTENTS (continued)

Page

CHAPTER SIX: INTERVIEWS WITH PERSONNEL INVOLVED WITH ON-GROUND AIRCRAFT DEICING 6-1

6.1 Commercial Airline Personnel. 6-1

6.1.1 Maintenance Personnel. 6-1
6.1.2 Pilots 6-4

6.2 General Aviation Personnel. 6-7

6.2.1 Fixed-Base Operators 6-7
6.2.2 Pilots 6-8

6.3 Summary 6-8

CHAPTER SEVEN: ACCIDENTS RELATED TO ON-GROUND ICING 7-1

7.1 Conditions Conducive To Icing 7-1
7.2 Accident Data Bases 7-2

7.2.1 Data Bases Reviewed. 7-2
7.2.2 Data Base Summary. 7-2

7.3 Data Base Discussion. 7-10

CHAPTER EIGHT: CURRENT RESEARCH 8-1

8.1 Association of European Airlines Fluid Research 8-1
8.2 Boeing Commercial Airplane Company Experiments with AEA Type II Fluids. 8-4
8.3 KLM/Kilfrost Research to Determine Ice Protection Properties of ADFS. 8-8

CHAPTER NINE: SUMMARY 9-1

APPENDIX A: BIBLIOGRAPHY. A-1

APPENDIX B: LIST OF ABBREVIATIONS B-1

APPENDIX C: COMPANY BROCHURES C-1

APPENDIX D: ACKNOWLEDGEMENTS D-1

CONTENTS (continued)

LIST OF ILLUSTRATIONS

Figure		Page
2-1	Freezing Point Curves of Aqueous Glycol Solutions	2-2
2-2	Refractometer and Antifreeze Protection Measurement Scale	2-3
2-3	Freezing Point Curves of Various ADFs	2-12
3-1	Trump Model D-40-D.	3-3
3-2	Trump Model DD-1000	3-7
3-3	Trump Model DA.	3-8
3-4	FMC Model TM-1800	3-10
3-5	FMC Model LA-1000	3-13
8-1	A Block Diagram of the Cold Wind Tunnel	8-2

LIST OF TABLES

Table		Page
2-1	Guideline to Holdovertimes: AEA Type I Fluids.	2-9
2-2	Guideline to Holdovertimes: AEA Type II Fluids	2-10
2-3	Comparative Properties of Ethylene, Diethylene, and Propylene Glycol.	2-14
2-4	Composition of Military Type I and Type II ADFs	2-18
2-5	Chemical and Physical Properties of Military Type I and Type II ADFs.	2-18
4-1	AEA's Aircraft Deicing and Anti-Icing Procedures.	4-12
7-1	Accidents/Incidents Related to On-Ground Icing (1977-1985)	7-3
7-2	Summary of ASRS Entries of Supposed Incidents Related to Ground Deicing Procedures.	7-11

EXECUTIVE SUMMARY

The Federal Aviation Administration (FAA), as part of its ongoing effort to promote and enhance aviation safety, may provide advisory information and other guidance documentation when safety is affected. FAA Advisory Circular (AC) 20-117, "Hazards Following Ground Deicing and Ground Operations Conducive to Icing," is an example of such documentation. That AC, which emphasizes the "clean aircraft concept," is directed to all members of the aviation community. In support of the FAA's efforts to enhance aviation safety, it contracted with ARINC Research Corporation to study current ground deicing and anti-icing procedures.

Deicing usually employs a glycol based aircraft deicing fluid (ADF) which is applied by means of truck-mounted deicing units; however, brooms and brushes are sometimes used to help remove contaminant accumulation. The deicing vehicles have capacities ranging from 700 gallons to 1800 gallons. Smaller, portable tank units that are carried on carts or trailers are also used. The more complex deicing vehicles contain elaborate heating systems and mixing systems that allow the operator to modify the concentration of the ADF in the deicing mixture as necessary during the operation.

Operational procedures employed in on-ground aircraft deicing vary according to the type of accumulation on the surface of the aircraft. The procedures used by most airlines are based upon the recommendations of the aircraft manufacturers. The airlines provide guidelines to help deicing personnel determine the appropriate amount of ADF to be used in the deicing mixture.

Most deicing operations are conducted at the gate, but central or remote locations are sometimes used. Central facilities exist at Dorval Airport and Mirabel Airport, both in Montreal, Canada; Charles de Gaulle Airport, Paris, France; and Kallax Airport, Luela, Sweden. Remote deicing facilities, sometimes employed during periods of heavy frozen precipitation, are composed of two or more deicing vehicles situated in a car-wash type of arrangement. The aircraft are parked between the vehicles for deicing. Central and remote deicing facilities can be especially effective when located near the end of the runway so that the time between deicing and taekoff is minimal.

Interviews were conducted with commercial airline maintenance personnel and pilots and with general aviation (GA) fixed-base operators (FBOs), maintenance personnel, and pilots regarding procedures used for the on-ground deicing and anti-icing of aircraft. These interviews revealed that:

- Deicing procedures do not vary much between airlines
- Some airlines use premixed deicing solutions; others use proportional mixing systems available on some deicing vehicles
- Pilots and deicing personnel in North America are not very aware of AEA Type II fluids
- One airline reported that landing gear is deiced, especially when slush is present on the runway
- GA pilots would like better training regarding the hazards associated with icing

A review of data bases maintained by the FAA, the International Air Transport Association, the International Civil Aeronautics Organization, the National Aeronautics and Space Administration, the National Transportation Safety Board, and the U.S. Army, Navy, and Air Force revealed that 67 accidents and incidents related to on-ground icing were reported between 1977 and 1985. Fourteen of these accidents were fatal, with a total of 116 fatalities.

Research related to on-ground deicing technology is currently being conducted by the Association of European Airlines (AEA). Recently, Boeing Commercial Airplane Company and KLM Royal Dutch Airlines completed other related research efforts. The AEA is currently sponsoring an aircraft anti-icing research program to study the affects of AEA Type I and II fluids on aircraft aerodynamics or flight characteristics. The Boeing Commercial Airplane Company conducted wind tunnel tests to investigate the possible aerodynamic effects of AEA Type II fluids when used on commercial jet transports. Finally, KLM Royal Dutch Airlines and Kilfrost, Ltd., have conducted experiments with various ADFs in an attempt to obtain insight into the ice protection properties of these fluids.

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND

The Federal Aviation Administration (FAA) as part of its on-going effort to promote and enhance aviation safety, provides advisory information and other guidance documentation when safety is affected. FAA Advisory Circular (AC) 20-117, "Hazards Following Ground Deicing and Ground Operations Conducive to Icing," is an example of this effort. FAA AC 20-117 emphasizes the "clean aircraft concept" following ground operations in conditions conducive to aircraft icing. That advisory circular is directed to all members of the aviation community, including aircraft manufacturers, airline engineering, maintenance, service and operations organizations, and aircrews of all aircraft types and categories.

The information included in FAA AC 20-117 provides a basic understanding of the types of accumulation that may be encountered during icing conditions and general guidelines for their removal. Guidelines for inspecting the aircraft to ensure that it is free of contaminant accumulation are presented. These guidelines are intended to assist the aviation community in complying with Federal Aviation Regulations (FAR) Sections 91.209, 121.629, and 135.227, which make the clean aircraft concept law.

The ice, frost, or snow that accumulates on aircraft surfaces can be removed by a variety of methods outlined in FAA AC 20-117. These include manual methods, such as using brooms or applying hot water, applying aircraft deicing fluids (ADFs), or applying a mixture of ADF and water. FAA AC 20-117 cautions that presently available ADFs should not be considered to have anti-icing qualities for a measurable period of time due to the multitude of variables associated with weather conditions. A pre-flight inspection, conducted during or immediately following the deicing/anti-icing process, will be necessary to determine whether the aircraft is clean and ready for takeoff.

Since the publication of FAA AC 20-117 in December 1982, there have been new developments in ground deicing/anti-icing technology and

procedures at aircraft operators, airports, universities, government agencies, and at ADF manufacturers and vendors. In addition, while FAA AC 20-117 provides extremely detailed information regarding ground deicing and anti-icing procedures for ground and flight crews, there is a question of what it is the airlines are actually doing, and to what extent, if any, have their present day procedures superceded those detailed in FAA AC 20-117. The FAA contracted with ARINC Research Corporation to study the present, proposed, and projected state of the art regarding these issues.

1.2 PURPOSE

This report is intended to document the state of the art of on-ground deicing and anti-icing applicable to aircraft certified for FAR Parts 91, 121, and 135 operations. The information included in this document was obtained through an examination of airline and aircraft manufacturer maintenance manuals and product literature, a literature survey, on-site observations, an examination of aviation accident and incident data bases, and discussions with airlines, aircraft manufacturers, ADF manufacturers, vehicle manufacturers, pilots, deicing personnel, fixed base operators (FBOs) and other industry personnel from the United States, Canada, and Europe.

CHAPTER TWO

AIRCRAFT DEICING/ANTI-ICING FLUIDS

Aircraft deicing/anti-icing fluids are glycol-based fluids used to remove ice, snow, and frost (deice), and prevent further accumulation (anti-ice) on the aircraft. There are a variety of ADFs available today. These include ethylene glycol-based fluids such as those used in North America, fluids designed to specifications provided by the Association of European Airlines (AEA), and fluids designed to specifications provided by the United States military. The characteristics and properties of these fluids are described in the remainder of this chapter.

2.1 GENERAL CHARACTERISTICS

ADFs are sometimes referred to as freezing point depressant (FPD) fluids because when added to water, they lower the freezing point of the water. ADFs can be mixed with water to various concentrations in order to achieve the desired deicing and anti-icing performance. The following paragraphs describe the general characteristics of ADFs.

2.1.1 ADF Properties

Various chemical properties are important in characterizing ADFs. These include freezing point, specific gravity, refractive index, and viscosity. These properties are described in the following paragraphs.

2.1.1.1 Freezing Point

The freezing point is the temperature at which the first crystals of a fluid form. Below this temperature a slushy solution may exist which will still flow. As shown in Figure 2-1, the addition of any glycol to water lowers the freezing point of the mixture up to a concentration of 60 percent glycol, 40 percent water, which is usually referred to as a 60/40 mixture. At an ADF concentration higher than 60/40 it is difficult to measure freezing point because of the behavior of the fluid. As shown in Figure 2-1, the behavior of the mixture's freezing point curve is actually reversed between 90 to 100 percent ethylene glycol concentrations. In fact, the freezing point of 100 percent ethylene glycol is comparable to the freezing point of a 30/70 solution.

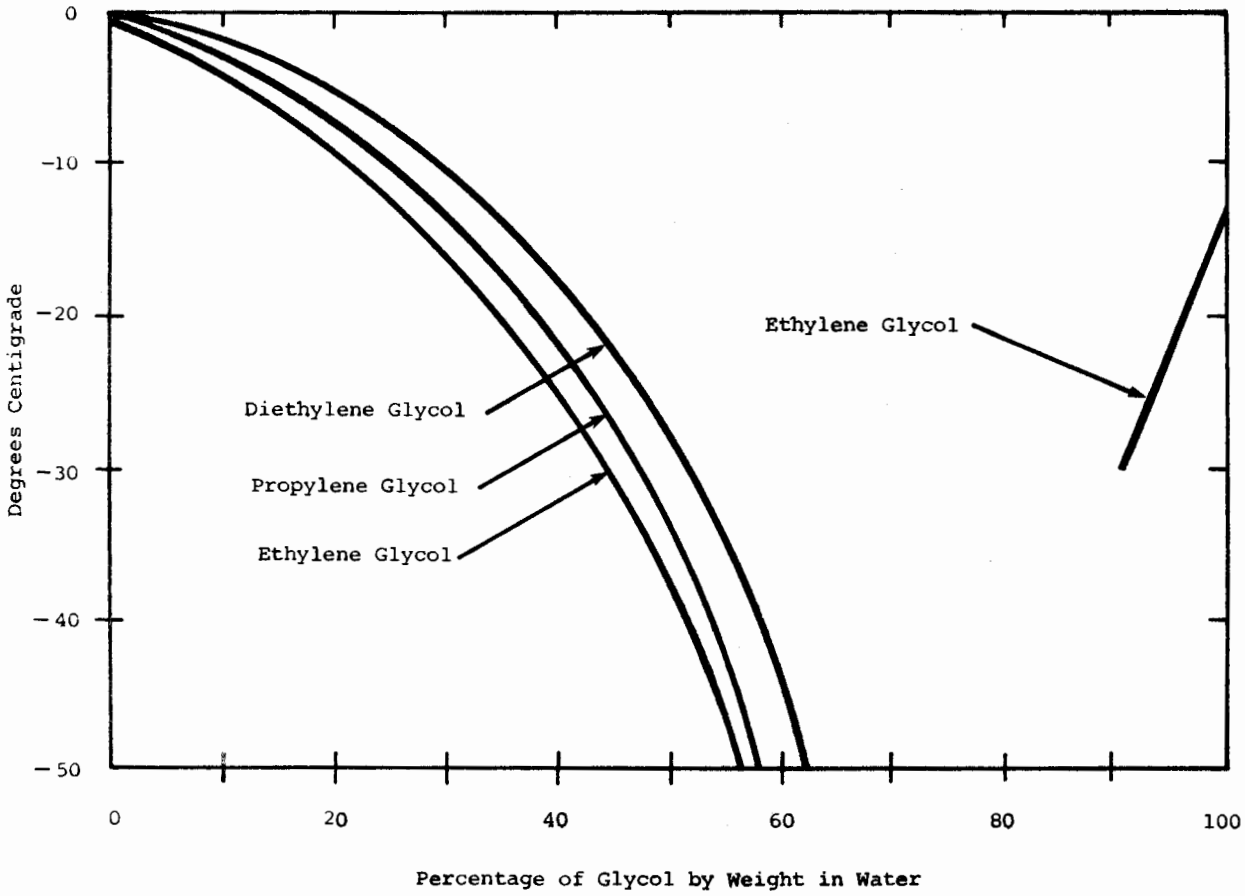

FIGURE 2-1

FREEZING POINT CURVES OF AQUEOUS GLYCOL SOLUTIONS

2.1.1.2 Specific Gravity

Specific gravity is the ratio of the weight of a given substance to the weight of an equal volume of a reference substance, usually water. A specific gravity hydrometer can be used to determine the freezing point of a given fluid. However, most operators prefer to use a refractometer rather than a specific gravity hydrometer because the specific gravity of a deicing fluid varies significantly with ambient temperature whereas the refractive index does not vary as much. Hence, refractometers provide a more accurate measure of ADF concentration in the field.

2.1.1.3 Refractive Index

The refractive index of a material is an optical measurement of its ability to bend a beam of light entering it. The refractive index gives an indication of the concentration of glycol in a gylcol/water mixture. A refractometer, of the type shown in Figure 2-2, is an instrument used to

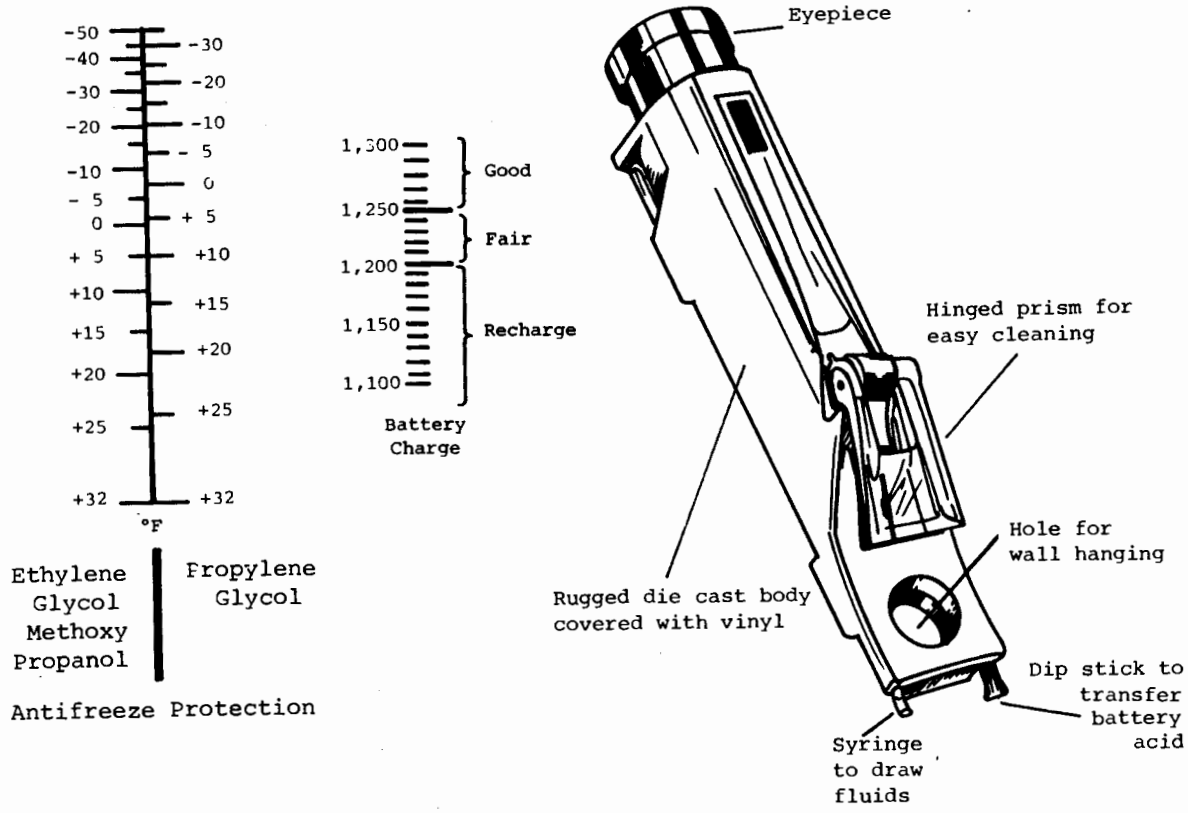

FIGURE 2-2

REFRACTOMETER AND ANTIFREEZE PROTECTION MEASUREMENT SCALE

measure the indexes of refraction and is often employed to measure anti-freeze protection of a given mixture, on the basis of the mixture's refractive index. The refractometer gives an immediate reading of the mixture's freezing point within an accuracy of 1°F. The refractometer provides a reading for hot or cold fluids and automatically corrects for fluid temperature variance. Most deicing equipment operators use the refractometer to determine the freezing point of a given fluid.

2.1.1.4 Viscosity

Viscosity is a measure of the internal friction of a fluid. The tendency of the fluid to flow decreases as the viscosity increases. That is to say that as the fluid becomes thicker it flows more slowly. The ADFs used in North America and Europe have different and distinguishing viscous properties, which will be discussed in detail in subsequent sections. Fluid viscosity is an important property to consider when studying ADFs since it is one of the primary differences between North American and thickened European ADFs.

2.2 NORTH AMERICAN COMMERCIAL FLUIDS

2.2.1 North American ADFs: Types and Manufacturers

The concentrated ADFs used by North American commercial airlines and the general aviation community are usually composed of 80 to 90 percent ethylene glycol and 10 to 20 percent water, corrosion inhibitors, wetting agents, and other glycols such as diethylene or propylene glycol. Users can purchase ADF in a concentrated solution or a 50 percent ADF with 50 percent water by volume solution. ADF manufacturers have chosen to use ethylene glycol as the main component in these ADFs because it has the lowest freezing points by weight percent compared to all other glycols, as shown in Figure 2-1. Further, ethylene glycol is readily available in North America since it is the main component used in automotive antifreeze.

The major manufacturers of ADFs in North America are Dow, Union Carbide, and Texaco. Most users refer to ADFs as deicing fluids, glycol, or in some regions, as MISCO. The manufacturers publish brochures, product information, and material safety data sheets to discuss the behavior and characteristics of their respective ADFs. The information provided by these publications typically includes physical properties such as appearance, freezing point, ph, specific gravity, flash point, and sometimes viscosity, pour point, refractive index, and fluid composition. The manufacturers also provide general fluid application recommendations, precautionary procedures, recommended methods of adjusting the concentration of the ADF, storage procedures, and health and environmental effects. The characteristics of primary interest are the freezing point, viscosity, and health and environmental effects.

2.2.2 North American ADFs: Usage

Commercial airlines, FBOs, and the military services are the primary users of ADFs in North America. They purchase their fluids directly from the chemical manufacturers cited above, regionally located private distributors for the chemical manufacturers, or other users. Depending on the size of their deicing operations, users have storage facilities ranging from 35,000-gallon underground tanks to 50-gallon barrels. Airlines that have large ADF storage facilities at a particular airport sometimes sell a portion of their ADF to other airlines who may not have such a storage facility.

Actual storage varies from user to user. FBOs generally purchase glycol in 50- to 100-gallon barrels and tap them when necessary. Some airlines store ADF in ground-level tanks located on their "fuel farms." Others share large ADF storage facilities. One airline stores ADF in a 10,000-gallon tank located underground near its ramp area and in another 10,000-gallon reserve tank remote from the ramp. Another airline has a 35,000-gallon underground tank, which feeds the ADF into an intermediate tank. Water to be mixed with the ADF is also piped underground. The ADF and water are maintained at a temperature of 32°C (90°F), during the deicing season. When the deicing trucks are being filled, a steam generator heats both the water and ADF in the intermediate tanks to a temperature between 60° and 70°C (140° and 160°F).

The concentration of the deicing fluid must be monitored to ensure that the proper amount of ADF is included to achieve expected performance. Some users check the freezing point or concentration of the fluid when the ADF is pumped into the deicing trucks. This check is performed regularly and the results are kept in a log by some users, while others spot check and do not keep a log. These checks are usually performed by the maintenance manager, foreman, or lead mechanic. Some airlines verify the concentration of the mixture by using flow monitoring devices, which indicate the number of gallons of water and ADF used. Flow is controlled with valves and meters or with a computer. Of the FBOs interviewed in the Denver area, four of the smaller ones who use limited quantities of ADF rarely check the concentration of the ADF before it is applied to the aircraft.

The majority of FBOs use limited quantities of ADF since most of their customers prefer having their aircraft deiced by placing them in a heated hangar. In general, this method of deicing is less expensive than using a deicing fluid containing an ADF. For example, one midwest FBO charges $65 per night to store a Lear Jet in a hangar as compared to $150 to deice the same aircraft with an ADF-based deicing solution.

2.3 EUROPEAN COMMERCIAL FLUIDS

There are currently two types of ADFs used in Europe. Specifications for these fluids, known as AEA Type I and Type II fluids, are provided in "The Association of European Airlines Recommendations for Deicing/ Anti-icing of Aircraft on Ground." This document was prepared by the AEA's Deicing/Anti-icing Task Force in October 1982 and was revised in September 1983. The task force, which was initiated in 1982, includes representatives from the following European airlines:

- Lufthansa German Airlines
- Air France
- Finnair
- British Airways
- KLM Royal Dutch Airlines
- Scandinavian Airline System
- Sabena Belgium World Airlines
- Swissair

The two ADFs specified by the AEA are distinguished by material requirement, freezing point, rheological properties (viscosity and plasticity) and anti-icing performance. All other properties specified by

the AEA such as flash point, storage stability, and material compatibility, must be satisfied by both fluids. The following paragraphs describe the details of AEA Type I and Type II fluids.

2.3.1 European ADFs: Types and Manufacturers

AEA Type I fluids contain a minimum of 80 percent glycols and are considered "unthickened" because of their relatively low viscosity. These fluids are used for deicing operations and provide protection against refreezing only when no precipitation is falling. AEA Type I fluids contain a fire inhibitor to minimize potential fire hazards resulting from interaction between aqueous glycol solutions and noble metal electrodes impressed with a direct current potential. This inhibitor is also contained in U.S. Military Type II fluid, which is discussed in Section 2.5 of this chapter. These fluids, at a 50/50 concentration, have a minimum freezing point of -20°C (-4°F). AEA Type I fluid manufacturers include Kilfrost, Shell, and British Petroleum. The North American fluids produced by Dow and Union Carbide are rarely used in Europe but are considered to fall into the category of AEA Type I fluids.

AEA Type II fluids contain a minimum of 50 percent glycols. A thickening agent is added to the fluid, thus enabling it to adhere to the aircraft surface, forming a thickened coating to protect the surface from freezing precipitation. These fluids are used for deicing and anti-icing operations and provide protection against refreezing during precipitation. They are recommended for use on aircraft with takeoff rotation speeds greater than 85 knots. The AEA believes that at this speed the fluid, when applied in 100 percent ADF concentration or a 75/25 mixture, is sheared off the aircraft surface, rendering the wing sufficiently clean.

Kilfrost Limited, based in England, and Hoechst Corporation, based in West Germany, are the two main producers of AEA Type II fluids. SPCA, a French company, has produced an ADF but the fluid has not met all the requirements of an AEA Type II fluid as specified in "The Recommendations for Deicing/Anti-icing of Aircraft on Ground."

AEA Type II fluids, which have been used in Europe for approximately 15 years, are required to satisfy certain anti-icing performance standards. Those standards were established by the AEA on the basis of many years of operational experience and on the results of a high-humidity holdover test and freezing rain endurance test that were conducted at Kilfrost's environmental chamber to measure anti-icing performance of AEA Type II fluids. The high-humidity holdover test was designed to simulate the exposure of an aircraft parked in the open air overnight. AEA Type II fluids were tested under the following conditions for this experiment:

Test room volume:	minimum 1 m^3 for each 10 dm^2 test panel surface
Air exchange rate:	10 to 12 exchanges per minute

Air temperature:	5°C (41°F) reducing at an even rate to -5°C (23°F) over four hours and maintained at -5°C (23°F) to the end of the test
Air relative humidity:	100 percent relative humidity (saturated without visible droplets)
Test panel material:	Aluminum alloy 2024 polished
Test panel dimension:	10 centimeters by 30 centimeters (4 inches by 12 inches)
Test panel slope:	10°
Test panel temperature:	5°C (41°F) reducing at an even rate to -10°C (14°F) over four hours and maintained at -10°C (14°F) to the end of the test

A Brookfield counter-rotating mixer was used to apply the AEA Type II fluids to the test panel, which simulated the shear effect of the actual industrial spray equipment. The panel surfaces were completely wetted at the application temperature of 5°C (41°F). After a test period of eight hours, the AEA Type II fluids were required to have protected the test panel from any freezing greater than the AEA's acceptable limit of 2.5 centimeters (1 inch) at the upper end of the test panel.

The freezing rain endurance test was designed to simulate the exposure of an aircraft to rain when the air temperature and the aircraft skin temperature are below 0°C (32°F). AEA Type II fluids were tested under the following conditions for this experiment:

Air temperature:	maintained at -5°C (23°F)
Panel temperature:	maintained at -5°C (23°F)
Test panel slope:	10°
Rain droplet size:	20 micrometers and 50 percent of droplets' diameter in the range of 15 to 35 micrometers
Rain intensity:	5 gm/dm^2 per hour

The rain was simulated by supplying water at constant pressure through nozzles producing a rain mist of variable droplet size and intensity. The AEA Type II fluids were applied to the test panel by use of the same method as described for the previous test. The fluids were applied evenly at -5°C (23°F) and allowed to stabilize for five minutes. The rain drops were dispersed with an evenly controlled flow pattern. The rain intensity during the test period was measured by weighing the ice formed on a blank control panel. After a test period of 30 minutes, the AEA Type II fluids were required to have protected the test panel from any freezing beyond

the AEA's acceptable limit of 2.5 centimeters (1 inch) at the upper end of the test panel. It is important to note, however, that the condition simulated by this test is more like freezing ground fog than freezing rain, since freezing rain droplets are on the order of 1000 to 2000 micrometers in diameter. Thus, titling this test a freezing rain endurance test may be misleading.

Currently, both AEA Type I and Type II fluids are used at European airports. The AEA, in an effort to standardize the deicing/anti-icing process, developed the following anti-icing code and corresponding holdover guidelines. These guidelines, however are not approved by the FAA since they are in conflict with the clean aircraft concept.

CODE: 1. "Anti-icing AEA Type I"

This code leads to holdovertimes* shown in the Type I fluids chart (Table 2-1).

NOTE: The anti-icing performance of all fluids not qualified as AEA Type II should be judged as AEA Type I quality. Therefore, the above code is to be used.

2. "Anti-icing AEA Type II/100" for 100 percent AEA Type II fluid.

"Anti-icing AEA Type II/75" for 75/25 AEA Type II fluid mixture.

"Anti-icing AEA Type II/50" for 50/50 AEA Type II fluid mixture.

The concentration of any mixture is measured by volume. The anti-icing fluid concentration is always called out first; i.e., 75/25 is a mixture of 75 percent anti-icing fluid and 25 percent water.

This leads to holdovertimes shown in the Type II fluids chart (Table 2-2).

NOTE: The next lower anti-icing code is to be used when actual mixtures differ from those specified.

2.3.2 European ADFs: Usage

AEA Type I and Type II fluids as delivered to the user are required by the AEA to have enough stability to perform in accordance with the AEA specifications after two years of storage in a normal environment. The AEA specifies that the supply tanks are to be constructed from stainless steel or glass reinforced plastic, and partitioned to prevent surge effects. Generally, European airlines purchase concentrated ADF, which is stored in 150,000-liter (40,000-gallon) tanks, heated by steam or hot water lines running through the tank.

*Holdovertime is the length of time an ADF protects a clean aircraft from refreezing.

TABLE 2-1

GUIDELINE TO HOLDOVERTIMES: AEA TYPE I FLUIDS*

Weather Conditions	Temperature Range		
	0°C and Above	0°to -7°C	-8°C and Below
Frost	45 Mins	45 Mins	30 Mins
Freezing Fog	30 Mins	15 Mins	15 Mins
Steady Snow	15 Mins	15 Mins	15 Mins
Freezing Rain	5 Mins	3 Mins	--
Rain or Cold Soaked Wings	15 Mins	--	--

*100% ADF CONCENTRATION.
Caution: The protection time will be shortened in severe weather conditions. High wind velocity and jet blast can cause a degradation of the protective film. If these conditions persist, the time of protection can be shortened considerably.

According to one AEA Type II fluid manufacturer, the most economical method available to continuously heat ADFs is to use a heat exchanger containing hot water under pressure or steam from the airport's central heating system. The heating coils should be heated to a maximum temperature of 130°C (280°F). Airline experience has shown that heating ADFs with gas combustion heaters in a typical mobile deicing unit costs nearly four times as much as the hot water coil method and electrical heating costs approximately twice as much as the hot water coil method.

Concentrated AEA Type II fluids can be stored at 60°C (140°F) for long periods of time if they are continuously circulated. Since these fluids exhibit pseudo-plastic behavior, they do not move away from the source of heat under convection and can become locally over-heated close to such heat sources as the coils mentioned in the previous paragraph. The rate of heat transfer from the heater to the fluid depends on the temperature difference between the two. If the fluid around the heater

TABLE 2-2

GUIDELINE TO HOLDOVERTIMES: AEA TYPE II FLUIDS

Temperature Range	0°C and Above			0° to -7°C			-8° to -14°C		-15° to -25°C
ADV Concentration	100/0	75/25	50/50	100/0	75/25	50/50	100/0	75/25	100/0
Weather Conditions									
Frost	12 Hrs	6 Hrs	4 Hrs	8 Hrs	5 Hrs	3 Hrs	8 Hrs	5 Hrs	8 Hrs
Freezing Fog	3 Hrs	2 Hrs	1.5 Hrs	1.5 Hrs	60 Min	45 Min	1.5 Hrs	60 Min	1.5 Hrs
Steady Snow	60 Min	45 Min	30 Min	45 Min	30 Min	15 Min	45 Min	30 Min	45 Min
Freezing Rain	20 Min	10 Min	5 Min	20 Min	10 Min	3 Min	-	-	-
Rain on Cold Soaked Wings	60 Min	45 Min	30 Min	-	-	-	-	-	-

reaches the same temperature as the heater, no heat transfer takes place. Therefore, AEA Type II chemical manufacturers recommend that the fluid be mechanically circulated in the tank.

AEA Type II producers do not recommend heating the concentrated fluids for extended periods of time because water loss leaves the fluid in a gel-like state. It is possible to add water back into the fluid as long as circulation is taking place. Centrifugal circulation pumps with a capacity of 10 to 20 gallons per minute are acceptable for maintaining the fluid's performance. Both the inlet and the outlet of the pump should be near the bottom of the tank to prevent entrapment of air in the fluid, which results in foaming. One manufacturer recommends the use of an impeller to slowly stir the fluid.

Concentrated AEA Type II fluids are most effective for anti-icing when applied to the aircraft without being heated. However, fluids heated to temperatures up to 60°C (140°F) will flow smoothly on the wing, but more may run off leaving a thinner film and inherently reducing holdover-times. When diluted AEA Type II fluids are stored at 60°C (140°F) and above, water vapor rises from the surface and condenses on the cooler, upper parts of the tank. This may cause rusting if the tank is not constructed of appropriate materials.

2.4 COMPARISON OF NORTH AMERICAN AND EUROPEAN COMMERCIAL FLUIDS

North American and European ADFs are very similar. They are all glycol-based fluids which utilize the freezing point characteristics of the fluids to deice and anti-ice aircraft on the ground.

AEA Type II fluid was developed in England over 15 years ago as a response to the Royal Air Force's requirement for anti-icing protection against frost conditions that inhibited operational readiness of their aircraft. Currently both AEA Type I and Type II fluids are used in Europe for aircraft anti-icing. Airlines may use different types of ADFs at different locations depending on the winter weather conditions and the available deicing facilities.

Some of the advantages and disadvantages of using North American and AEA Type I ADFs are as follows:

- Fluid does not remain on aircraft in any appreciable amount and therefore has no detrimental effects on aircraft aerodynamics or performance.

- Airlines can use established deicing procedures and currently available equipment.

- This type of fluid requires no special handling or storage.

- These fluids provide only limited anti-icing protection, which may result in aircraft having to be deiced more than once.

Some of the characteristics of AEA Type II fluids are as follows:

- These highly viscous fluids may remain on the wing and may reduce takeoff performance (see Section 8.3). The fluids may also violate the clean aircraft concept described in FAA AC 20-117.

- North American airlines will need to retrofit deicing trucks and modify deicing procedures to accommodate the distinct characteristics of these pseudo-plastic fluids (Section 2.3).

- These fluids are not readily available in the United States; however, three foreign carriers began using AEA Type II fluids at JFK airport during the 1984/85 deicing season.

- These fluids require special handling and storage.

Currently the cost of North American ADFs ranges from $2.50 to $4.50 per gallon, depending on the volume of the purchase. AEA Type II fluids cost in excess of $6.00 per gallon in Europe. However, these fluids may cost less if produced in the United States since the cost of petroleum-based products is usually lower here than in Europe.

2.4.1 Properties

The chemical properties of North American and European ADFs are discussed in the following paragraphs.

2.4.1.1 Freezing Point

The freezing point of various North American and AEA Type II fluids are shown in Figure 2-3. The curves are similar except that the steepest curve has a higher concentration of ethylene glycol than the others. It is not possible to accurately measure the freezing point of the ADFs noted by the dashed sections of the curves in Figure 2-3. The concentrated AEA Type II fluids are composed of approximately 50 percent glycols. Therefore, their freezing points are much higher at each concentration level than the freezing points of the North American fluids. Because of their higher freezing points, they do not have a temperature range where the

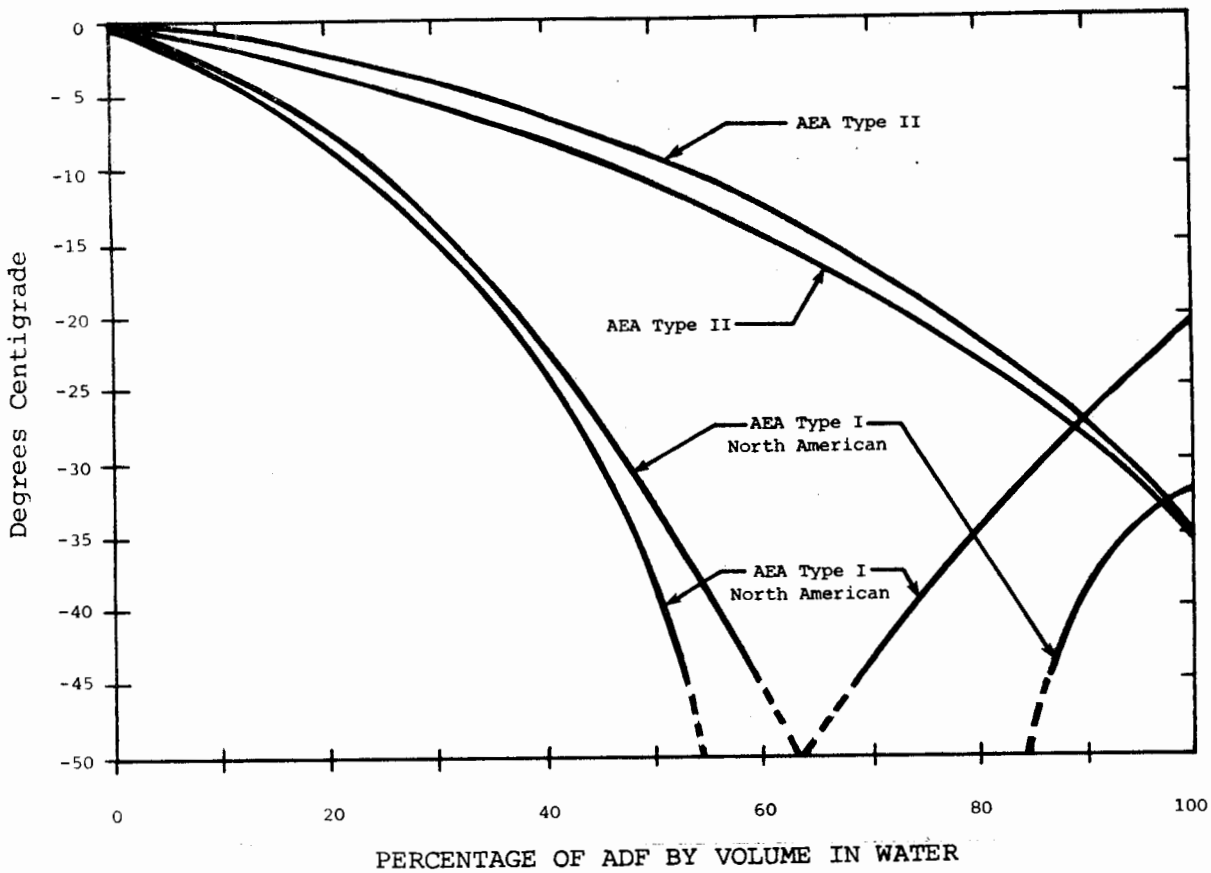

FIGURE 2-3

FREEZING POINT CURVES OF VARIOUS ADFs

freezing point cannot be measured. Since the North American and AEA Type I ADFs have lower freezing points than AEA Type II ADFs, they are used at typical concentrations of 30 to 70 percent, but may be used in concentrations as high as 100 percent. AEA Type II ADFs are used at concentrations of 50 to 100 percent.

2.4.1.2 Viscosity

The viscosity of AEA Type II fluids is higher than that of North American fluids because thickeners are added to them. These highly viscous ADFs, which have a consistency similar to vegetable oil, remain on the surface of the aircraft to provide the holdovertime and anti-icing protection specified by the AEA. The AEA specifies that these fluids are to be used on aircraft whose takeoff rotation speed is greater than 85 knots and therefore produces enough shear force to shed the Type II fluids. However, there is some industry concern that the Type II fluids do not leave the surface of the aircraft even at this rotation speed and therefore may impair aircraft cleanliness and aerodynamic performance. As a response to these concerns, the AEA is now studying the effect of AEA Type II fluids on aircraft performance (see Section 8.1).

2.4.2 Environmental Effects

Transport Canada, a Canadian government agency that owns and operates many of Canada's airports, is also responsible for ensuring that storm water effluent to natural water bodies meets guidelines established in the Canada Water Act. According to a study by Transport Canada, as a heated ADF mixture is sprayed on the aircraft, approximately 16 percent adheres to the aircraft, 49 percent spills onto the apron, and 35 percent is carried away by the wind. After monitoring the composition of storm water at various Canadian airports, Transport Canada has concluded that glycol and fuel are the most serious storm water pollutants discharged to receiving waters surrounding an airport. Currently, Transport Canada is writing a report discussing on-ground aircraft deicing, emphasizing environmental effects and current methods of attempting to reduce the resulting pollution.

In many cases a 50/50 concentration of ADF is used during a deicing operation, which means a probable minimum of 25 percent by volume of glycols eventually enters into the airport sewer system or flows directly into receiving waters. Considering that ADFs are usually used in large quantities in a short period of time, there could be a tremendous effect on the environment, especially since most airports in North America and Europe do not treat waste water containing ADF.

ADFs are biodegradable. This means that the organic material in ADF, specifically the glycols, can be reduced to a stable inorganic form, such as carbon dioxide and water. During the biodegradation process oxygen is consumed. The amount of oxygen consumed is called the biochemical oxygen demand (BOD). BOD_5 is the BOD measured over a five-day period and is

used as a standard reference when discussing the biodegradability of a substance. It provides an indication of the depletion of available dissolved oxygen that is necessary to support aquatic life.

Ethylene glycol is the primary active ingredient in North American ADFs, diethylene and propylene are the main glycols in both AEA Type I and Type II ADFs. A comparison of the BOD and toxicity of these glycols is shown in Table 2-3. Toxicity is measured in lethal doses (LD), which will be discussed in Section 2.4.3.

TABLE 2-3

COMPARATIVE PROPERTIES OF ETHYLENE, DIETHYLENE, AND PROPYLENE GLYCOL

Property	Ethylene Glycol	Diethylene Glycol	Propylene Glycol
Biodegradability BOD_5	750 gm/l	890 gm/l	1000 gm/l
Toxicity LD_{50}(humans)	1.4 ml/kg (1.56 gm/kg)	1.0 ml/kg (1.12 gm/kg)	7.0 ml/kg (7.79 gm/kg)
LD_{50}(rats)	5.5-8.5 ml/kg (6.1 gm/kg)	14.8-20.9 ml/kg (16.6 gm/kg)	32.5 ml/kg (33.7 gm/kg)

As shown in Table 2-3, one liter of propylene glycol will deplete one thousand grams of oxygen. Propylene glycol depletes about 33 percent more oxygen than ethylene glycol.

Transport Canada has hypothesized that glycol pollution resulting from deicing is not very obvious because:

- Deicing fluids are used during cold weather when the activity of micro-organisms in the environment is least. The odors from bacteria that would be evident had the pollution occurred during warm weather are not apparent in low winter temperatures.

- The receiving waters are likely to be frozen over during the winter when deicing takes place; therefore, fish killed due to oxygen depletion are not immediately noticeable.

- The rate of oxygen absorption decreases because of lowered ambient temperatures.

- The amount of oxygen which can be dissolved in water varies inversely with the temperature. Therefore, there is more oxygen available for absorption by the waters during cold weather.

- The rate of re-aeration in the receiving waters is faster during cold weather, provided that the water surface is not frozen.

- If the area is already polluted, then the additional loading may be difficult to recognize.

2.4.2.1 Storm Water Retention Pond System at Calgary International Airport

Recycling the glycol used for on-ground aircraft deicing operations is one method of reducing the supposed environmental effects of the deicing fluid. A storm water retention pond system such as the one used at Calgary International Airport in Calgary, Canada, also provides environmental protection. The storm water retention pond system was introduced at the airport in 1977 when the Air Terminal Complex initially began operation. The system served the north central storm water drainage system, receiving drainage that was discharged into a surrounding water basin. Environmental concerns were raised by users of the Air Terminal Complex and local residents as a result of the unpleasant odors emitted by the ponds, according to a document submitted to Transport Canada by Underwood McLellan Ltd. in September 1983. The ponds were the subject of a series of tests and discussions with city, provincial, and federal environmental agencies. A primary concern was the high BOD_5 level that appeared to be the result of an accumulation of ethylene glycol, the main component of North American ADFs.

A project to eliminate the unpleasant odors and, if practical, to reduce the BOD_5 level was undertaken in 1983. The project included the addition of a floating aeration device into the pond system. The aeration device was intended to replenish the oxygen in the collected water, thus reducing the BOD_5 level and the unpleasant odors.

The installation of the aeration device was completed in late 1984. The unpleasant odors were eliminated and the BOD_5 level was sufficiently reduced so that the ponds safely drain into the surrounding water basin. The cost for the pond modification was $61.6 million ($84.4 million Canadian).*

Although aerated ponds appear to offer an environmentally safe alternative to a glycol recycling system, the ponds at Calgary have attracted birds that may present a hazard to aircraft.

---

*A conversion rate of $0.7345 Canadian dollars per U.S. dollar was used to calculate this U.S. dollar figure.

Transport Canada has also investigated the use of an absorbent material to retain glycol. This material would be spread on the ground surrounding any deicing area and later picked up and transported to a remote land fill. The estimated cost of this procedure is $33,000 ($45,000 Canadian) per year.

2.4.3 Health Effects

Ethylene and diethylene glycols are considered toxic for humans whereas propylene glycol is not. As shown in Table 2-3, the lethal dose of ethylene glycol for 50 percent of the human population or the LD_{50} value is 1.4 ml/kg. A 150 pound person would die from drinking less than four ounces of pure ethylene glycol. The same person would die from drinking less than three ounces of diethylene glycol. Propylene glycol has an LD_{50} value seven times greater than diethylene glycol (that is, seven times as much would have to be consumed to have the same effect) and is considered relatively non-toxic. Although 3 or 4 ounces of glycol seems to be a relatively small amount, the deicing personnel would have difficulty ingesting that amount considering that the ADF used during deicing is usually diluted with water by 50 percent or more and the concentrated ADF is not 100 percent glycol.

Swallowing small amounts of ethylene and diethylene glycol may cause abdominal discomfort and pain, dizziness, and have other effects on the central nervous system and kidneys. All glycols cause some irritation upon contact with the eyes or the skin; however, although the irritation is described as "negligible," chemical manufacturers recommend avoiding skin contact with the ADF and wearing protective clothing when performing normal deicing operations. There is no indication that ethylene glycol is absorbed through the skin in sufficient quantities to cause physical damage. The inhalation of ethylene glycol vapors may cause headaches and throat irritations. The use of heated ethylene glycol in a poorly ventilated workspace may produce nausea and vomiting. Inhalation of other glycols appears to present no significant hazard in ordinary applications.

Because most aircraft are deiced when the passengers are aboard, there is very little possibility that the glycol could be of any danger to them except in the following instance. In the past five years there has been one incident in The National Aeronautics and Space Administration's (NASA's) Aviation Safety Reporting System (ASRS) data base where the captain reported smelling stinging odors in the cabin and later smoke pouring in from under his seat. He suspected that somehow deicing fluid entered into the air conditioning unit and caused the annoying smoke and odors when the heat was turned on. The situation subsequently caused him to return to his originating airport, without further incidence after the heat was turned off.

The AEA specifies that undiluted ADFs used in Europe must meet the local toxicity regulations. If no local regulations exist, the following guidelines, provided by the AEA, prevail:

- LD_{50} (oral in rats) $\geq$ 20 gm/kg

- aerosol or vapor inhalation toxicity of the fluid must be compatible with a TLV-TWA (Threshold Limit Value-Time Weighted Average) of a minimum 300 parts per million.

Only propylene glycol meets this specification. Most European localities have regulations less stringent than those provided by the AEA.

2.5 UNITED STATES MILITARY AIRCRAFT DEICING FLUIDS

The United States Department of Defense has issued Military Specification MIL-A-8243C for "Anti-icing and Deicing-Defrosting Fluids." This document specifies two types of ADFs:

- MIL-SPEC Type I - standard

- MIL-SPEC Type II - standard with inhibitor

Military Type I and Type II fluids are essentially the same except that Military Type II fluids contain sodium salt of tolytriazole, the same fire inhibitor used in AEA Type I fluids. Military Type I and Type II fluids are unrelated to AEA Type I and Type II fluids. Military Type II fluids, however, meet the specifications for an AEA Type I fluid. Military Type I fluids are not AEA fluids because Military Type I fluids do not contain the fire inhibitor specified for an AEA Type I fluid.

The composition and chemical and physical properties of military fluids are shown in Tables 2-4 and 2-5. In Table 2-4 the component 1,2-glycols designates two glycols that are specified as a mixture of three parts ethylene glycol and one part propylene glycol. There is some concern in the deicing fluid community, including users and chemical manufacturers in North America and Europe, that because the military fluids are defined by material composition as opposed to deicing and anti-icing performance their performance may not be equivalent to other available ADFs.

Military fluids are produced by various manufacturers, including Texaco, Union Carbide, and Dow. However, the military services purchase the ADFs through various local distributors rather than from the chemical manufacturers. These ADFs are furnished in 5- or 55-gallon molded polyethylene containers.

2.6 SUMMARY

The chemical properties, performance characteristics, and supposed environmental and health effects of ADFs of different types, produced by various manufacturers, were discussed in this chapter. Currently, there is discussion in the international deicing community surrounding the advantages and disadvantages of using AEA Type II fluids versus North American and AEA Type I fluids, and the true environmental and health effects of ADFs.

TABLE 2-4

COMPOSITION OF MILITARY TYPE I AND TYPE II ADFs

Component (percent by weight)	Type I	Type II
1, 2-glycols, minimum	88.0	88.0
Water	9.0 - 10.0	9.0 - 10.0
Dibasic potassium phosphate (K_2HPO_4), maximum	1.1	1.1
Sodium di-(2-ethylhexyl) sulfosuccinate (100 percent active)	0.45 - 0.55	0.45 - 0.55
Sodium salt of tolyltriazole	--	0.50 - 0.60

TABLE 2-5

CHEMICAL AND PHYSICAL PROPERTIES OF MILITARY TYPE I AND TYPE II ADFs

Characteristics	Requirements
Alkaline earths	None allowed
Chlorides	None allowed
Corrosiveness	*
Flash point °C (°F), min.	101.7 (215)
Pour point °C (°F):	
Undiluted	-54 (-65)
70 percent aqueous solution	-54 (-65)
Specific gravity (undiluted material) at 15.6°C (60°F)	1.100 to 1.106
Color (Type I only)	Not darker than standard
Ether	None allowed
Acetate solvents	None allowed

*The metal specimens can show no trace of corrosion. Slight discoloration of the cadmium plated panels will not be considered objectionable.

The primary advantage offered by AEA Type II fluid is superior anti-icing protection over AEA Type I fluid. However, there is concern about the effects of AEA Type II fluids on the aerodynamics and performance of aircraft since these pseudo-plastic fluids adhere to the aircraft surface. Several organizations are conducting research in response to this concern. These efforts are further discussed in Chapter Eight.

The glycols contained in ADFs can cause varying degrees of environmental pollution and detrimental health effects to humans. Efforts to reduce these environmental effects, such as the storm water retention pond system in Calgary, are receiving widespread attention from the deicing and environmental protection communities.

CHAPTER THREE

ON-GROUND AIRCRAFT DEICING EQUIPMENT*

The on-ground deicing/anti-icing equipment presently marketed to the aviation community has evolved from the mop and bucket to the mobile platform sprayers to the presently used truck-mounted aerial units with variable ADF/water mixture concentrations that can be sprayed on the aircraft. Commercial airlines require deicing equipment that will allow them to clear contaminant accumulations adhering to the aircraft prior to takeoff. The timing of the deicing process is crucial in assuring a clean aircraft at takeoff and therefore requires the fast and systematic cleaning afforded by the large 1000- to 1800-gallon units available today. The FBOs handling general aviation aircraft are able to use smaller deicers, such as units mounted on trailers or pick-up trucks, for deicing/anti-icing. However, large deicing units may also be found at FBO stations that are contracted by commercial airlines to conduct deicing operations. These various equipments are described in general terms in Section 3.1 of this chapter. Section 3.2 describes, in detail, some of the vehicles on the market today.

3.1 GENERAL DESCRIPTION

Most deicing vehicles are composed of a chassis, main and auxiliary engine, aerial device, fluid system, and heating system, although the complexity of the vehicle varies among manufacturers and models. The deicing unit chassis provides both mobile and stationary support for the driver's cab, engines, aerial device, and fluid tanks. There are two engines on the large units, one for the propulsion of the unit and an auxiliary engine to power the fluid pumps and hydraulic fluids that enable the actuators to move the aerial devices on the top of the vehicle.

The aerial device is connected to the roof of the vehicle at one end with a basket for the operator to work from at the other end. An aerial device enables an operator to be positioned above the surface of the aircraft to be deiced. The method of raising the operator into position, and the vertical and horizontal arcs these devices can move through vary depending on the manufacturer and model of the unit.

*The FAA does not endorse products or manufacturers. Trade or manufacturer's names appear herein solely because they are considered essential to the object of this report.

There are controls for positioning the basket in the cab and in the basket. Baskets vary in size and weight capacity.

From the basket, an operator can control the fluid concentration being sprayed on the aircraft and the stream pattern of the fluid. Controls incorporated into the fluid gun located at the basket enable the adjustment of the fluid pattern and, on some units, the proportioning of ADF and water. This proportional mixing is designed to help the operator to achieve the most economical use of ADF appropriate to the ambient weather conditions. A high pressure hose carries the ADF and water up to the basket where the mixing is accomplished. The heated water and ADF are drawn from separate reservoir tanks. The water tank is generally two to three times larger than the ADF tank. These tanks are either connected, allowing fluid to flow between them, or are separate systems. The tanks are usually constructed of stainless steel and are enclosed in a housing on the aft section of the chassis, which also encloses the heater and auxiliary engine. An instrument panel containing a set of malfunction lights, fluid pressure gauges, and various system status annunciators are located on the outside of the housing.

3.2 SPECIFIC MANUFACTURERS

The following paragraphs provide a description of various models of equipment available from several deicing vehicle manufacturers whose equipment was observed being used to deice/anti-ice aircraft at several airports and FBO stations.

3.2.1 The Ted Trump Company

The Ted Trump Company manufactures a wide variety of deicing equipment, ranging from 700-gallon truck-mounted deicers to units capable of pumping up to 1800 gallons of deicing fluid to basket extension units for spraying deicing fluid. Some vehicles in the product line are currently being modified and a new deicer is being introduced to meet the demands of the user community. A description of some of the Trump products is included in the following paragraphs.

3.2.1.1 Trump D-40-D Deicer

The 1800-gallon D-40-D model (Figure 3-1) is the deicer that was most frequently observed during the on-site observations conducted for this study. The concepts employed in this unit, which are described below, can also be found in the smaller Trump vehicles.

3.2.1.1.1 Vehicle

The D-40-D chassis, a Ford C800, provides both mobile and stationary support for the unit. The vehicle is powered by a 389-cubic-inch V8 engine with an automatic transmission. During the deicing operation the vehicle is mechanically prevented from traveling at speeds above 5 miles

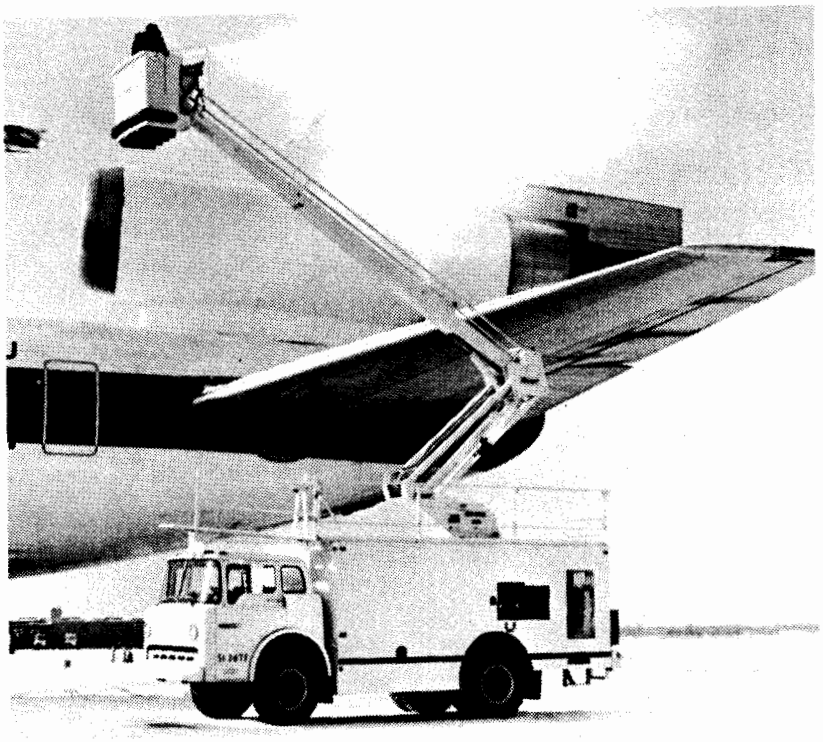

FIGURE 3-1

TRUMP MODEL D-40-D

per hour (MPH). When not deicing the truck is able to operate at speeds of 25 to 30 MPH. A cab from which the driver can monitor and control various systems of the unit is located on the front end of the vehicle. The auxiliary engine and fluid level and malfunction indicators can be monitored from within the cab. The majority of the cab's roof consists of a window and wiper system. An intercom system, using a headset and line microphone for both driver and operator enable audio communication. The window permits them to exchange hand or other visual signals.

3.2.1.1.2 Auxiliary Engine

The auxiliary engine, located behind the cab, provides the primary power for the deicer portion of the vehicle. This engine provides power for both the water and ADF pumps, for the hydraulic pump for the boom operation, and for the heater blower fan. The water and ADF pumps are for nozzle output pressure used in the deicing operation. The hydraulic pump output is used for the boom control and the spring lockout operation (SLO). The mechanically driven heater blower fan supplies combustion air and cooling air flow for the heater operation. The engine has a protective circuit that monitors coolant temperature and oil pressure. In the event of a coolant overheat or oil pressure failure, the primary ignition is interrupted causing the engine to shut down. The engine safety system

will also shut the engine off immediately in the event of a fire, and a carbon dioxide cartridge will then discharge dry fire-extinguisher chemicals into the engine compartment.

3.2.1.1.3 Aerial Device

The aerial device on the Trump D-40-D is a three-part articulating boom. The lower boom is connected at its base to the truck turret and at the top to the elbow frame that connects to the work basket. The elbow frame is kept at a constant attitude as the angle of the lower boom changes. A single hydraulic cylinder controls the movement of the upper boom. The elbow supports these actuators and provides the pivoting points for its rotation. Two tubular steel leveling rods enable automatic leveling of the basket. Attached to the top end of the upper boom, the rods run along the upper boom and carry water and ADF to the work basket.

The work basket is constructed of fiberglass and reinforced plastic. It is large enough to carry two operators and has a maximum weight capacity of 450 pounds. An access door, two lamps for use during night operations, and an intercom system are standard equipment on the basket. The hydraulic controls for positioning the boom are located in the basket, housed in a protective covering to prevent hose lines from becoming snagged and inadvertently moving the basket. The maximum working height is 46 feet, and the maximum horizontal reach is 28 feet, measured from the centerline of the truck, with boom fully extended.

Boom controls are located in the basket and at the base of the lower boom. The vertical and horizontal movements of both booms and their rotation are controlled at the lower control station. Control commands issued from the lower station override those issued from the basket. A hydraulic motor drives a large worm gear mounted on roller bearings that, with a large gear bolted to the pedestal, enable the aerial device to rotate through ± 370 degrees. The boom movement controls, auxiliary pump control station light, and emergency switch can all be operated from both control stations. The upper control station has an additional switch for purging the fluid lines. The motion of the upper boom is restricted to provide additional safety for the basket operator. The upper boom must be raised prior to raising or rotating the lower boom, and the upper boom should not be lowered below a horizontal position to avoid excessive stress. Spring lockouts in each boom help to eliminate bouncing of the vehicle on its springs and provide increased vehicle rigidity and stability. Neither boom can be raised unless these devices are engaged.

3.2.1.1.4 Fluid System

The D-40-D has a total fluid capacity of 1800 gallons: a 1500-gallon water storage tank and a 300-gallon ADF storage tank. The water storage tank is much larger than the ADF storage tank because the percentage of water in the deicing mixture is usually higher than that of the ADF. These tanks may be interconnected when a premixed water and ADF solution is being used in the deicing operation. The tanks are constructed of stainless steel with internal perforated baffling to inhibit sloshing and

fluid impact when the vehicle comes to a stop. The tanks are filled and inspected through three 15-inch openings on the top of the vehicle. A gauge located in the cab provides a means for monitoring the fluid level in each tank. The main components of the fluid system are fluid tank, pumps, flow monitoring switches, and relief valves.

The fluid system is equipped with three flow-monitoring switches. These switches monitor the flow velocity of fluid from each storage tank and the heater. The switches are operated by a paddle-type device in each fluid line.

The fluid system contains three high-pressure relief valves, one at the ADF pump outlet, another at the heater outlet, and a third in the line leading to the basket. These valves are set to activate at 450 pounds per square inch.

An unloader valve is located upstream of the mix monitor and proportioner value assemblies. The unloader valve allows the ADF fluid pressure to be significantly higher than the water pressure.

3.2.1.1.5 Proportional Mixing

The proportional mixing system enables the operator to choose the concentration of ADF in the fluid being sprayed. The control for this system is located at the basket. A handle is moved to open and close the orifice of the mixing valve. The percentage of ADF in the line is indicated on the mix monitor in the basket. The system measures the specific gravity of the fluid to determine the ADF concentration of the fluid (see Section 2.1.1.2).

The fluid guns are located at the basket and on the ground level. Although the operators can spray the same fluid concentration from each location, each gun operates independently. The spray pattern, fluid flow rate, and fluid control handle are all incorporated in the gun. The spray pattern can be adjusted by turning the tip of the nozzle. A full clockwise adjustment allows for a solid stream of fluid, which is used when removing ice and snow from the aircraft surface. A wide-angle spray is used to remove frost and to anti-ice the aircraft. The fluid flow rate can be set from 20 to 80 gallons per minute (GPM). A handle on the top of the gun opens and closes the nozzle for the settings selected on the gun. This handle is not spring loaded and must be pushed forward to discontinue the fluid flow.

3.2.1.1.6 Purge System

The purge system enables the water pump, heater, and lines to the basket to be filled with a 50/50 mixture. This system is used to prevent water from freezing in the lines during short periods of outdoor storage. The purge switch is activated from the upper control station. When this switch is activated, the purge valve is opened, thus enabling the ADF to flow into the water system. The switch is deactivated when the fluid gun is operated.

3.2.1.1.7 Fluid Heating System

The main component of the fluid heating system on the D-40-D is the Trump M2 heater. This heater is located in the rear of the truck. The electrical distribution panel, air blower, nozzle ignitor assembly, and three concentric fluid lines are other components of the fluid heating system. Safety devices incorporated in the system will shut down the heater and indicate at the ground control station panel when malfunctions have occurred. These devices include a low-air switch that is tripped if there is insufficient air for fuel combustion. The fluid flow switch, also a part of the safety system, is tripped when the water flow rate through the heater is too low. If either of these switches is tripped, the heater will automatically shut down. An ultraviolet flame sensor can also shut down the heater if the pilot flame is not present.

3.2.1.2 Trump DD-1000

The Trump DD-1000 deicing vehicle (Figure 3-2) has recently been introduced by the Ted Trump Company as a response to demands from the user community for a deicing vehicle with ground-level basket entry. This unit is similar in appearance to the Trump D-40-D model although it has a maximum fluid capacity of 1000 rather than 1800 gallons. The DD-1000 chassis, a Ford 600, has a smaller wheel base than the Ford C800 used in the D-40-D model, and thus provides the DD-1000 more maneuverability between aircraft. An overhead window (kept clear by a two-speed wiper system) in the cab permits visual communication between the driver and basket operator. An audio system composed of a headset and a microphone provides audio communication. The rear section of the chassis carries the deicing equipment and auxiliary engine that provides power to this equipment.

3.2.1.2.1 Auxiliary Engine

The auxiliary engine provides the power for the water, ADF pumps and hydraulic fluid pumps, and the air blower of the heater. The safety system for the auxiliary engine provides the ability to monitor the oil pressure and engine temperature. The engine automatically shuts down when the oil pressure is too low. Annunciator lights indicate no fluid is passing through the water pump, low engine fuel pressure, and low oil pressure prior to shutdown.

3.2.1.2.2 Aerial Device

The aerial device on the DD-1000 is a three-part articulating boom. The base of the turret is attached to the top of the vehicle and the lower boom is attached to the upper end of the turret. This turret enables the booms to be rotated 360 degrees. The lower boom is also attached to an elbow section containing the hydraulic actuators that enable the vertical motion of the booms.

FIGURE 3-2

TRUMP MODEL DD-1000

A basket with a 300-pound capacity is attached to the top end of the upper boom. The DD-1000 is the only Trump vehicle with a basket that can be lowered to the ground to let the operator get in. The maneuvering of the basket and aerial booms is controlled at either the basket or ground control station. The basket controls are shielded from the hose. The basket can be raised to a maximum working height of 39 feet, which enables an operator to deice and view the upper surface of the horizontal stabilizer on a B-727, the highest horizontal surface of any commercial aircraft. The operator can also perform maintenance operations on the centerline engine of a DC-10 from this position. The boom can reach 24 feet to either side.

3.2.1.2.3 Fluid System

The fluid system of the DD-1000 is similar to that of the D-40-D. The standard fluid system capacity is 1000 gallons, but an optional 1200-gallon system is available. The separate water and ADF tanks are constructed of stainless steel, with internal baffles to reduce corrosion and fluid sloshing. These tanks are filled through openings on the roof of the vehicle and their fluid levels are indicated on the housing on the driver's side of the vehicle. They can be interconnected to spray a premixed deicing solution. The water tank on the DD-1000 is four times

larger than the ADF tank. This allows the operator to use the hot water to remove snow and ice before spraying ADF. This method affords the users considerable cost savings and reduces the amount of glycol required, and therefore its environmental ipact. The ADF proportioning system, GLYPRO, is an optional system on the DD-1000.

3.2.1.2.4 Fluid Heating System

The main component of the fluid heating system is the Trump M1 heater, which can burn either gasoline or jet fuel. This unit is a vertical heating system constructed of stainless steel. An enclosed flame similar to that in the M2 heater is used to transfer heat to the fluid. This heater unit offers safety controls providing safety backup systems. The detection of any abnormal operation causes the safety backup controls to automatically shut down the heater.

3.2.1.3 Trump Model DA

The Trump model DA (Figure 3-3) has a 700-gallon capacity fluid system and is carried on a Ford 350 chassis. It is equipped with both power steering and automatic transmission. The intercom system, which provides audio communications between driver and operator, is available in two combinations, a speaker-microphone system in the cab and basket or headsets with microphones. The rear section, as with the other Trump deicers, houses the deicing equipment.

FIGURE 3-3

TRUMP MODEL DA

3.2.1.3.1 Auxiliary Engine

The auxiliary engine provides power to the water, ADF, and hydraulic pumps. The engine controls are located on the ground control station on the driver's side of the vehicle. The hydraulic pump powers the spring lockout cylinders; these actuators eliminate the need for outriggers and help guard against operator error. The hydraulic pump driven by the auxiliary engine also powers the aerial device of the unit.

3.2.1.3.2 Aerial Device

The DA model uses a three-stage telescoping aerial device. This aerial device system extends vertically from the rear section of the vehicle. It is not capable of horizontal displacement. This system retracts to a height of 13.5 feet, and can be easily garaged for servicing by removing the work basket.

The work basket is large enough for one operator. Two lamps for night operations are enclosed in a protected area located in the basket. The basket on the upper end of this device can be raised to a height of 35 feet.

3.2.1.3.3. Fluid System

The fluid system of the Trump DA deicer has an ADF storage tank capacity of 160 gallons and a water storage tank capacity of 540 gallons. The tanks are constructed of stainless steel with internal perforated baffles that inhibit sloshing and damage from fluid impact. The fluid is pumped through the system to the nozzle, which has a flow capacity of 20 to 40 GPM. The operator can adjust the nozzle's spray pattern to vary the pattern from a solid stream to a wide angle. A proportional mixing system, as previously described in Section 3.2.1.1.5, is optional. Also available is a mix monitor, which measures the concentration of the deicing mixture by determining the specific gravity of the fluid.

3.2.1.3.4 Fluid Heating System

The main component of the fluid heating system on the Trump DA deicer is the M1 heater. This heater, which is also used on the Trump DD-1000, was described in Section 3.2.1.2.4.

3.2.2 FMC Corporation Airline Equipment Division

The Airline Equipment Division of FMC Corporation, previously known as the John Bean Division, manufactures deicing vehicles with capabilities similar to those of the Trump vehicles described in Section 3.2.1. The two most popular FMC vehicles are the TM-1800 and the LA-1000. These vehicles have 1800-gallon and 1000-gallon fluid capacities, respectively. The vehicles are described in the following paragraphs.

3.2.2.1 TM-1800

The TM-1800 (Figure 3-4) is a highly maneuverable self-propelled deicing vehicle with a wheelbase of 11.25 feet, which provides the vehicle with a 26.25- foot turning radius. A Ford C800 chassis, modified to include heavy-duty springs, is standard equipment. During deicing operations the vehicle travels at approximately 4 MPH, although the vehicle is capable of traveling at speeds of 50 MPH on the highway. An optional speed-limiting device is available to restrict the vehicle to the lower speed.

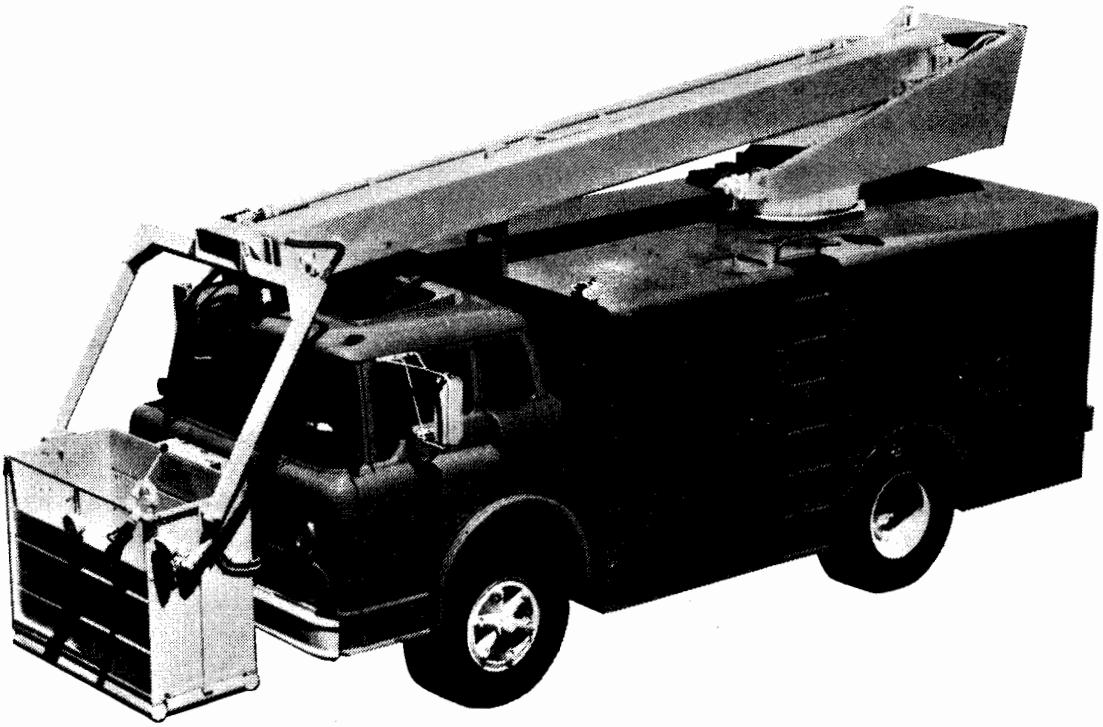

FIGURE 3-4

FMC MODEL TM-1800

3.2.2.1.2 Aerial Device

The telescoping boom on the TM-1800 was specifically designed for deicing applications. It incorporates a flexible yoke that allows the operator to reach all surfaces of an aircraft, even for a B-747. The telescoping boom allows the basket to be brought to ground level, enabling

safe entry during inclement weather and permitting the easy loading of tools needed for repairs during maintenance operations. The basket has a maximum weight capacity of 450 pounds and can accommodate two operators.

3.2.2.1.3 Fluid System

The TM-1800 fluid system, which includes a proportional mixing capability, comprises two pumps, an ADF storage tank, a water storage tank and proportional mixing valves. The pumps are self-priming FMC JB2-S fluid pumps that supply water and ADF to the proportional mixing valves. The larger tank contains water heated to 96°C (205°F); the smaller tank contains ADF, which is not directly heated, but reaches a temperature of approximately 39°C (102°F) due to the constant recirculation of the fluid and conducted heat from the water tank. A heat exchanger within the ADF storage tank enables the heated water to transfer heat to the ADF as the water returns to the water tank. The proportioning system enables the basket operator to deliver a constant percentage of deicing fluid to water without the necessity of repositioning the control lever for different flow rates. The TM-1800 system is capable of flow rates between 25 and 100 GPM and mixture concentrations containing from 0 to 70 percent ADF.

The FMC Model TM-1800E incorporates FMC's Euromix Proportional Mixing System rather than the proportional mixing system described in the preceding paragraph. This Euromix system is capable of pumping North American, AEA Type I, and AEA Type II ADFs. It is designed so that it does not degrade the thixotropic quality of AEA Type II fluids. These fluids require special handling, including special pumping and heating, in order to maintain their effectiveness (see Section 2.3.2). An electrically operated clutch in the ADF pump of the Euromix system is engaged and disengaged by a combination of flow and pressure switches to ensure an even flow of ADF on demand without shearing or unnecessary recirculation. Since AEA Type II fluids are most effective for anti-icing operations when they are applied unheated, the Euromix system heats the water to be used for deicing separately from the ADF.

The tank selection option is available as an alternative to the proportional mixing system. This option offers the two-step deicing procedures (see Section 4-5) without the necessity of a second fluid pump or a proportioning valve at the basket. The tank selection system includes a split-tank arrangement similar to the proportional mixing system. The tanks may be heated separately or together and the fluid can be pumped from either tank. In many applications, one tank is filled with a deicing mixture and the other with an anti-icing mixture. The basket operator can switch from a deicing mixture to an anti-icing mixture and back again without having to coordinate with the ground operator. Indicator lights allow the ground personnel to continuously monitor the mode of operation in which the basket operator is working. Since the concentration of the solution in each tank cannot be adjusted, the aerial operator cannot inadvertently apply more or less ADF than was previously determined to be necessary for the weather conditions.

A comparison of the standard proportional mixing system with the tank selection system reveals advantages and disadvantages of each system. The proportional mixing system permits a variety of water/ADF concentrations to be sprayed even if the flow rate changes. The disadvantages of this system are that the system is complex; it has relatively high maintenance costs; the basket operator must have a thorough understanding of deicing/anti-icing procedures; and the concentration of deicing mixture being applied is known only to the basket operator. The advantages of the tank selection option are lower initial cost and easier maintenance of the system. Training of the basket operator can be limited to the operation of the system and does not have to include the theory and judgments associated with selecting the correct concentration of the fluid being applied. A disadvantage of this system is that the application of ADF is limited to the concentration of the mixture contained in the tank. It cannot be altered in response to observations of the actual conditions during the operation. The tank selection system is a good companion system to the Euromix option offered because the operator can deice with a heated solution and then apply a coating of AEA Type II fluid in its most effective form, unheated, for anti-icing.

3.2.2.1.4 Heating System

The TM-1800 model vehicles employ two self-contained fully enclosed flame fluid heaters. The heaters can be operated independently or simultaneously. This provides a backup system in the event of a failure on either of the control systems for either heater circuit. The combined output of the heaters is over 2,000,000 BTU/hr. The heaters are placed in series with the fluid spray nozzles, which allows the TM-1800 to heat the fluid immediately before it is discharged at the nozzle.

The TM-1800E model uses a vertical heater and coil design. This design was introduced in 1978 to replace the horizontal heater originally used on the TM-1800. It is believed that the vertical heater is better suited for mobile deicing equipment since its design eliminates the possibility of fuel puddling between the heater coils, which can cause local hot spots, possibly resulting in heater failure and potentially dangerous burnout situations.

Each heater contains a combustible blower. The blower starts when the heater switch is turned on. An interlock switch prevents the starting of the heater until the blower is running and the fumes have been purged. The blower continues to run for three minutes after the heater is shut down to purge fumes and cool down the combustion chamber. The blowers are automatically shut down while the engine is not running so that cold air is not blown over the coils, drawing heat away from the fluid.

3.2.2.2 LA-1000

The LA-1000, also known as the Flite Line Maintenance Master, is a 1000-gallon deicing/anti-icing vehicle manufactured by the John Bean Division of FMC (Figure 3-5). This vehicle is a self-propelled, self-contained deicer. The three-point suspension chassis carries the

FIGURE 3-5

FMC MODEL LA-1000

engine, cab, and deicing equipment. It is equipped with a telescoping and elevating boom on which the operator's basket is suspended. The standard vehicle contains a fluid system for application of deicing fluid or washing the aircraft. The basic fluid system consists of a high-pressure fluid pump, a gasoline-fired heater, and a 1000-gallon-capacity, interconnected, three-tank fluid system. There are two hose lines and discharge guns provided for application of the fluids. One hose line is connected to a hose reel on the left front side of the vehicle for ground-level work, and one is mounted on the boom basket.

3.2.2.2.1 Vehicle

Mounted on a three-point suspension chassis, the vehicle has a maximum speed of 12 MPH. A model D-172 Ford water-cooled engine powers the vehicle, hydraulic system pump, and fluid system pump. The engine speed is governor-controlled and is set by an adjustable throttle control located on the cab instrument panel. The four-speed truck transmission is connected to the rear axle by a drive shaft: both forward and reverse have four speeds. A single front wheel, located on the centerline of the vehicle, is used for turning. The power steering system enables the

driver to rotate the front wheel in an arc of 125°. This steering system is aided by the differential braking of the rear wheels when operating on icy or uneven pavement. The braking action can be provided to each individual set of dual rear wheels by the driver actuating a selector switch on the instrument panel.

A one-man cab is located on the left side of the vehicle. The windshield amd top and rear window are made of safety glass. The rear window can be opened for ventilation. A heavy-duty windshield wiper system is also provided. The driver is able to monitor and control the systems through instruments, automotive controls, and operational controls from the cab. The instrument and control warning lights for the alternator, oil pressure, fluid pump, and fluid heater are located on the control panel in the cab.

The vehicle lighting consists of automotive headlights and tail and stop lights. An adjustable spotlight is positioned on the front of the vehicle for use with the ground hose line and a light is located in the reel compartment of the ground hose. There are two fixed floodlights and one adjustable spotlight located at the basket on the boom.

3.2.2.2.2 Aerial Device

The boom is located on the top of the vehicle and is pivoted at the right rear side of the vehicle. The telescoping extension and retraction of the boom is powered by a hydraulic motor and a gear reducer on the left side of the boom. The extendable section of the boom is equipped with a safety mechanism and automatic brake to prevent uncontrolled retraction or extension of the boom in the event of a mechanical or hydraulic failure. The emergency boom control switch cuts power to the boom and stops all movement from both the basket and cab until the switch is returned to the on position. The driver can use this switch to override the normal controls and stop the boom.

An operator's basket is suspended at the end of the extendable section. The basket contains a set of controls for raising, lowering, extending, and retracting the boom. A signaling switch to communicate with the driver regarding boom rotation and fluid selection is also located in the basket. Both the driver in the cab and the basket operator have positioning controls for the boom. The controls that are operated first will lock out the other station to prevent the controls from being overridden by the other control station. The vehicle must be turned to move the boom through a horizontal arc; the boom itself is capable of vertical motion only.

3.2.2.2.3 Fluid System

The basic fluid system on the LA-1000 consists of three fluid tanks, a fluid pump, hoses, discharge guns, and connecting piping and valves. There are two tanks located on each side and one in the center of the vehicle. The tanks are interconnected and have a combined capacity of

1000 gallons. The fluid is pumped from the tanks through the heater to the fluid spray guns.

The fluid pump is connected to the rear of the engine. A disengage pump light will become illuminated on the cab control panel when there is an insufficant supply of fluid at the fluid pump caused by a pump malfunction, low fluid level in the tanks, or an obstruction in the fluid lines. The fluid is pumped from the heater to the spraying guns. The hand-held fluid guns are located at the basket and attached to the ground hose. The fluid spray pattern can be adjusted by rotating the barrel on the forward part of the gun.

3.2.2.2.4 Heating System

The main component of the fluid heating system is a heater mounted on the left side of the vehicle aft of the cab. It is a gasoline-fired circulating heater that can achieve a maximum fluid temperature of 82°C (180°F). The fluid is circulated through the heater by the fluid pump. The ignition and flame portions of the system contain sensors that illuminate indicators in the event of a malfunction. A factory-installed preset thermostat changes the flame height when the fluid reaches the preset temperature. The thermostat will change the heater flame from low to high when the fluid temperature drops below the preset temperature.

3.3 OTHER MANUFACTURERS

In addition to Trump and FMC, deicing equipment is also manufactured by King Seagraves, Robert Mitchell, Inc., Stanray, and Stinar. Robert Mitchell, Inc., previously known as Goetrum, markets equipment specially designed for Air Canada. FBOs provide the primary market for the other manufacturers. Truck-mounted deicers and mobile units mounted on carts and trailers are available from these suppliers.

CHAPTER FOUR

DEICING/ANTI-ICING PROCEDURES

Operational procedures employed to accomplish on-ground aircraft deicing/anti-icing vary depending on the type of accumulation on the surface of the aircraft. The general procedures used by various airlines are similar, although some have purchased special equipment such as brooms and hoses to help remove certain types of accumulation normally experienced in particular geographic regions.

4.1 GENERAL PROCEDURES

The training conducted by most commercial airlines to educate deicing personnel and deicing procedures used by commercial airlines, FBOs, and general aviation pilots are described in a general nature in the following paragraphs.

4.1.1 Training

The airline personnel responsible for aircraft deicing/anti-icing on-ground operations are trained through the use of manuals, films, videotapes and hands-on experience with deicing/anti-icing equipment. This training is generally conducted during the warmer months preceding the deicing season. Instruction in deicing/anti-icing vehicle operation, positioning of the vehicle about various aircraft, and the application of deicing fluid are included in the training programs. Deicing/anti-icing procedures are reviewed annually throughout the airline community as part of the cold weather operations review.

The personnel receive instruction concerning the selection of the appropriate deicing mixture for the ambient weather conditions. As the weather conditions change, the personnel monitor the fluid concentration and its effectiveness by use of a refractometer (Section 2.1), and adjust the ratio of ADF to water as necessary to achieve the longest possible holdovertime and most economical use of the ADF. The type of equipment an airline operates will dictate which employees are responsible for the ADF concentration selection, although the instructions are provided for all the personnel involved with the deicing/anti-icing operations. The conversions involved to change the ADF/water ratio are performed by using graphs, tables, or equations with the conversion method dependent on the

airline. These methods enable the personnel to take into account the amount and concentration of fluid remaining in the deicing vehicle, the concentration of the remaining fluid, and ambient weather conditions, especially temperature and type of accumulation.

The FBOs contracted by an airline to perform deicing operations may be trained according to the deicing/anti-icing procedures of that particular airline if those are the procedures that the FBO is obligated to employ. If the FBO operates using his own procedures this is clearly stated in the contractual agreement and the appropriate release forms must be filed after each deicing/anti-icing procedure.

4.1.2 Aircraft Surfaces

An aircraft is systematically deiced and anti-iced in weather conditions conducive to icing, which are described in detail in Chapter Seven. The various aircraft surfaces each require some unique technique in the operation in order to achieve a clean aircraft.

4.1.2.1 Wing

The wings are the main lifting surfaces of the aircraft and therefore must be free of contaminants to operate efficiently. An accumulation of frost, snow, or ice on the wing changes the aircraft's aerodynamic characteristics including pitching moments, drag, and lift capability; it also increases the weight to be lifted.

The spraying of heated deicing fluid to remove frost, snow, or ice from the wing has a preferred starting position at the leading edge wing tip toward the aft and inboard direction, although weather conditions may require an alternate starting point. If the fluid is sprayed from the inboard portion to the outboard portion of the wing, excessive stress may be placed on the wing from the accumulation on the outboard portion. Spraying in the recommended direction may result in accumulation forming in the track and hinge areas. Clearing the tracks and hinges may require spraying from the trailing to leading edge, but the airlines recommend that the aircraft manufacturers' deicing and anti-icing procedures be adhered to where possible.

In some aircraft, devices have been incorporated in wings to enhance their lifting capabilities and provide control of the aircraft in flight. The extendable surfaces (i.e., leading edge slats, trailing edge flaps) should be retracted to avoid accumulating frost, snow, or ice during time at the gate or in overnight storage. A surface that is extended in weather conditions requiring deicing/anti-icing is visually inspected to ensure the surface, tracks, hinges, seals, and actuators are free of any contaminants prior to the retraction of the surface. The range of travel of all surfaces is checked prior to takeoff as part of the normal takeoff procedure. The underside of the wing is generally only deiced/anti-iced in slushy runway conditions, when the tires may splash slush up onto the wing during takeoff.

Snow, frost, and ice contaminants may be manually removed through the use of brooms, brushes, or squeegees. The deicing personnel use these devices to push and pull the contaminants over the leading and trailing edges of the wing. These manual methods of removal require personnel to exercise caution so as not to damage any portion of the wing (for example, vortex generators) or fill gaps between control surfaces with contaminants.

4.1.2.2 Tail

The tail surfaces require the same caution afforded the wing during the deicing procedure. The uppermost surface is cleared first during the deicing/anti-icing operation to avoid placing excessive stress on the tail structure. Unlike the wing the tail does not have extendable surfaces although the balance cavity bay area between moveable and stationary surfaces requires close inspection. The proper positioning of the horizontal stabilizer, in the nose down position, will allow the fluid and contaminants to run off and not into the balance panel cavity. When contaminants do collect in the surface juncture they must be removed since the seals can freeze and impede the movement of the elevator.

4.1.2.3 Fuselage

Deicing the fuselage is accomplished through the use of brooms, cloth or nylon ropes, or an application of heated deicing fluid, depending on the type and amount of accumulation. The fuselage is deiced/anti-iced from the top down. Clearing the top of the fuselage by manual methods requires that personnel use caution not to damage protruding equipment (such as antennas). Spraying the upper section first with heated ADF results in a need to use less fluid, since the fluid flowing down the sides of the fuselage warms them and removes accumulations. This reduces the cost of deicing. It also enables the windows and windshield of the aircraft to be deiced, since direct spraying of the surfaces can cause thermal shock that might result in a cracking or grazing of the windows. A film of deicing fluid over the windows can distort the view out of them, so the fluid must be removed from the crew's windows.

Deicing the top of the fuselage is especially important on aircraft with an aft-mounted centerline engine. The ingestion of ice or snow into an engine could result in the engine stalling or damage to the engine.

The aircraft nose or radome is deiced and anti-iced to eliminate snow or ice accumulations from being projected into the crew's field of vision during takeoff. Because this area contains navigation and guidance equipment, it is cleared of accumulations to ensure proper operation of the sensors.

The cargo and passenger doors are also deiced and anti-iced in order to ensure proper operation. The hinges and tracks are inspected to ensure that they are free of accumulations. Accumulation may not impair their operation on the ground but may freeze at flight altitudes, preventing them from being opened at the aircraft's destination.

The orifices and probes along the fuselage require caution during the application of deicing fluid. Direct spraying into these openings can result in faulty instrument readings. The drainage system's plumbing cannot be adequately checked in weather conditions requiring deicing/anti-icing to assure that the fluid is draining and no blockage is occurring.

4.1.2.4 Engines

The procedures for engine and auxiliary power unit (APU) deicing require a minimum use of deicing fluid. These fluids, if ingested into the APU, can cause smoke and vapors to enter the cabin. Most aircraft operating procedures manuals recommend the activation of the engine anti-icing system during all ground operations when icing conditions exist or are anticipated.

Engine deicing/anti-icing can be characterized as preventive medicine. The emphasis is placed on avoiding ice or snow accumulation in the engine rather than how to remove these accumulations. Airline manuals specify that engine intake areas are to be inspected immediately after shutdown for the presence of ice. Any accumulation must be removed while the engine is cooling, prior to the installation of engine plugs and covers. The engine plugs trap the residual heat in the engine, melting any overlooked contaminants. For turbojet and turboprop aircraft the overlooked contaminants can then collect and refreeze at the bottom of the compressor section, thus locking in the lower blade tips of the compressor in ice. The engine plugs also prevent snow or rain from blowing into the intake and freezing the variable inlet guide vanes of turbojet and turboprop aircraft. In order to prevent the plugs from freezing to the nacelle, a light coating of ADF may be applied to the plug. Engine plugs are also used in piston aircraft to prevent frozen precipitations from accumulating at the air intake. The following paragraphs are only applicable to turbojet and turboprop aircraft.

The N1 fan rotation must be observed prior to starting the engine. If the N1 fan is not observed rotating in the wind, it should be turned by hand. If the engine fan cannot be rotated by hand it must be deiced, which is accomplished by blowing warm air over the area. The warm air is blown over the area until the section rotates and is dry. The areas must be dry to help prevent the fan from refreezing. This is the only method of deicing mentioned in the airlines' and aircraft manufactures' literature.

Ice can accumulate on the engine's compressor blades while the aircraft is in line for takeoff. The taxi areas are treated with chemicals to inhibit freezing. The evaporated moisture and vapors from those chemicals remain close to the ground and can be ingested by the engine. The vapors adhere to the compressor blades and continues to build up if the engines are maintained at idle. Engine manufacturers and airlines recommend that thrust levers be periodically advanced to an N1 RPM of 70 percent to 80 percent to prevent ice buildup, which can result in reduced thrust and dynamic imbalance of the compressor section if not removed.

4.1.3 Types of Accumulation

The type of accumulation on the aircraft surface (frost, snow, or ice) is a key factor in determining the type of deicing/anti-icing procedure that will be employed. The particular procedures are described below.

4.1.3.1 Frost

There are varying types of frost discussed in the airline manuals. The first, hoar frost, is a light frost through which the paint markings can be distinguished. This type of frost should be removed prior to takeoff, unless it is polished smooth.

Frost other than hoar frost is removed from the aircraft except that frost accumulations of less than 1/8 inch on the lower side of the wing are generally ignored. However, the FAA recommends that underwing frost always be removed and, when practical, the surfaces be anti-iced to delay the formation of frost. Frost is normally removed by spraying the aircraft surface with hot water or heated ADF.

Frost may form on the fuel tanks as a result of low fuel temperature and high humidity air encountered during descent and on the ground. Frost in this area is generally removed without spraying. Rather, the aircraft is refueled with warmer fuel. The warmer fuel raises the temperature of the tanks which melts the frost.

4.1.3.2 Snow

Snow removal methods vary with the consistency and amount of accumulation on the aircraft. Dry, loose snow that is not adhering to the aircraft may be removed by blowing cold air or nitrogen gas across the contaminated surface. Usually this type of snow is allowed to blow off of the aircraft during the takeoff roll.

A variety of techniques are used to remove snow that is adhering to the surface of the aircraft. Small amounts of accumulation may be removed by spraying the aircraft with a heated deicing mixture. The thermal and mechanical energy of the coarse stream of hot fluid melt, dislodge, and flush away frozen accumulations. This method is not always practical for large accumulations. For them, alternative methods are employed. Brooms, brushes, and cloth or nylon ropes are sometimes used to remove the accumulation from the aircraft surface before one-step or two-step deicing/anti-icing procedures are followed. Caution must be exercised when attempting to remove accumulations by means other than spraying to avoid damaging equipment protruding from the aircraft surface and to prevent blocking inlet vents with snow.

During severe weather conditions an aircraft may be placed inside of a hangar to keep it warm and prevent snow from accumulating. This is also effective for melting small amounts of accumulation. Some airlines conduct

complete deicing/anti-icing operations inside a hangar immediately before takeoff, although this is rare. This method can affect other airline operations.

4.1.3.3 Ice

The fluid spraying procedures used for the removal of ice are similar to those used for frost and snow removal. The airlines and aircraft manufacturers caution against banging, pounding, or scraping the aircraft during ice removal to prevent structural damage to the aircraft. The fluid spray gun should be held the recommended distance, in some cases as far as eight feet, from the aircraft surface. This prevents damage to the skin that can occur from holding the gun too close. Also, spraying from this distance helps prevent excessive fluid loss to the atmosphere that can result from holding the gun too far from the aircraft.

The method generally accepted to remove ice is by spraying a solid stream of heated deicing fluid, which may or may not contain ADF, on the ice until the metal skin is exposed. The heat will then dissipate through the metal, loosening the ice from the skin. The loosened ice will generally slide off vertical surfaces and be blown off the horizontal surfaces by the continued spraying of the fluid.

The use of large volumes of warm air to remove ice is recommended by airframe manufacturers and airlines. However, the melted ice can run down onto other sections of the aircraft and refreeze. The use of a large volume of warm air is more effective than a small volume of hot air since air heated above 93°C (200°F) can cause structural damage to the areas of the aircraft using honeycomb construction techniques.

4.2 PROCEDURES RECOMMENDED BY AIRCRAFT MANUFACTURERS

The deicing/anti-icing procedures provided in the aircraft maintenance manuals detail those deicing/anti-icing operations that help to maintain the aircraft in a clean and safe condition. The manufacturers issue manuals for each aircraft type and use general instructions in discussing commonalities among aircraft in these manuals. The clearing of ice, snow, and slush from the balance cavity bays on a B-737 is recommended, while the B-747 manual does not address this subject. Other specific recommendations include clearing the engine inlet areas and S-duct on L-1011 aircraft and the number 2 engine of DC-10s and clearing the tail portion of B-727 and DC-9 aircraft prior to any other surface to avoid possible tipping of the aircraft.

4.3 PROCEDURES RECOMMENDED BY COMMERCIAL AIRLINES

The commercial airlines establish their individual deicing/anti-icing policies by using the recommendations provided by the aircraft manufacturers for a particular aircraft type, the deicing equipment manufacturers'

recommended procedures, and their own experience gained when operating the aircraft and equipment in icing conditions. Most commercial airlines have a specified personnel hierarchy that becomes effective during deicing operations. This hierarchy is intended to help maintain organization and ensure that procedures are being followed during deicing operations.

The preliminary actions taken by Airline A when a deicing operation is imminent help to prepare for the actual spraying operation. First, the deicing units are checked to ensure that the ADF and water tanks are full, heated, and serviceable. Then the ramp area is cleared so that the deicing personnel and equipment can carry out the operation unhindered. This airline has formed committees to help evaluate the following factors, which affect deicing operations:

- severity of the storm
- serviceability of deicing equipment
- number and types of deicing equipment on hand and their operating capability
- deicing staff requirements
- ADF inventory and need to reorder
- layover aircraft protection
- methods of information transfer to the passengers regarding delays, alternate modes of transportation, and available hotel space

Airline A also schedules a meeting after each activity to review the station's performance during the deicing operation. The airline's station manager is responsible for convening this meeting, identifying areas needing improvement, and directing the appropriate corrective action. He is also responsible for preparing a report that documents the deicing operation. This report must include the following statistics: the total number of aircraft, gallons of deicing fluid used, gallons of water used, overnight aircraft on station, and takeoff delays associated with deicing.

Airline A recommends the number of trucks to be used to deice particular aircraft types, the order in which the various aircraft surfaces are to be deiced, and the location of the aircraft while it is being deiced. The deicing operation is usually carried out while the passengers are on board. This airline, like most others, recommends that the APU be shut down during deicing. The air conditioning is not operational without the APU and the cabin temperature must be monitored and the passengers kept comfortable during the deicing operation.

Airline B publishes its deicing/anti-icing procedures in a general manual used for the fleet as well as in the manuals for individual aircraft types. The general manual discusses the deicing personnel and flight crew

responsibilities, methods for removing contaminant accumulations, and the operation of deicing equipment. This airline has a deicing committee at its hub airport. This committee consists of a system control tower manager, maintenance deice foreman, station assistant manager, and a pilot. The tower manager coordinates with the other committee members to keep them advised of the airline's deicing capabilities at the hub and estimated takeoff delays during deicing. The maintenance foreman is responsible for ensuring that the deicing equipment and personnel are ready. The maintenance foreman also maintains radio communications with the flight crew and other personnel. The station assistant manager must ensure that a sufficient number of deicing personnel are available for the given situation. The station assistant must maintain radio communication with the station personnel to effect any changes in aircraft loading or gate assignments.

The conditions may become so bad that it is most effective to deice in a hangar. In this case, the maintenance foreman notifies the other committee members that the ramp is no longer an adequate deicing location. The tower manager then coordinates with the station assistant manager to determine which aircraft will be loaded and brought into the hangar for deicing. Two bays in the hangar are equipped with ground power for the aircraft so that the engines and APU can be shut down and the air conditioning can continue to operate during the deicing operation. In the hangar, the aircraft hot water is used to remove the snow and ice, and a protective coat of ADF is sprayed on. The aircraft is then pushed out of the hangar for immediate dispatch to the runway area.

This airline has a specific method for removing frost from the aircraft surface. The surface is cleaned by spraying hot water and then is permitted to dry. If there is evidence of ice formations on the aircraft after the hot water spray, there is a follow-up application of an 80/20 deicing mixture. Snow and ice are removed according to the general recommendations provided by the aircraft manufacturers and ADF suppliers.

The flight crew is responsible for the inspection of the aircraft prior to takeoff. At 15-minute intervals between the completion of the deicing operation and takeoff, a crew member must inspect the aircraft for additional accumulation. The flight crew is also responsible for monitoring the engine indications, such as EPR, N1, and N2, to assure that the sensors are functioning properly.

Airline C normally uses a 60/40 deicing mixture. This airline bases specified fluid flow rates on the weather conditions and type of accumulation. A flow rate of 30 GPM is specified for use in most weather conditions and for ADF concentrations between 30 percent and 65 percent. A flow rate of 60 GPM is recommended in high wind conditions. The 95 GPM and 125 GPM nozzle settings are used during hot water deicing, when ice or large amounts of snow are to be removed.

ADF concentration is checked before it is transferred from the delivery tank to the storage tanks. This test is usually accomplished with a refractometer. In some cases, a hydrometer is used but this

requires close monitoring of the ambient temperature during the testing procedure. The water and ADF solutions mixed in the deicing trucks are tested after mixing to verify the ADF concentration. The proportional system on the deicing vehicle is tested for correct calibration at the beginning of each deicing season and after any maintenance on the spray nozzle or proportional valve. Any stations that use undyed ADF are required to check the proportional system before commencing deicing operations each day.

The airline cautions that although the fluid mixture is not particularly harmful, every precaution must be taken to prevent the inhalation of the fluid vapors. The eyes and body must be washed immediately with soap and water if they come in contact with the fluid. The deicing operators wear protective gloves while spraying to help protect their hands from burns that can result from the high temperature of the deicing fluid.

Procedures specified by Airline D are similar to those described in the preceding paragraphs. The responsibility for coordinating ground deicing procedures and personnel training is delegated to the maintenance supervisor or the customer service manager. They are also responsible for verifying the concentration of the ADF shipments. This airline has specified a minimum ADF concentration of 30 percent to be used in all deicing operations conducted when ambient temperature is below 1°C (34°F).

Airline E uses 60/40 or 50/50 deicing mixtures for all operations. Some locations use premixed solutions at these concentrations. The airline requires that concentrations of these solutions be verified by the maintenance operations center manager on duty. This airline also contracts with other organizations to deice their aircraft. The contractor's procedures and equipment must meet the airline's specified requirements for deicing.

Airline E maintains its deicing vehicles in a standby condition throughout the deicing season. This requires the truck to be filled with a 60/40 solution. When temperatures are -21°C (-5°F) or below, the truck must be filled with a 50/50 mixture. The vehicles are brought to a ready condition by heating the fluid when deicing conditions are imminent. The fluid must maintain a freezing point 20°F below that of the outside temperature and a maximum concentration of 60/40 must not be exceeded. The recommended spraying temperature of the fluid is between 71°C (160°F) and 82°C (180°F). Small amounts of dry snow, not adhering to the surface of the aircraft, may be permitted to remain on the aircraft prior to takeoff, with the captain's approval, since this type of accumulation may blow off during taxi out. However, such operation violates the clean aircraft concept described in FAA AC 20-117.

The deicing operations described by Airline F detail the procedures used at the airline's major hub. A snow desk operation is established for each deicing operation. The snow desk is manned by the line support services manager, the facility manager, and the system ramp control manager, who is also designated the snow desk commander. The snow desk commander is responsible for overall ramp coordination, pushback, and coordination with the FAA control tower.

The decision to implement the snow desk must be made three hours prior to forecasted freezing precipitation, to ensure adequate communications and ramp preparation. The hub operations management is responsible for monitoring the weather conditions and coordinating all necessary actions to protect and operate the ground support equipment. The deicing requests are made through the hub control room manager to be forwarded to the the snow desk.

The line maintenance staff is required to equip certain pieces of equipment with tire chains, start deicing vehicles, and inform the ground support equipment maintenance staff regarding the number and type of equipment needing chains.

The deicing vehicles undergo a pre-operations routine, which includes inspection, topping of the fuel and deicing fluid storage tanks, and heating the fluid to 82°C (180°F). Upon completion of the deicing operation, all vehicles return for a post-operation inspection and are filled with fuel and ADF. When additional deicing is required, the aircraft must return to a specific location and notify the ramp clearing facility. The additional deicing is done by the nearest available vehicle with an adequate supply of fluid on board.

The deicing crew and flight crew communicate with placards and hand signals. The flight crew is queried by the deicing personnel as to whether they require deicing. The crew signals by a thumbs-up (affirmative) or thumbs-down (negative) reply. Upon completion of the deicing operation, the deicing operator displays a "DEICING COMPLETE" placard to notify the flight crew. The deicing vehicle and aircraft maintain an eight-foot clearance throughout the operation.

Airline F specifies that the aircraft maintenance foreman is responsible for coordinating on-ground aircraft deicing. He must also verify that the deicing equipment is checked weekly for operational readiness between October 1 and March 31.

The standard deicing solution for winter operations at Airline F is 50/50 deicing mixture above 0°C (32°F), at lower temperatures the mixture may need to be adjusted to protect against freezing. The airline recommends that the deicing fluid be heated to between 60°C (140°F) and 93°C (200°F) for expedient and efficient aircraft deicing. The most commonly used fluid flow rates are between 60 GPM and 125 GPM. The 30 GPM setting is recommended for anti-icing procedures only.

4.4 PROCEDURES EMPLOYED BY THE GENERAL AVIATION COMMUNITY

The deicing procedures employed by the general aviation (GA) community vary from placing the aircraft in heated hangars to melt the accumulation to deicing with fluids containing an ADF. There are no written procedures documenting the methods used in the GA community. There is also a lack of training among GA pilots and some FBOs regarding effective ways to deice and anti-ice aircraft. Many GA pilots cancel flights, rather than taking

off in icing conditions. However, as discussed in Chapter Seven, many accidents attributable to on-ground icing involving GA aircraft do, in fact, occur. Further information concerning on-ground deicing procedures was obtained through pilot interviews. This information is discussed in Chapter Six.

4.5 PROCEDURES RECOMMENDED BY THE ASSOCIATION OF EUROPEAN AIRLINES

The European airlines follow the procedures outlined by the AEA in "Recommendations for Aircraft Deicing/Anti-Icing on Ground." These procedures, which were developed with input from ground personnel and pilots, establish the minimum requirements for deicing and anti-icing of aircraft on the ground to provide an aerodynamically clean aircraft for takeoff. The AEA anti-icing code is to be used by ground crews to inform flight crews about the quality of protection the aircraft has received against accumulations of frost, snow, or ice on the surface of the aircraft.

The anti-icing code describes the quality of treatment the aircraft has received. The anti-icing AEA Type I and Type II fluid holdovertimes were shown in Tables 2-1 and 2-2. The AEA Type I fluids mainly provide protection against refreezing when no precipitation is occuring.

The AEA Type I fluids are used for deicing aircraft and provide limited anti-icing protection when there is no precipitation (see Table 2-1). The AEA Type II fluids provide protection against refreezing under both precipitation and non-precipitation conditions. The AEA specifies that airlines and handling agents must be aware of the various requirements for handling the two types of fluids, as described in Chapter Two.

The AEA recommends a quick, continuous operation for the removal of frost, snow, or ice from an aircraft surface to preserve the holdovertime of the fluid. These recommendations describe two methods for deicing and anti-icing, referred to as one-step and two-step deicing. Table 4-1 shows a comparison of the two methods and how each is to be used. One-step deicing combines deicing and anti-icing into one process. This process has a specific temperature limitation at -14°C (7°F) for AEA Type II fluids, as shown in Table 4-1. For AEA Type I fluids the one-step deicing requires the freezing point of the mixture to be at least 10°C (18°F) below ambient temperature. For AEA Type I fluids the two-step deicing process requires that in the deicing step, as shown in Table 4-1, the freezing point of the mixture can be at most 7°C (13°F) above the ambient temperature. One-step deicing uses a heated mixture of ADF and water, with mixture concentration determined by weather conditions. The advantage of one-step deicing is that it usually takes less time than two-step deicing because aircraft surfaces are sprayed once and not twice.

Two-step deicing separates the deicing and anti-icing processes. Two-step deicing is usually used when there is a heavy accumulation of ice, snow, or frost on aircraft surfaces, time and equipment permitting

TABLE 4-1

AEA'S AIRCRAFT DEICING AND ANTI-ICING PROCEDURES

Ambient Temperature Degrees Centigrade	ADF Concentration in Water					
	AEA Type I Fluids			AEA Type II Fluids		
	One-Step Deicing Deicing and Anti-Icing	Two-Step Deicing		One-Step Deicing Deicing and Anti-Icing	Two-Step Deicing	
		Deicing	Anti-Icing		Deicing	Anti-Icing*
0	Freezing point of mixture must be at least 10°C below ambient temperature.	0/100	Freezing point of mixture must be at least 10°C below ambient temperature.	50/50	0/100	50/50 or 75/25 or 100/0
- 5						
- 7		Freezing point of mixture can be a maximum of 7°C above ambient temperature.		75/25	50/50	75/25 or 100/0
-10						
-14						
-15						100/0
-17					75/25	
-20						
-25						

*Concentration depends on weather conditions.

(see Section 3.2.2.1.3). Because the deicing and anti-icing processes are separated, the AEA recommends using hot water or a hot ADF/water mixture to deice and a stronger mixture to anti-ice. The two-step deicing has the possible advantage of conserving glycol since the glycol is used mainly as an anti-icer. The anti-icing concentration is determined by the ambient temperature and weather conditions for both AEA Type I and II fluids. The anti-icing step involves applying a mixture of ADF and water or 100 percent ADF. The holdover time is longest when unheated, 100 percent ADF is applied. The AEA specifies that anti-icing must be performed within three minutes of the beginning of deicing, in order to avoid the possibility of ice reforming on aircraft surfaces. The use of AEA Type II fluids in 100 percent concentration or 75/25 mixture, as specified in Table 4-1, is limited to aircraft with a rotation speed greater than 85 knots. The AEA believes that this limitation assures that a sufficient amount of fluid will flow off during the takeoff run.

The person releasing the aircraft is responsible for the correct and complete deicing/anti-icing of the aircraft. This is reported to the flight captain by using the appropriate AEA code. Once he accepts the aircraft, the captain is responsible for maintaining it in a state free of frozen contaminants. He must decide if additional deicing is required. The release of the aircraft to the captain comes with the understanding that the following precautions have been observed by the deicing personnel and flight crew: the fluid has not been directly sprayed at orifices along the aircraft, angle of attack sensors, or windows; the fluid that entered the engines, other intakes, and control surface cavities was minimal; the air conditioning and APU bleed air were selected off during deicing; both wings and stabilizers received the same complete treatment; and fluid on the cockpit window has been removed. The AEA recommends that the balance bay cavities and wings be checked for additional accumulation after prolonged delays.

The final check of the aircraft after deicing verifies that the wings and stabilizers are clean in accordance with the aircraft manufacturer's recommendations. The landing gear, inlets, scoops, and ram tubes must be checked for any accumulation. The openings for the APU and air conditioning and their adjacent areas must be clear. Any engine that has been subjected to strong snowfall or freezing rain is checked for accumulations of snow or ice in the inlet area prior to start-up. The AEA also recommends that the rear side of the fan blades on the engine be checked for ice buildup before start-up.

CHAPTER FIVE

CENTRAL AND REMOTE DEICING FACILITIES

Deicing operations can be conducted at various airport locations including the gate area, a central facility, or a remote facility. A central deicing facility is a fixed site where aircraft from various airlines are deiced prior to takeoff. The central facility may have fixed or mobile deicing vehicles and sometimes includes a glycol recovery system. A remote deicing facility is located away from the ramp area, and has several deicing vehicles positioned by a particular airline in a car wash arrangement to deice aircraft on the way to the runway. Remote facilities are used by some airlines temporarily during periods of heavy snow, ice, or freezing rain. The following paragraphs describe a variety of central and remote facilities. A discussion of the advantages and disadvantages of deicing aircraft at the gate, a central facility, and a remote facility, is also included.

5.1 CENTRAL DEICING FACILITIES

Central deicing facilities have been constructed and operated with the objectives of reducing time between deicing and takeoff, reducing delays sometimes associated with deicing at the gate, reducing the high cost of deicing, and reducing the supposed environmental effects of deicing fluid. Most central deicing facilities include the following elements:

- fluid storage, heating, and dispensing system
- fluid application system
- effluent collection and storage system
- effluent clearing and reuse method
- effluent reconcentration system
- guidance and traffic control system

Four central deicing facilities have been constructed in Europe and North America. They are located at Charles de Gaulle Roissy Airport, Paris, France; Dorval Airport, Montreal, Canada; Mirabel International Airport, Montreal, Canada; and Kallax Airport, Lulea, Sweden. These facilities are described in the following paragraphs.

5.1.1 Charles de Gaulle Roissy Airport

The central deicing facility at Charles de Gaulle Roissy (CDG) Airport in Paris was the first such facility to be built and operated at a major international airport. It is owned by the Paris Airport Authority and Air France is responsible for its operation and maintenance. The facility was first operated in 1974 with two major objectives. First, the Paris Airport Authority hoped to minimize the ecological impact of deicing fluids by providing a means to collect the fluids before they escaped into the surrounding environment. Second, the facility was intended to reduce the cost of deicing since all costs were to be shared among the airlines using the facility. This central facility is used only for deicing operations. Anti-icing operations at CDG airport are conducted at the gate.

The deicing facility at CDG airport consists of two distinct areas: a deicing station and a partially buried recycling plant. There are presently two deicing stations at the facility. The second deicing pad, which began operations during the 1984-1985 season, was constructed with funds from the airlines using the facility and is intended to reduce the problems of delays from traffic congestion. The deicing facility can accommodate aircraft ranging in size from the Twin Otter to the Boeing 747.

When the facility was first operated in 1974 only mobile equipment was used at the deicing station. This equipment was replaced during the 1975-76 season with two permanent gantry crane type structures. Each crane can spray deicing fluid on one half of an aircraft, longitudinally.

Each crane supports a work platform that extends approximately 115 feet from the center of rotation. The platforms are located 40 feet and 23 feet above the ground and can be rotated 180 degrees. The horizontal rotation of each crane is controlled through a remote-control console located near the top of each work platform. Each platform has spray nozzles with which to deice each side of the aircraft. Special ground nozzles are available to deice landing gear and other low parts of the aircraft when necessary. The fluid is pumped to the work platform nozzles through flexible pipes originating at the distribution and recycling facility. The fluid is heated to between 80°C and 90°C (176°F and 194°F) before it is dispensed. It is pumped at a minimum rate of 700 GPM.

The deicing fluid used at this facility is a mixture of an ethylene glycol-based ADF, called Napgel, and water. Napgel, an Association of European Airlines Type I fluid, is manufactured by BP Chemical Company. A mixture of 30 percent Napgel and 70 percent water is used when ambient temperature is -7°C (19°F); at -25°C (-13°F) a mixture of 50 percent Napgel and 50 percent water that has a freezing point of -36°C (-33°F) is used for deicing.

The deicing pad consists of a concrete surface with a raised centerline that causes the excess deicing fluid to flow toward the east and west boundaries of the pad. The fluid is collected in a steel-edged trough at the boundaries of the pad and channeled to the underground recycling facility located to the south of the deicing facility. A six-inch-high curb at the edges of the concrete surface prevents the fluid from spilling into the soil near the deicing pad.

The recycling facility was designed to recycle ADF from the runoff collected around the deicing pad. The fluid enters the settling tanks, which have a capacity in excess of 52,000 gallons. Here sediment and other solid particles from the runoff are removed by passing the fluid through a finely meshed filter. Once the filtration process is completed the fluid is pumped into a supply reservoir that can store in excess of 26,000 gallons. The glycol concentration is checked and pure ADF is added to the filtered ADF to attain a 50 percent concentration before the mixture is returned to the heating and pumping system. Refractive index techniques are used to monitor the concentration of the deicing mixture.

When an aircraft reaches the deicing facility, the deicing operators and the flight crew communicate by radio to assure that cabin ventilation intakes are closed before the aircraft is sprayed with deicing fluid. The engines and propellers continue to run during the spraying, although precautions are taken to avoid direct spraying into the engines and APU inlets as well as other critical areas. Each airline receiving the deicing service has a representative present to monitor and inspect the process. Generally, the deicing process is completed in five to 10 minutes depending on aircraft model. Takeoff is expected to occur within six minutes after an aircraft leaves the deicing facility.

The central deicing facility operating expenses are shared by the airlines using the facility. The annual fee for members (major European and U.S. air carriers) for 1984 was $1,082.00 (10,390 French francs)*. Non-members are charged an average annual fee based on the fluid used in the deicing season. The fee charged to non-members in 1984 was $6,546.00 (62,842 French francs). The cost per aircraft varies with facility usage, type of aircraft, and weather conditions.

5.1.2 Dorval Airport

The central deicing area at Dorval Airport in Montreal, Canada, serves Air Canada and Air Ontario. This facility includes four permanently stationed deicing vehicles, water and ADF storage tanks, and effluent recovery tanks.

---

*A conversion rate of 9.6 francs per U.S. dollar was used to calculate these U.S. dollar figures.

Narrow-body aircraft are deiced on a pad located close to the runway. The deicing units are supplied with the deicing mixture via a network of flexible piping connected to the storage tanks. After deicing, the excess fluid drains off the pad into effluent recovery tanks. The recovered fluid is then transported to a chemical plant where the impurities are filtered away and the deicing mixture is restored to its original concentration.

The equipment at the Dorval facility is operated by airline maintenance personnel. Upon completion of the operation, an airline representative inspects the aircraft. He is responsible for ensuring that the aircraft is free of contaminant accumulation prior to requesting clearance for takeoff.

5.1.3 Mirabel International Airport

The Mirabel International Airport central deicing facility was constructed in 1976, at a cost of $5.14 million ($7 million Canadian)*. The facility was intended to serve as a pilot project to eliminate the pollution problem associated with deicing aircraft at the gate using glycol-based deicing fluids.

The central deicing facility at Mirabel consists of two deicing pads, an aircraft guidance and control system, and a fluid supply and collection system. The two deicing pads, located between runways A and B, are accessed by common taxiways at the east and west ends. The pads have raised concrete centers with asphalt shoulders. A guidance system of recessed centerline lights runs through the pads and the approaches. The outer edges of the deicing area are delineated by surface-mounted lights. Personnel located in a nearby control building coordinate the queuing of the aircraft and operate red and green traffic lights to direct aircraft entering the facility and stopping at the deicing position.

The fluid supply and collection system consists of four 68,150-liter (18,000-gallon) glycol storage tanks and six 68,150-liter (18,000-gallon) storage tanks for the recovered fluid, all located above ground. The glycol tanks are connected to heaters and pumps that distribute the fluid to hydrants on either side of each deicing pad. Fresh ADF is fed from the storage tank to a 45,400-liter (12,000-gallon) receiving station, connected to the deicing station by buried plastic lines. The concentration of the fluid entering the recovery tanks is monitored periodically with densiometers. Fluid that will be transported away for reconcentration or disposal is pumped from the underground recovery tanks to the discharge hydrants at the receiving center.

The deicing facility at Mirabel was designed for fixed spraying, using equipment that allows the operator to be positioned above the aircraft (high-access mobile cranes). This high-access equipment was

*A conversion rate of $0.7345 Canadian dollars per U.S. dollar was used to calculate these U.S. dollar figures.

intended to increase the speed of the process by allowing the aircraft engines to run during the deicing process. However, operations opened with the deicing being accomplished by operators positioned on mobile, truck-mounted aerial platforms because the high-access mobile cranes had not been installed. Engines on the side of the aircraft being deiced must be shut down while the mobile deicers are being operated. Engines on the opposite side of the aircraft may be kept running.

The capacity of the Mirabel deicing facility is dependent upon various factors such as the size and type of aircraft and ambient weather conditions. During an average deicing operation the facility is capable of handling six B-747 aircraft or 12 DC-8 aircraft per hour.

The Mirabel central deicing facility was closed after two seasons of operation because of various problems that sometimes resulted in delays of up to four hours during periods of heavy snow. These problems included:

- A poorly organized dispatching system of aircraft to the facility, which resulted in queuing problems.

- Visibility during deicing conditions is usually very poor and the guidance of aircraft onto the pad was difficult, especially when the pilot was unfamiliar with the facility.

- The time spent maneuvering the mobile vehicles around the aircraft and lack of engine starting capabilities at the pads added to the delays in deicing, since aircraft were deiced one side at a time.

- The glycol recovery was impaired because the fluid collected on the ramp area and was blown away by jet blast. Drainage troughs were too wide for snow plow blades to keep them cleared, and the fluid remained on the ground to be carried away by the snow plows.

- Blowing snow, which would have normally passed over dry pavement, adhered to the pavement of the pad which had become wet from the deicing fluid. The resulting accumulation made movement of aircraft onto the pad and deicing vehicles around the aircraft difficult. It also retarded runoff into the drainage system.

- The pumping and heating tanks and piping equipment did not operate properly since their above-ground, outdoor locations left them constantly exposed to the weather.

- Snow removal around the equipment was a laborious, costly operation and occasionally resulted in damage to the equipment.

Improvements were made to the central facility after the 1977-78 season. These included improved guidance and traffic control systems, enclosure of the above-ground tank area, and an improved fluid recovery system. However, these improvements did not improve the facility's performance sufficiently to justify continued operation.

5.1.4 Kallax Airport

The central deicing facility at Kallax Airport in Lulea, Sweden, opened for the 1984-85 season. This facility is a test plant employing methods not previously used at other central deicing facilities. The objectives of the plant include a 30-percent reduction in deicing costs, fewer delays due to deicing, a higher level of flight safety due to the automated system, a better working environment for the ground staff, and a reduction of the environmental effects of glycol through a closed system and recycling of the deicing fluids.

The facility at Kallax is an automated, computer-controlled plant through which aircraft pass on their way to the runway. The deicing fluid is sprayed by 152 computer controlled nozzles, simultaneously. Photocells and computers adjust the spray pattern depending upon the size and shape of the aircraft being deiced. Engines are kept running throughout the process, which is estimated to take less than two minutes. A porous asphalt cover on the taxiway pad enables the excess glycol to flow along a drainage system for recycling. The fluid is collected, cleaned and the glycol content restored to the original concentration level to be used again.

5.1.5 Pros and Cons of the Centralized Deicing Facility

Each of the central deicing facilities described above was constructed to help alleviate several problems sometimes encountered during deicing operations. These problems include takeoff delays that sometimes occur during conditions of on-ground icing, the supposed adverse environmental effects of excessive amounts of ethylene glycol contained in some deicing fluids, and the relatively high cost of conducting individual deicing operations.

The potential advantages associated with a centralized deicing facility are the following:

- reduce the time between deicing and takeoff
- recycle the ADF contained in the deicing mixture
- reduce the supposed detrimental environmental impact of some glycols contained in ADFs
- make sufficient quantities of ADF and water available to effectively deice numerous aircraft without interrupting operations
- spray the correct ratio of ADF and water for the ambient weather conditions
- offer cost savings to the airlines

The ability of a central deicing facility to help achieve these goals is dependent upon the following factors, which affect the performance and efficiency of the facility:

- The elapsed time between deicing and takeoff can be reduced most effectively when the facility is located close to the most heavily used runways, aircraft guidance through the facility is easy, pilots are familiar with the guidance system, and the airport traffic volume does not become too heavy for the facility to handle.

- The collection of the effluent that can be recycled reduces the amount of glycol that enters the waterways surrounding the airport.

- The recycling of the ADF and restoration of the fluid to the desired concentration is best accomplished at the central facility rather than shipping the collected fluid to another plant for recycling. The added cost of shipping the ADF and having it processed by another organization are thus eliminated.

- The storage tanks for ADF and water at central facilities are much larger than those on the deicing vehicles used by individual airlines. Therefore, operations are interrupted to fill the storage tanks less frequently than to fill the tanks on mobile deicing vehicles.

Most deicing facilities include a proportional mixing system that enables operators to adjust the concentration of the deicing mixture as appropriate for the ambient weather conditions, thus reducing wasted ADF. This more efficient use of ADF along with the recycling reduces the cost of deicing incurred by the airlines during cold weather operations. Also, the airlines benefit from additional cost savings when a central facility is available since they do not individually have to buy and maintain the vehicles and equipment used during deicing operations.

Only four facilities have been constructed and one of those, Mirabel, is currently not operating. While the facility at Kallax only began operations during the 1984-1985 season, a review of its effectiveness is presently under way by Transport Canada. The facilities at Mirabel and Charles de Gaulle have experienced problems:

- The use of the central facility at Mirabel actually increased takeoff delays at the airport due to the poorly designed guidance system, equipment failures, and poor queuing of aircraft.

- Both the Charles de Gaulle and Mirabel facilities have the capability to recycle ADF. However, the design of the Charles de Gaulle facility allows the fluid to be blown away from the pad area, unable to be reclaimed or recycled. At Mirabel the draining troughs leading to the collection tanks frequently became filled with snow, inhibiting the recycling efforts.

- Deicing fluid at Charles de Gaulle is sprayed without shelter from the elements. This results in significant amounts of fluid being carried away by wind.

- Aircraft engines and propellers are kept running, which both airframe manufacturers and United States airlines recommend against. This practice reduces delays from stopping and starting the engines, but can inhibit the accurate spraying of some aircraft surfaces. The ingestion of glycol into the engine can result in damage if the glycol is burned in the engine. The Mirabel facility required the engines be shut down on the side of the plane being deiced and although this also decreased the facility's capacity, it was not in conflict with the recommendations of the airlines and aircraft manufacturers.

- High access spraying equipment was not installed in the Mirabel facility as planned, but the facility operated using mobile truck deicers that usied a proportioning system to spray the fluid.

- The cost savings offered the airlines is often negated by the cost associated with recycling the fluid, whether this is done at the facility or elsewhere.

- Aircraft takeoff delays increase operating costs.

Airlines in the the United States are presently responsible for aircraft maintenance, including deicing, and adhering to the clean aircraft concept described in FAA AC 20-117. The operators of a central facility would assume the responsibility associated with deicing aircraft. Also, the airlines who now have individual procedures for deicing aircraft would have to agree upon a set of deicing procedures to be implemented at a central facility.

5.2 REMOTE DEICING FACILITIES

The remote deicing operation is generally employed when the traffic flow into a terminal is high, creating a great demand for gate space. This operation involves the aircraft being pushed back from the gate to an area away from the traffic flow. Alternatively, the aircraft may taxi to an area closer to the runway from which the aircraft will take off. The deicing trucks are positioned in this area and clear the aircraft of the contaminant accumulation immediately before takeoff. The airlines perform this deicing operation on their own aircraft and therefore the gates are opened in a logical sequence able to accommodate the airlines' incoming traffic for the terminal. The aircraft that are deiced at remote locations shut down their engines, which may increase their time in the queue for takeoff. This method of deicing/anti-icing allows the airline to monitor more closely the potential delays that can be experienced as a result of deicing operations. Airlines that subscribe to the hub and spoke concept of operations, which is becoming increasingly popular in the aviation community, frequently use this method of deicing/anti-icing at their hub.

The remote site deicing/anti-icing operations are also employed by some airlines at airports that do not have enough terminal space for all the aircraft and the passengers and cargo are boarded at remote locations. These airlines perform deicing operations after all passengers have boarded the aircraft. This situation is considered remote since the deicing is not performed at a gate.

5.2.1 Pros and Cons of Remote Deicing

The remote deicing operation is similar to the gate deicing/anti-icing operation in that the same equipment is used, the ADF runs off into the airport drainage system, and the engines are usually shut down. Remote deicing offers the advantage of reducing the elapsed time between deicing and takeoff. Therefore, fewer aircraft require additional deicing. This results in fewer delays and decreased expenditure to conduct deicing operations. Remote deicing leaves gates available for loading and unloading of passengers and cargo. A disadvantage of deicing at a remote location is that aircraft may have to wait in line to be deiced at the remote location.

5.3 COMPARISON OF DEICING AT VARIOUS LOCATIONS

Deicing operations conducted at the gate, a remote location, or a central deicing facility each have associated advantages and disadvantages. The most common location among airlines worldwide for performing deicing operations is at the terminal gate. Airlines have been maintaining their own aircraft and determining deicing procedures and are comfortable with continuing the present system. Deicing operations at a remote location are increasing in popularity at hub locations, specifically because the necessary gates are free for aircraft arriving at peak times. In the United States, airlines that use remote locations say they prefer to deice at the gate whenever possible. Many pilots reported that they would like to be deiced as close to takeoff as possible, preferably as they approach the runway as discussed in Chapter Six.

Although the central deicing facility concept has not been tested in the United States, this concept is continuing to be explored in Europe with the newly opened facility at Kallax Airport in Sweden. The central facility can help to reduce the supposed adverse environmental impact of the glycol contained in the ADF, while neither the remote location nor gate deicing operation provides this capability.

CHAPTER SIX

INTERVIEWS WITH PERSONNEL INVOLVED WITH ON-GROUND AIRCRAFT DEICING

Interviews were conducted during the period from January through September 1984 with commercial airline maintenance personnel and pilots and with general aviation fixed-base operators, maintenance personnel, and pilots regarding procedures and techniques used for the on-ground deicing and anti-icing of aircraft. The following paragraphs document the findings of these interviews. The reader is cautioned that there are probably other procedures that were not mentioned in the interviews.

6.1 COMMERCIAL AIRLINE PERSONNEL

Commercial airline personnel involved in various aspects of on-ground aircraft deicing were interviewed as part of this effort. Sixteen maintenance personnel representing 13 U.S. and European commercial airlines were interviewed at six locations. These personnel are trained in the operation and use of deicing equipment and the application of deicing fluid to commercial aircraft.

Data were collected from 170 commercial pilots by means of personal interviews and a questionnaire-type survey. ARINC Research personnel interviewed 13 pilots while conducting on-site observations of on-ground deicing operations. The other pilots offered information in response to a questionnaire distributed by three airlines and the Air Line Pilots Association (ALPA). Anonymous responses were returned to ARINC Research Corporation with no airline affiliation indicated.

6.1.1 Maintenance Personnel

The number of qualified trained deicing personnel at the airlines surveyed ranged from 18 to 175. The deicing crews at some airlines consist of maintenance personnel, while other airlines use line service personnel, such as baggage handlers supplemented by maintenance personnel to perform deicing work. Deicing personnel are initially trained in the classroom with lectures and audio-visual aids. This training is supplemented with on-site experience gained during actual deicing operations, as well as practice during the warmer months by maintenance personnel using deicing vehicles filled with water to wash the aircraft. Refresher training,

which includes a review of cold weather operations bulletins and training films, is conducted annually.

The deicing crews have the following responsibilities:

- Remove all frozen accumulations from the aircraft

- Ensure that the ADF is maintained at the proper concentration and temperature and that the optimum nozzle setting is used during deicing and anti-icing

- Avoid spraying deicing mixture into openings such as the APU, engines, and pitot static tubes.

Some airlines specify the ADF concentration to be used as a company standard; others permit the concentration to be determined by the deicing supervisor, whose decision is based on the ambient weather conditions. The concentration is checked with a refractometer or hydrometer each time the deicing truck is filled. Many airlines use a heated premixed deicing solution; others use deicing trucks that have separate compartments to hold ADF and water, which are proportionally mixed at the spray nozzle (See Section 3.2). The proportional mixing system helps minimize the amount of ADF used during each application since the concentration of the deicing mixture can be modified as appropriate for current weather conditions. However, some airlines have chosen to use premixed deicing solutions for the following reasons:

- Unheated water not purged from the system can freeze and damage the vehicle and/or make it unusable for several hours, until the ice thaws. This problem can be avoided by using a premixed deicing solution since the addition of ADF to the water will lower the freezing point of the solution well below 0°C (32°F).

- There is a possibility that deicing personnel may unintentionally apply hot water or a deicing mixture containing an inadequate amount of ADF that will freeze on the aircraft. A premixed solution eliminates the possibility of this type of operator error. Also, the concentration of the deicing mixture provided by the proportional mixing system varies slightly as the fluid is being sprayed, so deicing personnel sometimes set the concentration higher than necessary to ensure that the fluid being applied offers adequate protection. This defeats the supposed economical advantages of the proportional mixing system since too much ADF may be used.

- There is a possibility that either the ADF or water will be completely dispensed before the other, rendering the vehicle unusable until the empty tank is refilled. Therefore, the vehicle is not used to its maximum capacity.

The deicing crew may make recommendations to the flight crew regarding deicing, but the ultimate responsibility to have an aircraft deiced rests with the captain of the aircraft. The maintenance personnel who were interviewed stated that aircraft are usually deiced whenever there is any accumulation of ice, snow, or frost adhering to the surface. This is especially true on the East Coast where wet, heavy snow is common. Aircraft operating in the Midwestern United States, where the snow is usually dry and powdery, are sometimes permitted to take off with an accumulation of this type of snow on the aircraft surface. This type of snow tends to blow off of the aircraft during takeoff.

The maintenance personnel reported that aircraft seldom return to the gate for additional deicing. The responsibility for determining when additional deicing is required rests with the captain of the aircraft as does the responsibility to receive deicing initially. However, deicing personnel at some airlines said that they sometimes make recommendations to the pilot. Personnel from one airline reported that they often deice an aircraft more than once. Aircraft at that particular airline are usually deiced as soon as they are unloaded. This results in the longest possible delay between deicing and takeoff and may contribute to the relative frequency of additional deicing operations.

The flight engineer usually checks the aircraft prior to deicing during his initial walk-around. The deicing crew is responsible for ensuring the cleanliness of the aircraft after deicing. They signal, either orally or visually, to the flight crew to inform them when the deicing operation is complete. Re-inspection of the aircraft for additional accumulation is the responsibility of the flight crew. However, they sometimes request assistance from deicing personnel.

The deicing procedures described by the maintenance personnel did not vary significantly among various airlines. One deicing vehicle is used per aircraft, except for wide-bodies, for which two or three vehicles may be used. Representatives from three airlines reported that they use brooms and fabric hoses to remove ice from the aircraft surface before applying a deicing mixture, especially when the accumulation is greater than three inches and ambient temperature is below -7°C (20°F). A lead maintenance mechanic from another airline stated that although large brooms are available for use during the deicing operation, they are not used because the airline's management believes that the procedure is excessively time consuming and labor intensive. The aircraft engines are turned off while the aircraft is being deiced, but the APU can be running, as specified in the aircraft manufacturer's and airline operations manuals. However, a representative from one airline said that aircraft are deiced with the engines running. He did not report any problems associated with this practice.

Special procedures are sometimes invoked during periods of heavy, freezing precipitation and in the early morning. Remote deicing operations were cited by the personnel interviewed as a possible way to reduce delays that frequently occur during such conditions. Representatives of two airlines mentioned that during heavy precipitation they deice fully loaded

B-747 and DC-10 aircraft in a hangar. One deicing operator reported that the airline he represents requires a ramp foreman to check all aircraft for frost accumulation each morning. All aircraft having accumulation on any surface are then deiced. He noted that frost normally forms on aircraft shielded from the wind.

The personnel interviewed indicated that to the best of their knowledge most airlines provide deicing services at their hub or major facility to other airlines at that location. In such a case, deicing may be performed according to the procedures specified in the customer's operations manuals or according to the airline performing the deicing, depending on the contract. In the latter case customers are required to sign consent forms verifying their knowledge and acceptance of the deicing procedures. Depending on the circumstances, most airlines will deice their own aircraft before those of their customers.

The maintenance personnel interviewed seemed satisfied that deicing operations resulting in a clean aircraft and personal safety. There were no problems reported associated with fluid toxicity. Some of the personnel complained that the ADF causes slipperiness in the ramp area, which makes walking and maneuvering the deicing vehicles difficult. One airline representative reported that a deicing operator was killed and another injured on separate occasions when the bucket disengaged from the boom of the deicing truck. Since that time the airline has installed safety harnesses that are connected to the boom for the basket operators. All airlines provide protective clothing such as rainsuit, gloves, goggles, and masks. Operators at some airlines are required to wear this clothing; at other airlines wearing the clothing is optional.

Some airlines reported problems with foreign object damage when engines ingested ice, especially in the center or number two engine of DC-10, B-727, and L-1011 aircraft. Others said that they found that spraying the flaps on B-727 and DC-9 aircraft with pure ADF to be an effective method of preventing slush from adhering to these surfaces during takeoff. They also said that nose brake rotors on B-727 aircraft can freeze when slush accumulates on them during takeoff. This can be prevented by deicing the nose brakes in slush conditions.

Most maintenance personnel were unfamiliar with AEA Type I and Type II fluids.

6.1.2 Pilots

Most of the flight crew members surveyed reported that the captain delegates to the first or second officer the responsibility for determining whether on-ground deicing is necessary. This crew member visually inspects the aircraft for frozen accumulation during the pre-flight walk-around. Some crew members mentioned that they check for ice by feeling the aircraft surfaces. Although many said that all surfaces must be ice-free prior to takeoff, the majority specified the wings and the control surfaces as the most critical surfaces.

The flight crew inspects the aircraft periodically from the cockpit window to assess the need for additional deicing. These visual inspections are conducted at various time intervals depending on the weather conditions. Most crew members use time and weather conditions as the primary factors when determining if additional deicing is required. One airline specifies that these inspections must be conducted at 20-minute intervals between deicing and takeoff. Snow and ice buildup on the windshield wipers and the fading of the dye in the applied ADF were cited as frequent indicators that additional deicing is required. A few pilots consider the accumulation on other aircraft as an indication of build-up on their aircraft although most of those surveyed said they did not regard this as important information. When there is a question of how much ice or snow has accumulated on the aircraft the first or second officer may walk back into the cabin to visually inspect the wings through the cabin windows.

Engine and wing anti-icing is usually activated according to company policy. In many cases the engine anti-ice can be turned on immediately after engine start, whereas the wing anti-ice is activated after takeoff. Pilots and maintenance personnel from one airline said that they recommend turning off the wing anti-ice during approach. This allows the wings to cool before landing and helps prevent precipitation encountered on the ground from melting and re-freezing on the wing.

The following is a summary of the comments we received regarding potential adverse effects of conditions experienced during periods of on-ground icing.

A. Runway slush splashed on the aircraft from other aircraft.

   Most crew members have not experienced this condition because of the adequate separation between aircraft during taxi. However, in the few cases where this type of contamination was experienced, the personnel reported they needed a longer takeoff roll. One captain cited problems with wheel retraction resulting from slush buildup on the landing gear.

B. Engine instruments giving erroneous indications due to adverse weather conditions.

   A substantial number of flight crew members participating in this survey have experienced the engine pressure ratio (EPR) gauge giving erroneous indications; however, they reported little to no effect on aircraft performance.

C. Damage to engine due to ingestion of ice or snow accumulations.

   Several respondants reported engine damage due to ingestion of ice.

D. Performance degradation due to frost, snow, or ice accumulations.

Thirty-five percent of the flight crew members surveyed have experienced performance degradation due to frozen accumulations on the aircraft. This resulted in the aircraft requiring increased runway length and higher speed for takeoff and landing, vibration stability and control problems, and degraded climb performance. One crew member reported manipulating the nosewheel to lift the aircraft off the ground to avoid runway slush.

Most of the flight crew members surveyed felt that the deicing procedures currently used are adequate and had no suggestions for improvement. However, one pilot mentioned the desire for the ADF to provide longer holdovertimes. The most frequently cited suggestion for improving the deicing process is to decrease the time delay between deicing and takeoff through the use of a car-wash type of deicing facility (see Chapter Five) at the end of the runway. A scenario described by one of the captains in an effort to stress the importance of quick deicing just before takeoff is as follows:

> You are several hours behind, near the end of crew duty time, and number 6 in a line of 25 aircraft waiting to take off when you notice the snow build-up on your nose and wings to a marginal level. The captain has to make a difficult decision on whether or not to return to the gate and request additional deicing, where he would then be the last in the takeoff sequence.

Another suggestion was better education for the flight crew and the ground crew regarding the hazards of ice, snow, and frost accumulations on the aircraft and the importance of proper ground deicing. One pilot suggested that under conditions conducive to icing the flight crew should report to the aircraft 10 minutes earlier than under normal conditions in order to monitor the deicing process better. Some pilots believed that the deicing process is best regulated by the airline itself with minimal intervention by the Federal government.

Additional information obtained from this survey is as follows:

- Although it is the pilots' responsibility to request deicing, they believe it is the deicing crews' responsibility to properly deice.

- Most aircraft are deiced with both the APU and the engines turned off.

- The pilots who have had their aircraft deiced in Europe have not noticed any difference between the ADFs used there and in North America.

6.2 GENERAL AVIATION PERSONNEL

Information regarding on-ground aircraft deicing was collected from GA FBOs and pilots. We interviewed nine users of deicing equipment representing eight FBO organizations about equipment used and procedures followed to deice GA aircraft.

In addition, 41 GA pilots offered information and opinions regarding deicing procedures and techniques pertaining to GA aircraft. ARINC Research personnel interviewed 12 of these pilots. The remaining 29 pilots responded anonymously to questionnaires that were distributed at two airports and returned to ARINC Research Corporation.

6.2.1 Fixed-Base Operators

The smaller FBOs that participated in the survey usually place aircraft in a heated hangar to melt any frozen accumulation and thereby deice the aircraft. The aircraft is then left in the hangar or wing covers are installed to prevent further accumulation. These methods of deicing and anti-icing are more economical than using a deicing/anti-icing solution containing ADF. These FBOs also reported that, in many cases, their customers choose not to fly in conditions conducive to icing.

The larger FBOs surveyed require line service personnel to carry out deicing operations. Heavy accumulation is usually cleaned off the surface of the aircraft with brooms, brushes, and hoses. Deicing/anti-icing fluid may then be applied. This fluid is usually dispensed from a "home-built" deicing vehicle which consists of a 300- to 400-gallon ADF storage tank attached to a pick-up truck. The personnel interviewed reported few delays at GA airports resulting from deicing operations.

The FBOs surveyed usually service single-engine light planes through twin-engine turbojets: however, some are contracted by various commercial airlines to deice air carrier jets. The procedures and equipment used in these situations are comparable to those used by the airlines themselves. One particular FBO that is contracted to deice by a commercial airline stated that his company uses a 50/50 deicing solution to remove frozen accumulation and uses a refractometer to verify the concentration each time the deicing vehicle is refilled.

One FBO expressed concern that the ADF appears to corrode the paint on some GA aircraft. Another mentioned that he had experienced slipperiness in the deicing area and one co-worker experienced an upset stomach after applying the ADF. One FBO manager reported that sometimes it was difficult to find an adequate light source to accurately read the refractometer. He also believed that the braking and the wiper systems on the deicing vehicles could be improved. Some FBOs expressed the belief that they are obligated to recommend deicing to a pilot during icing conditions. Others operate under the policy that it is the pilot's responsibility to request deicing and that they have no right to make recommendations on this issue.

6.2.2 Pilots

The GA pilot questionnaires were distributed by various FBOs and a FAA Flight Service Station. The questionnaire was designed to assess the pilots' general knowledge of and their experiences regarding on-ground deicing, and to determine the number of pilots who have taken off with frozen accumulation and what effects this has had on their aircraft's performance.

Most of the GA pilots participating in this study deice their aircraft by manually brushing off the accumulation with brushes and brooms or by leaving the aircraft in a hangar until takeoff. Less than half reported that they deice with a deicing mixture containing ADF. A few stated that they do not fly in icing conditions. All pilots surveyed, except one, said that they inspect the cleanliness of the aircraft by physical inspection while walking around the aircraft. The remaining pilot checks the cleanliness of aircraft by visually inspecting the aircraft while in the cockpit. When anti-icing is required, a glycol-based solution is applied or the recently deiced aircraft is placed in a hangar.

Twenty-five percent of the GA pilots surveyed have taken off with approximately 1/8 inch of ice, snow, or frost adhering to the aircraft fuselage. Half of these pilots reported a noticeable degradation in aircraft performance. Twenty-five percent of the sampled pilots have cancelled flights because of inadequate deicing/anti-icing. These pilots reported that they would cancel flights less often if more effective deicing alternatives were made available.

The GA pilots who participated in this study offered the following suggestions for improving the deicing/anti-icing process and its effectiveness in the GA community:

- Chemical manufacturers and distributors should make less expensive ADFs available.

- ADFs should be capable of providing longer holdovertimes.

- Training should be made available to increase pilot understanding or awareness of the process and its importance.

- It should be possible to deice the aircraft in blocks without taxiing to another area.

6.3 SUMMARY

The interviews described in this chapter revealed several important points regarding deicing operations:

- Deicing procedures do not vary much among airlines.

- Some airlines use premixed deicing solutions; others use proportional mixing systems available on some deicing vehicles.

- Commercial pilots in North America are not very aware of AEA Type II fluids.

- One airline reported that landing gears are deiced, especially when slush is present on the runway.

- GA pilots would like better training regarding the hazards associated with icing.

Our discussions with other airline personnel revealed that one North American airline is conducting operational performance tests with AEA Type II fluid. Another airline has purchased 100 gallons of AEA Type II fluid and plans to conduct research into the holdovertimes that might be achieved by using this fluid during deicing at its hub.

In addition to these interviews, ARINC Research conducted on-site observations of deicing operations as part of this effort. The observations were conducted at Kansas City, Baltimore, and both JFK and LaGuardia in New York. The procedures that we observed were in accordance with the information presented in this chapter.

CHAPTER SEVEN

ACCIDENTS RELATED TO ON-GROUND ICING

Aircraft on the ground or in flight are susceptible to accumulation of ice, snow, or frost under various atmospheric and operational conditions. These accumulations can impair aircraft performance, and can result in an accident or incident. However, icing can be difficult to identify as a cause or contributing factor in aircraft accidents because the ice can melt and disappear before an investigation team can clearly determine its presence. This chapter describes conditions conducive to aircraft icing, and contains a summary of accidents and incidents related to on-ground icing that occurred between 1977 and 1985. Recognizing those conditions can help to determine whether icing may have been a cause or contributing factor in an accident.

7.1 CONDITIONS CONDUCIVE TO ICING

During ground storage or ground operations, aircraft are susceptible to some of the same conditions that can be encountered in flight as well as to conditions conducive to icing unique to ground operations. Such conditions, which are detailed in Appendix 3 of FAA AC 20-117, are summarized as follows:

- Freezing rain and drizzle
- Frozen precipitation such as snow, sleet, or hail
- Supercooled ground fog and ice clouds
- Operation on ramps, taxi ways, and runways containing moisture, slush or snow
- Snow which may be blown onto aircraft by ambient winds from snowdrifts, other aircraft, buildings, or other ground structures
- Recirculated snow blown by engine, propeller, or rotor wash
- Conditions of high relative humidity that may produce frost formations on aircraft surfaces that have a temperature at or below the frost point.

Other factors should also be considered when attempting to determine whether an accident or incident may be attributable to on-ground icing. These factors include calendar date, location, and ambient temperature, and elapsed time between takeoff and the accident or incident, since accidents caused or contributed to by ice, frost, or snow that accumulated on the ground can occur up to five minutes after takeoff.

7.2 ACCIDENT DATA BASES

The following paragraphs describe the accident data bases that were reviewed as a part of this study. A summary of accidents and incidents that were caused or contributed to by ground icing is also included below.

7.2.1 Data Bases Reviewed

Seven accident/incident data bases were reviewed to determine the number of accidents attributed to on-ground deicing/anti-icing that occurred during the period 1977 to 1985. These data bases are maintained by the following organizations:

- Federal Aviation Administration (FAA)
- International Air Transport Association (IATA)
- International Civil Aeronautics Organization (ICAO)
- National Aeronautics and Space Administration (NASA)
- National Transportation and Safety Board (NTSB)
- United States Army (USA)
- United States Navy (USN)
- United States Air Force (USAF)

Other relevant accident data bases are maintained by the Air Transport Association (ATA) and ALPA, but those data bases contain entries that are extracted from the NTSB data base. We did not review those data bases because accident summaries were provided to ARINC Research Corporation by NTSB.

7.2.2 Data Base Summary

A list of accidents involving aircraft structural, engine and engine component icing is presented chronologically in Table 7-1. The data presented in this table was extracted from the data bases provided by IATA, ICAO, NTSB, USN, and USAF. The table shows the date and location of the accident/incident, mission purpose, aircraft type, whether the aircraft was certified for flight into known icing conditions, related FAR part,

TABLE 7-1

ACCIDENTS/INCIDENTS RELATED TO ON-GROUND ICING (1977-1985)

Date	Location	Purpose/ A/C Type	Certification	Related FAR Part	Phase of Operation	Fatal Accident	Injuries T	F	S	M/N	Cause/Factor	Source
1/04/77	Frankfurt, Germany	Scheduled Passenger/ Boeing 737	yes	121	Takeoff	No/Incident	53	0	0	53	Snowfall began before takeoff taxi. Pilot chose not to deice. Experienced loss of directional control.	IATA
1/13/77	Anchorage, Alaska	Scheduled Freight/ DC-8	yes	121	Takeoff (shortly after; initial climb)	Yes	5	5	0	0	Cause: stall aggravated by airframe icing.	IATA
1/15/77	Frankfurt, Germany	Scheduled Passenger/ Boeing 737	yes	121	Shortly after takeoff rotation	No/Incident	53	0	0	53	Experienced excessive pitch which forced pilot to trim aircraft to full nose down. Cause: icing conditions at time of takeoff.	IATA
1/26/77	Near Oslo, Norway	Scheduled Passenger/ Boeing 737	yes	121	Takeoff	No/Incident	53	0	0	53	Experienced roll to right and pitched up 21 degrees. Cause: use of reverse idle before takeoff causing snow to be blown down onto right wing.	IATA
1/31/77	Anchorage, Alaska	Non-scheduled Freight/ Chase C122	unknown	135	Takeoff (initial climb)	Yes	3	1	2	0	Factor: wing and tail covered with hard frost. (Aircraft had been cleaned of frost with a broom 2 hrs prior to takeoff).	IATA
2/20/78	Near Hannover, Germany	Scheduled Passenger/ Boeing 737	yes	121	Takeoff (initial climb)	No/Incident	90	0	8	82	Cause: airframe icing	IATA
11/07/78	Swan Hills, Canada	Non-commercial/ Beech 58 Baron	no	91	Takeoff (initial climb)	Yes	8	8	0	0	Factor: inadequate pre-flight planning, airframe ice; water/ice/ slush on runway	ICAO

(continued)

TABLE 7-1 (continued)

Date	Location	Purpose/ A/C Type	Certification	Related FAR Part	Phase of Operation	Fatal Accident	Injuries T	F	S	M/N	Cause/Factor	Source
11/10/78	Broomfield, Colorado	Non-commercial/ Cessna 421	unknown	91	Takeoff (initial climb)	No	1	0	0	1	Factor: inadequate pre-flight preparation; airframe ice	ICAO
11/17/78	Near Gallup, New Mexico	Non-commercial/ Commander 500	unknown	91	Takeoff (initial climb)	Yes	2	1	1	0	Factor: inadequate pre-flight preparation; airframe ice	ICAO
11/27/78	Newark, New Jersey	Commercial/ DC-9	yes	121	Takeoff (initial climb)	No	83	0	0	83	Factor: inadequate pre-flight preparation, icing conditions; air-frame ice	ICAO
2/06/79	Sevierville, Tennessee	Pleasure, Personal Transport Cessna 310Q	unknown	91	Takeoff (aborted)	No	1	0	0	1	Factor: icing condition; snow on runway; falling snow; freezing rain	NTSB
2/12/79	Clarksburg, West Virginia	Scheduled Passenger/ Nord 262	yes	135	Takeoff (initial climb)	Yes	25	2	8	15	Cause: captain's decision to take off with snow on wing and empennage surfaces resulting in loss of lateral control and lift as aircraft ascended out of ground effect; inadequate pre-flight preparation	IATA
2/16/79	Albuquerque, New Mexico	Pleasure, Personal Transport Grumman AAS	no	91	Initial Climb	N	1	0	0	1	Factor: icing conditions	NTSB
3/23/79	Cedar Rapids, Iowa	Non-commercial/ Beech-18	unknown	91	Takeoff (Run)	Yes	2	2	0	0	Factor: weather; airframe ice; water/ice/slush on runway	ICAO
9/14/79	Near Garfield, Colorado	Practice, non-commercial/ Beech A-36	no	91	Climb to Cruise	Yes	2	2	0	0	Factor: icing condition	NTSB

(continued)

TABLE 7-1 (continued)

Date	Location	Purpose/ A/C Type	Certification	Related FAR Part	Phase of Operation	Fatal Accident	Injuries T	F	S	M/N	Cause/Factor	Source
10/19/79	Koyuk, Arkansas	Dehavilland DHC3	no	91	Takeoff (aborted)	No	2	0	0	2	Factor: inadequate pre-flight preparation; airframe ice; ran off runway end; snow on wings, tail surfaces	ICAO
11/23/79	Anchorage, Alaska	Ferry/ Twin Pioneer	unknown	135	Takeoff	No	2	0	0	2	Cause/Factor: Ice and frost on wings, horizontal stabilizer, and elevator	IATA
2/15/80	Mukilteo, Washington	Rockwell Commander 700	unknown	135	Takeoff (initial climb)	Yes	7	5	2	0	Factor: accumulation on wings prior to takeoff; inadequate pre-flight planning; airframe ice	ICAO
2/16/80	Near Billeriea, Maine	Royal Air Force Cargo/ Bristol Britannia Series	yes	--	Enroute (climb to cruise)	Yes	8	7	1	0	Factor: airframe ice; icing conditions; inadequate pre-flight planning	ICAO
12/7/80	Broomfield, Colorado	Unknown/ Cessna 414	Yes	91	Takeoff (Aborted)	No	-	0	-	--	Factor: Icy run-way; Frost on airplane	FAA
12/12/80	Chapel Hill, North Carolinia	Unknown/ Piper		91	Ground Taxi	No	-	0	-	--	Cause: Frost on windshield blocked pilot's vision	FAA
12/21/80	Near Sierraville, California	Pleasure Personal Transport. Cessna 172M	no	91	Inflight	Yes	2	1	1	0	Factor: Icing conditions; Failed to obtain flying speed	NTSB
12/23/80	Bridgport, New Jersey	Unknown/ Gulfstream AASA	Yes	91	Takeoff (Aborted)	No	-	0	-	--	Factor: Icy build-up on wings	FAA
1/19/81	Susanville, Louisiana	Unknown/ Cessna 172	No	91	Takeoff (Ground Roll)	No	-	0	-	--	Cause: Frost on aircraft failed to obtain flying speed	FAA
1/30/81	Provo, Utah	Unknown/ Cessna 15316	Yes	91	Climb To	No	-	0	-	--	Factor: Snow, ice build-up	FAA
2/25/81	North Adams, Maine	Commercial/ Cessna 310R	no	135	Takeoff (initial climb)	Yes	2	2	0	0	Factor: icing conditions; pilot failed/incorrectly used anti-icing/deicing	NTSB

(continue

TABLE 7-1 (continued)

Date	Location	Purpose/ A/C Type	Certification	Related FAR Part	Phase of Operation	Fatal Accident	Injuries T	F	S	M/N	Cause/Factor	Source
3/5/81	Elkton, Maryland	Unknown/ Piper PA 32260		91	Takeoff (Ground Roll)	No	-	0	-	--	Factor: Light snow on aircraft; ice and slush on runway	FAA
3/5/81	Philadel-phia, Pennsyl-vania	Unknown/ Beech 618S	Unknown	135	Takeoff (Ground Roll)	No	-	0	-	--	Factor: Acceleration slow; ground crew swept snow off plane	FAA
3/11/81	Hazelton, Pennsyl-vania	Beech-18 (C-45)	unknown	91	Takeoff (initial climb, aborted)	No	3	0	0	3	Factor: snow on wings at takeoff; airframe ice; inadequate pre-flight planning	ICAO
3/14/81	Bloomsburg, Pennsyl-vania	Corporate/ Executive Cessna 402B	unknown	91	Takeoff (aborted, initial climb)	No	2	0	1	1	Factor: icing conditions; snow on runway	NTSB
4/4/81	Crystal, Minnesota	Unknown/ Cessna 401		91	Takeoff (Aborted)	No	-	0	-	--	Factor: Snow on aircraft; snow covered runway	FAA
8/15/81	Near Fairbanks, Alabama	Pleasure, Personal Transport. Piper PA-18	no	91	Takeoff (Run)	No	1	0	0	1	Factor: icing conditions; snow	NTSB
10/25/81	Broomfield	Unknown/		91	Takeoff	No	-	0	-	--	Factor: Snow and ice on wings	FAA
12/17/81	Show Low, Arizona	Unknown/ Piper PA28N180	Yes	91	Takeoff	No	-	0	-	--	Factor: Heavy frost on air-craft	FAA
1/13/82	Washington, D.C.	Commercial/ Boeing 737-222	yes	121	Takeoff	Yes	87	78	6	3	Cause: wing ice, miscel-laneous, ice; anti-ice/deice system not used	NTSB
1/13/82	Muenchen, Germany	Commercial/ Boeing 737-200	yes	121	Takeoff (initial climb)	No	98	0	0	98	Factor: fog; icing conditions; airframe ice	ICAO
1/14/82	Nuernberg, Germany	Commercial/ Boeing 737-200	yes	121	Takeoff (initial climb)	No	13	0	0	13	Factor: icing; conditions; airframe ice	ICAO

(continued)

TABLE 7-1 (continued)

Date	Location	Purpose/ A/C Type	Certification	Related FAR Part	Phase of Operation	Fatal Accident	Injuries T	F	S	M/N	Cause/Factor	Source
1/15/82	Newark, New Jersey	Unknown/ Lkheed 1011	yes	121	Climb to Cruise	No	-	0	-	--	Factor: ice on NR4 outer jack screws	FAA
2/2/82	Ft. Wayne Indiana	Unknown/ DAAV DHC7102	yes	121	Takeoff (Initial Climb)	No	-	0	-	--	Cause: inadequate ice removal from roll spoiler	FAA
3/14/82	Lake Tahoe, California	Pleasure, Personal Transport Cessna 182	no	91	Cruise	Yes	2	2	0	0	Factor: icing conditions; Cause: proper altitude not obtained	NTSB
4/7/82	Lincoln, Nebraksa	Unknown/ Cessna 340		91	Cruise (Forced landing)	No	-	0	-	--	Factor: Ice, snow on aircraft; vibration on aircraft; unable to climb	FAA
4/8/82	Moline, Illinois	Unknown/ STBROS SD330		135	Climb to Cruise	No	-	0	-	--	Cause: Ice accumulation in elevator horn	FAA
5/07/82	Calgary, Canada	DC-3	yes	135	Takeoff (aborted)	No	5	0	0	5	Factor: ice/slush on runway; inadequate pre-flight planning, snow; airframe ice	ICAO
11/28/82	Hayden, Colorado	Unknown/ Cessna 210		91	Takeoff (Aborted)	No	-	0	-	--	Factor: frost and ice on aircraft wings	FAA
11/28/82	Williamsport, Pennsylvania	Non-Commercial Cessna 172M	no	91	Forced Landing	No	2	0	0	2	Cause: inadequate ice/frost removal from aircraft (aircraft departed airport with ice on airframe); wing ice	NTSB
----	----	U.S. Military/C-5A	yes	--	Takeoff (initial climb)	No	0	0	0	0	Left forward main landing gear remained in transit on gear retraction after takeoff. Factor: snow and ice accumulation during taxi/ takeoff	U.S. Air Force
12/6/83	White Lake Town, Michigan	Unknown/ Cessna, T210M	Yes	135	Take Off (Initial Climb)	Yes	-	3	-	--	Factor: Airplane parked in snow before departure	FAA

(continued)

TABLE 7-1 (continued)

Date	Location	Purpose/ A/C Type	Certification	Related FAR Part	Phase of Operation	Fatal Accident	Injuries T	F	S	M/N	Cause/Factor	Source
12/10/83	Owosso, Michigan	Unknown/ Piper 22150		91	Takeoff (Forced Landing)	No	-	0	-	--	Factor: Failure to remove all snow from airframe	FAA
2/1/84	Newark, New Jersey	Unknown/ Boeing 727	Yes	121	Takeoff (Initial Climb)	No	-	0	-	--	Factor: Crushed ice and snow on airplane	FAA
3/30/84	Los Alamos, New Mexico	Unknown/ Piper PA28R200	Yes	91	Takeoff (Aborted)	No	-	0	-	--	Factor: Snow on aircraft and runway	FAA
10/20/84	Cheyenne, Wyoming	Unknown/ Cessna STC414	Yes	91	Takeoff (Initial Climb)	No	-	0	-	--	Factor: Snow on wings	FAA
11/20/84	Koliganele Alaska	Unknown/ Cessna 207		135	Takeoff (Ground roll)	No	-	0	-	--	Factor: Wet snow on wings and runway	FAA
12/17/84	Point Hope, Alaska	Unknown/ Cessna U206G		135	Takeoff (Initial Climb)	No	-	0	-	--	Factor: Airframe icing; poor visibility; crosswind	FAA
1/17/85	Cheasapeake Virginia	Unknown/ Cessna 401		91	Takeoff (Aborted)	No	-	0	-	--	Factor: Glaze of ice on wings	FAA
1/31/85	Huntington, West Virginia	Unknown/ Beech E185	Unknown	135	Takeoff (Initial Climb)	No	-	0	-	--	Factor: Snow on airframe	FAA
2/13/85	Manville, New Jersey	Unknown/ Cessna 182N	No	91	Takeoff (Initial Climb)	No	-	0	-	--	Factor: Ice on top of wings	FAA
2/27/85	Lees Summit	Unknown/		91	Takeoff	No	-	0	-	--	Factor: Snow and ice on wings	FAA
2/27/85	Edmond, OK	Unknown/ Beech A36TC	No	91	Takeoff (Forced landing)	No	-	0	-	--	Factor: Frost on wings	FAA
----	----	U.S. Military/T-39A	no	N/A	Takeoff (initial climb)	No	0	0	0	0	Snow/ice on nose gear uplock rollers. left slat frozen shut. Cause: ice accumulation during taxi to runway	U.S. Air Force
----	----	U.S. Military	----	N/A	Takeoff	No	0	0	0	0	Cause; weather; frozen slush on nose gear or uplock assembly prevented pulling up and locking the nose landing gear	USN

(continued)

TABLE 7-1 (continued)

Date	Location	Purpose/ A/C Type	Certification	Related FAR Part	Phase of Operation	Fatal Accident	Injuries T	F	S	M/N	Cause/Factor	Source
----	----	U.S. Military	----	N/A	In-flight (2 minutes after takeoff)	No	0	0	0	0	Snow and ice buildup in the spoiler compartments resulted in rolling movements to the standard side	USN
----	----	U.S. Military	----	N/A	Takeoff (aborted)	No	0	0	0	0	Abnormally cold weather caused pitot static system to freeze even though pilot heat had been activated after engine start. Takeoff aborted after 2000 ft. of roll on an 8000-ft. runway.	USN
----	----	U.S. Military	----	N/A	Takeoff	No	0	0	0	0	Cause: ice buildup around port landing gear. This resulted in failure of the landing gear to engage in the uplocked position	USN
----	----	U.S. Military	----	N/A	Takeoff	No	0	0	0	0	Cause: ice buildup; imbedded snow/slush from runway. This resulted in failure of nose landing gear to achieve full uplocked position.	USN
----	----	U.S. Military	----	N/A	Takeoff	No	0	0	0	0	Cause: ice caused left brake to lock.	USN
----	----	U.S. Military	----	N/A	Takeoff	No	0	0	0	0	Cause: snow and ice on runway. Pilot selected gear up, and nosewheel indicated unsafe up.	USN
----	----	U.S. Military	----	N/A	Takeoff	No	0	0	0	0	Cause: snow/slush on runway accumulated in nose area. Nose gear would not lock-up when landing gear was raised.	USN

phase of operation, whether the accident was fatal, number of injuries (total, fatal, serious, minor, or no injuries), a brief description of the accident/incident including cause and/or contributing factor relevant to on-ground icing, and identification of the data base from which the information was extracted.

Although some data was received from the Army, it did not provide the detail required to be included in Table 7-1. The Army did report that a total of 35 aircraft were involved in mishaps related to icing between 1 October 1973 and 1 March 1985, but the data provided were not sufficient to determine the portion of these mishaps related to on-ground icing.

NASA provided a list of entries from its Aviation Safety Reporting System (ASRS) that describes incidents related to on-ground icing. The entries in this system are submitted voluntarily and represent, at best, the perception of a specific individual who may or may not understand all of the factors involved in a given aviation-related situation. All entries have identifying details removed after receipt to prevent identification of submitting individuals. Therefore, there is no way to verify information in ASRS after preliminary processing by NASA. Table 7-2 provides a summary of the ASRS entries related to ground deicing procedures received between December 1978 and December 1983.

7.3 DATA BASE DISCUSSION

A review of the data bases provided by the FAA, IATA, ICAO, NTSB, USN, and USAF revealed 67 reported accidents/incidents related to on-ground icing between 1977 and 1985. Eight incidents related to on-ground icing were anonymously reported to NASA's ASRS between 1978 and 1983. Of the 67 accidents/incidents summarized in Table 7-1, 32 were operating under FAR part 91, 12 were operating under FAR part 121, 12 were operating under FAR part 135, 8 were on USN missions, 2 were on USAF missions, and 1 was operating for the Canadian Military. Fourteen of the 67 accidents summarized in Table 7-1 were fatal. There were 116 fatalities in these 14 accidents.

The accidents/incidents that occurred while aircraft were operating under FAR part 91 were caused or contributed to by icing conditions, airframe ice, and lack of pre-flight planning and preparation. This lack of planning may be related to the lack of awareness regarding the dangers associated with on-ground icing in the GA community, as reported by GA pilots and documented in Chapter Six of this report.

Causes and contributing factors cited in the summaries of accidents/incidents that occurred while aircraft were operating under FAR part 135 included wing and tail covered with hard frost, captain's decision to take off with snow on wing and empennage surfaces, and inadequate pre-flight planning. Many aircraft conducting FAR part 135 operations are sometimes deiced by FBOs. Our interviews reveal that some of these FBOs do not believe that they have the right to recommend that an aircraft be deiced, as discussed in Chapter Six. Also, the pilots of GA aircraft may be unaware of the extreme dangers associated with on-ground icing.

TABLE 7-2

SUMMARY OF ASRS ENTRIES OF SUPPOSED INCIDENTS RELATED TO GROUND DEICING PROCEDURES

Date	Location	A/C Type	Phase of Operation	Report Filed By	Summary
12/78	Austin, Texas	Medium large transport (Category C)	Pre-takeoff/ takeoff	Observer	Windows on right side of cockpit completely covered with ice obstructing all vision. Co-pilot attempted to scrape ice, but this effort was soon abandoned. Aircraft departed ramp and took off into non-positive controlled airspace with the ice-covered window.
02/79	Washington, D.C.	Medium large transport (Category C)	Pre-takeoff/ takeoff	Pilot	Pilot requested deicing by another carrier under contract by his company. He was informed that no equipment would be available for at least 2 hours. Walk-around showed evidence of dry, powdery snow on upper surfaces. After pushback inspection showed snow had blown off and there was no evidence of ice. Successful takeoff was then accomplished.
12/81	Chicago, Illinois	Medium transport (Category B)	Landing	Pilot	Upon arrival at destination crew observed flight/ground spoilers had not extended and could not be extended using the "flight/taxi" switch. Aircraft had been deiced prior to its departure. After additional deicing, control of the spoilers was regained. Pilot and maintenance personnel supposed that snow became packed in spoilers prior to departure and was not removed during initial deicing.
01/82	United States	Large transport (Category D)	--	Pilot	Prior to takeoff, pilot observed about 2 inches of snow on most surfaces and had a/c deiced with 60/40 mixture. Takeoff cleared and after 40 minutes, 1/4 inch frozen slush covered a/c. Pilot requested deicing a second time and took off after inspection showed a/c to be clean. After 1 hour flight, pilot discovered upon landing that a/c was covered with 1/8 inch or more of granular clear ice.
02/82	Anchorage, Alaska	Medium large transport (Category C)	--	Pilot	Flight attendants advised captain that there was an unusual, tart, stingy smell in the cabin. Captain noticed right pack air mix valve was nearly closed. Odor then appeared in cockpit. Captain decided to return to airport and turned off right pack. During descent he turned up left pack temperature. Smoke began to come out from under both packs and smoke stopped. Captain did not descend quickly enough and passenger oxygen was deployed. It is suspected that deicing fluid got into air conditioning system during deicing prior to takeoff.
01/83	Chicago, Illinois	Medium large transport (Category C)	--	Pilot	Captain reported damage to aircraft, which is assumed to have occurred during deicing. The damage, which was discovered after landing by outbound flight crew, included a damaged static port and right wingtip, a cracked navigation right cover, and a scrape mark on top of the wing.
03/83	Cleveland, Ohio	Medium large transport (Category C)	--	Pilot	Aircraft was deiced before taxi. After takeoff crew heard a loud bang and the left gear unsafe light was on when gear was retracted. Gear was reecycled and the light went out. Continued climb to cruise altitude until aircraft began to vibrate. Crew then reduced power and speed. Left engine oil quantity started to drop. Landed at intermediate location without incident. Inspection of engine showed possibility of foreign object damage as a result of ice ingestion from gear door or underside of flap area.
12/83	Seattle, Washington	Medium large transport (Category C)	--	Pilot	Deicing began without advice to crew. As a result, vapors entered cabin from incorrectly positioned air conditioning pack valve and APU running.

Note: Category B - Speed 91 knots or more but less than 121 knots
Category C - Speed 121 knots or more but less than 141 knots
Category D - Speed 141 knots or more but less than 166 knots

Seven of the 12 FAR Part 121 commercial aircraft involved in accidents summarized in Table 7-1 were B-737 aircraft. Of those seven, six belonged to foreign carriers. Several of these summaries indicate that the pilot reported excessive pitch up. Reports citing pitch up of these aircraft have been filed by pilots affiliated with a number of air carriers. In fact, the British Civil Aviation Authority (CAA) issued an airworthiness directive in June 1982 that ordered British operators of B-737 aircraft to modify their takoff procedures in icing conditions. This included increasing takeoff speed by 2 to 5 knots, depending on the model. When ambient temperature is less than 5°C (41°F) and visible moisture is present, limit rotation speed on takeoff to 3° per second in order to reduce stall margins. British sources cited 18 reports of B-737 instability in known or strongly suspected icing conditions between 1971 and 1981.

Seven of the 10 U.S. military accidents/incidents summarized in Table 7-1 involved freezing of some portion of the aircraft's landing gear. This problem has been experienced by at least one U.S. commercial airline. As discussed in Chapter Six, this airline reported that the landing gear on its aircraft is routinely sprayed with deicing fluid during deicing operations to prevent the freezing of slush that may accumulate during takeoff.

CHAPTER EIGHT

CURRENT RESEARCH

Research related to on-ground aircraft deicing technology is currently being conducted by the AEA. Other related efforts were recently conducted by Boeing Commercial Airplane Company and KLM Royal Dutch Airlines. This chapter provides a description of these research projects.

8.1 ASSOCIATION OF EUROPEAN AIRLINES FLUID RESEARCH

The AEA is currently sponsoring an aircraft anti-icing research program to study the effects of AEA Type I and II fluids (Section 2.3) on aircraft aerodynamics or flight characteristics. The AEA assumes that Type II fluids are not completely removed from the wing when aircraft rotation speed is reached. Therefore, the remaining fluid could contaminate the wing and violate the clean aircraft concept. Although airlines have years of experience in the use of AEA Type II fluids in Europe, there are no scientific test results available to verify that the performance degradation resulting from the residual fluid film is acceptably small. The intent of this research program is to scientifically determine the extent of performance degradation due to this residual fluid film. This program includes two phases. Phase I was designed to correlate flow behavior with film thickness and temperature over a flat plate. The Phase II tests will be conducted in a full scale wind tunnel where it will be possible to investigate fluid flow phenomenon using an actual wing section.

The Phase I tests were conducted in the Von Karman Institute's (VKI) 100 mm by 300 mm (4 inches by 12 inches) cross section cold wind tunnel (CWT), located in Brussels, Belgium. The CWT is capable of simulating the air speed variation of an actual B-737 takeoff from 0 to 122 knots in 30 seconds. The temperature of the air flow can be lowered to -20°C (-4°F). A block diagram of the CWT configuration is shown in Figure 8-1.

The Phase I tests consisted of measuring film thickness using a light absorption technique and continuously recording the behavior of the fluid film on two video-recording systems that included a color camera, a black and white camera, video tape recorders, and two color television sets. A group of neon tubes equipped with diffuser screens were used to provide

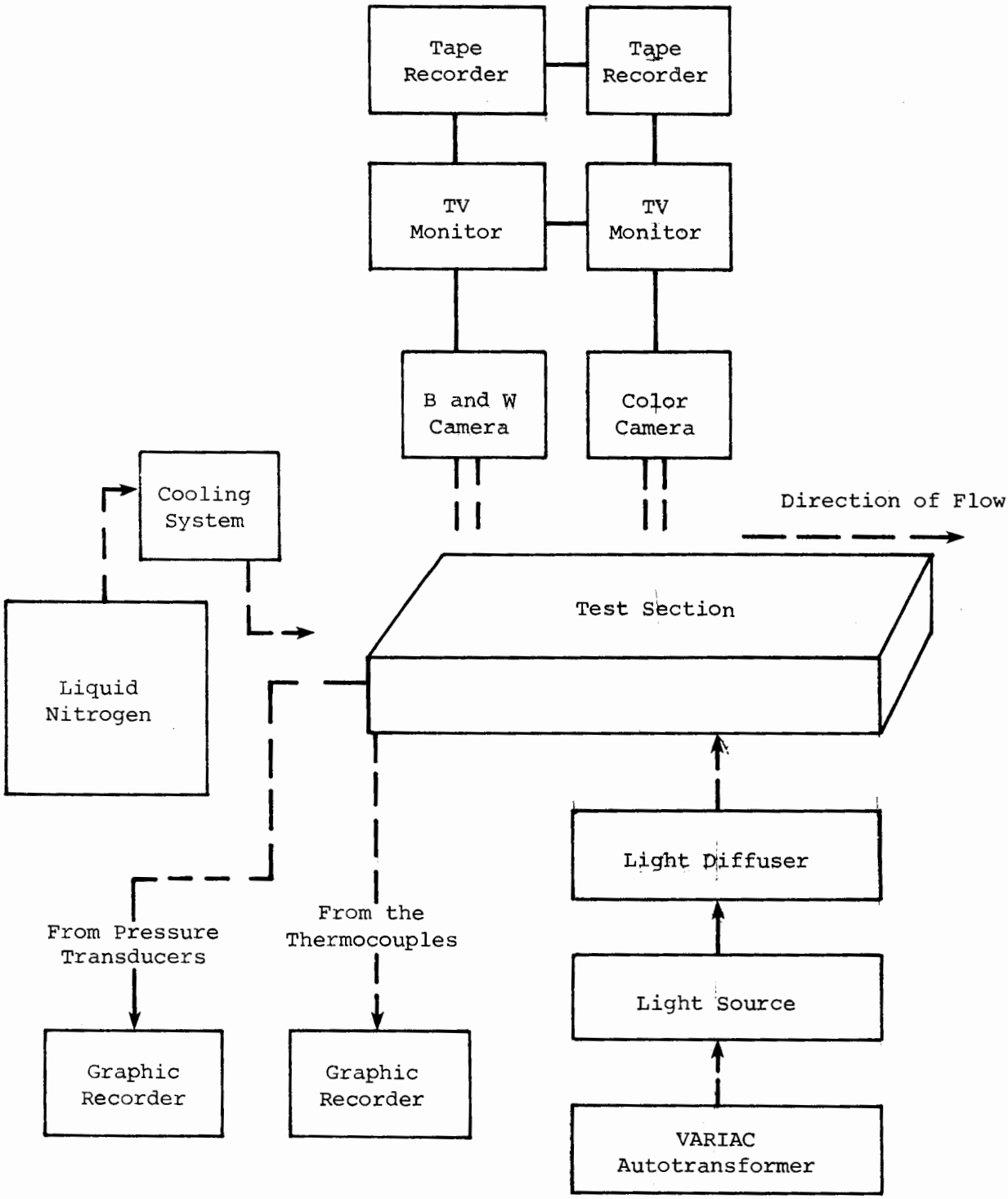

FIGURE 8-1

A BLOCK DIAGRAM OF THE COLD WIND TUNNEL

uniform illumination. The recorded test runs were then sent to the VKI Digital Image Processing System for analysis of the fluid distribution.

The Phase I tests were performed on one Newtonian fluid and four non-Newtonian (pseudoplastic) fluids. Six of the following fluids were considered for testing:

Newtonian	Non-Newtonian (pseudoplastic)
Kilfrost (mil. spec.)	Kilfrost ABC
SPCA 8243	Union Carbide ADF 2.2
	SPCA AD84
	Hoechst 1704/83 ADF

One of the two Newtonian and all of the non-Newtonian fluids were used for the tests. The terms Newtonian, non-Newtonian, or pseudoplastic, are used to describe the behavior of the fluids because not all the fluids meet the requirements for AEA Type I or Type II fluid. Initial fluid film thicknesses of 1, 2, and 3 mm (0.04, 0.08, 0.12 in) were each tested at 20°, 0°, -10° and -20°C (68°, 32°, 14° and -4°F). Two video cameras were used during each test run to enable observers to study the variation of fluid film thickness during the test, and the formation and movements of waves on the fluid surface. Eighty tests were run and 160 video recordings analyzed.

The Von Karmen Institute for Fluid Dynamics published the final report of AEA's Phase I research in May 1985. The final report, "Experimental Study of the Flow of a Film of Aircraft Deicing Fluid During a Simulated Takeoff at Subfreezing Temperatures," gave the following summary of results.

The results indicate that the variation in viscosity of non-Newtonian fluids affects their flow-off characteristics on a flat plate. The high-viscosity non-Newtonian fluids tend to flow off less easily than the other non-Newtonian fluids. Some of them show a marked dependence on temperature whereas others do not. Influence of the initial fluid thickness is generally small, or in some cases not well defined. The Newtonian fluid flows off much more easily and does not seem to be temperature dependent. Its residual thickness, however, is influenced by its initial thickness. The shear stresses, resulting from air friction during the take-off ground run were simulated in the CWT for the various fluids on the flat plate. They were fundamentally different for the two classes of fluids, and in both cases were higher than on a dry surface.

The Phase II tests will be performed in the temperature-controlled Wien (Vienna) Arsenal wind tunnel located in Vienna, Austria. Lift, drag, and pitching moment will be recorded during the simulation of typical commercial aircraft takeoff runs. Thus the aerodynamic effects of the fluid film on an actual wing section will be measured directly. Phase II was scheduled to be completed in December 1985. Because of the spectrum of fluid behavior in Phase I, all five of the fluids will be tested in

Phase II. The final analysis will correlate the behavior of the fluid film as measured in Phase I with the results of the full-scale wind tunnel tests conducted in Phase II.

8.2 BOEING COMMERCIAL AIRPLANE COMPANY EXPERIMENTS WITH AEA TYPE II FLUIDS

The Boeing Commercial Aircraft Company conducted wind tunnel tests to investigate the possible aerodynamic effects of AEA Type II anti-icing fluids when used on commercial jet transports, as documented in a report prepared by G. S. Hendrickson of Boeing Commercial Airplane Company (see Bibliography). Three wind tunnel tests were conducted at Boeing to investigate the shearing behavior and the possible aerodynamic effects of AEA Type II anti-icing fluids when applied in thin layers to the upper surface of aircraft wings. These fluids have been developed to protect the aircraft from frost, snow, or ice contamination for specific time periods during ground operations and are expected to shear off the aerodynamic surfaces during the takeoff ground roll. Both Hoechst 1704 and Kilfrost ABC were tested.

The first test, designated A1, was performed to demonstrate the feasibility of a fluorescent dye technique for measuring the fluid depth on a model airfoil in a wind tunnel environment. The second test, A2, was performed in the Boeing Research Wind Tunnel (BRWT), where both the aerodynamic forces and the fluid depth profiles could be measured but temperatures typical of anti-icing fluid use could not be attained. Testing was therefore conducted with "modified" AEA Type II fluids, which matched as closely as possible at 35°C (95°F) (the wind tunnel test section temperature) the viscosity of the actual Type II fluids at -18°C (0°F). A third test, A3, was performed in the Boeing Icing Tunnel (BIT), to measure the fluid depth profiles formed by the unmodified Type II fluids at temperatures typical of normal usage and to determine trends in the behavior of these fluids as a function of air temperature, surface temperature, and fluid concentration. The BIT facility was not capable of measuring the aerodynamic forces, but the depth profiles and wave patterns obtained in this test can be compared with similar data obtained in test A2, for which the corresponding aerodynamic effects are known. This comparison enabled a rough estimate of the aerodynamic effects of actual Type II fluids.

The fluid depth profiles were measured by means of a fluorescent dye technique developed in test A1. A small amount of dye (0.1 to 0.5 percent by volume) was added to the fluid of interest, so that when a fluid film was photographed under ultraviolet light, the "brightness" of the image was a function of the fluid film thickness. A calibrated plate, which had grooves of known depths milled into its surface, was filled with fluorescent fluid and photographed to determine the correlation between image brightness and fluid depth. The image brightness was quantified by measuring the optical density of the photograph negatives with a microdensitometer. A least squares polynomial regression on the calibration data calculated the actual fluid depth profiles from the photographs taken during each run. The useful range of depth measurements using this

technique appears to be about 0.002 to 0.1 inch, with good resolution of relative fluid depths. The calibration data suggest that the accuracy of the technique is limited to about ± 0.01 inch for measurements over most of its range.

The A2 test used an existing 24-inch chord 2-dimensional (2D), multi-element wing section model, which was configured to simulate the pressure distribution at a typical climbout angle of attack of a B-737-200 aircraft. The viscosity of AEA Type II anti-icing fluids decrease with increasing shear rates. This property is primarily responsible for the ability of these fluids to form a thick protective layer on the aircraft while it is at rest and to flow during the takeoff ground roll. The actual AEA Type II fluids were modified by the addition of thickeners. This was done to match at 35°C (95°F) the viscosity of the unmodified AEA Type II fluid at -18°C (0°F) over an appropriate range of shear rates. Since the boundary layer develops on top of the fluid, it is assumed that the wall shear stress on the airfoil determines the range of viscosities at the air/fluid interface, and thus the range of shear rates expected in the fluid. An approximate analysis of this sort for AEA Type II fluids at -18°C (0°F), showed that low shear rates are found on most of the wing and therefore the Brookfield viscometer measurements are the primary concern for modeling AEA Type II fluids. The viscosities of the modified fluids, Kilfrost ABC and Hoechst 1704, were measured at Boeing with a Brookfield viscometer. The measurements showed the viscosities of the actual fluids to be quite similar over a significant range of the shear rates. At higher shear rates, measurements provided by Haakes-Buchler Instruments, Inc., showed the modified Hoechst fluid at 35°C (95°F) to be slightly less viscous than the actual fluid. Boeing therefore concluded that the modified fluids model met the viscous properties of the actual fluid reasonably well over a wide range of shear rates. However, the results of this test have been questioned by some members of the deicing community.

The A3 test used the actual AEA Type II anti-icing fluids, so that the fluid depth profiles measured in both tests could be used to compare the behavior of the modified fluids in test A2 with that of the actual fluids in test A3 as an additional check on the fluid modeling.

The general procedures used to conduct tests A2 and A3 were very similar, except that the model in test A2 was rotated to approximately 11 degrees at a rate of 3 degrees per second at the end of the simulated ground roll whereas in test A3 the model was fixed in the ground roll attitude.

A calibration photograph was placed on each roll of film by placing the calibration plate, filled with the fluid of interest, on the model surface so that the camera and lighting configuration was included in the calibration. A layer of the same ADF as used in the calibration was then placed on the model's upper surface. The fluid was applied on the surface by pouring the fluid and spread using a straight edge with a gap between the surface and straight edge. This "spreader bar gap" was adjustable and set with feeler gauges on a flat surface. The actual initial thickness was determined from a photograph taken immediately after the fluid was

spread on the model. The model and fluid were then typically exposed to the ambient tunnel temperature for about five minutes, although in test A3 this "exposure time" was investigated as a test parameter. The takeoff ground roll was simulated by accelerating the wind tunnel airspeed at a constant rate to about 120 knots, approximately $V_{rotation}$ (V_R). Photographs were taken with an ultraviolet flash before and during the simulated takeoff procedure, and correlated with the airspeed and elapsed time measurements.

The effects of several different test parameters on the behavior of the actual AEA Type II fluids were investigated in test A3. Because force data could not be obtained in that test, another criterion for comparison had to be established. The most apparent and easily quantified characteristic of the fluorescent dye photographs is the location of the advancing wavefront, downstream of which there is little or no apparent disturbance of the fluid surface. Photographs showing the wavefront location at different times during a simulated takeoff ground roll with an actual AEA Type II fluid were presented in the Boeing report. These photographs suggest that very little fluid shears off the wing before this wavefront reaches the trailing edge.

The effects of exposure time, concentration, initial depth, acceleration rate, temperature, and fluid type on wavefront location as a function of airspeed were examined by Boeing. The exposure time investigated in test A3 is the length of time from when the fluid was spread on the model to the beginning of the takeoff simulation. During this time, the model and fluid are exposed to temperatures approximately the desired test temperature and with little or no wind. The longer the fluid is exposed to the ambient environment the greater the airspeed required and the longer it takes for the wavefront to reach a given chordwise location. The fluid that was exposed for 17 minutes reached locations beyond the 95 percent chord location and exposure times less than 17 minutes enabled the fluid to reach the trailing edge prior to rotation speed. The test did show that increasing the exposure time tends to inhibit wavefront movement.

The effect of increasing fluid concentration on wavefront movement is similar to that of increasing the exposure time but not as pronounced. Thus a concentration of 100 percent does not reach the aft chordwise locations as readily as lower concentrations. There was not a significant difference between the 75/25 and 50/50 fluids, but this may be due to the greater initial fluid depth of the 75/25 case.

The effect of airflow acceleration rate or time to rotation was tested for fast, normal, and slow rates. The increasing of acceleration rate resulted with the wavefront being further forward on the model than either a normal or slow rate. The slow acceleration rate enabled the wavefront to reach the trailing edge at approximately 15 to 20 knots lower airspeed than a normal acceleration. The increasing of acceleration rate results in less displacement of the wavefront as a function of airspeed.

The decreasing of the ambient temperature tends to inhibit the wavefront movement. The fluid at a temperature of -20°C (-4°F) and of an initial depth of 0.007 inch was unable to reach the trailing edge during a normal takeoff acceleration by the time rotation speed was reached. The fluids throughout the various tests were applied aft of the leading edge at a position corresponding to approximately a 10 percent to 20 percent chord location. The parameters investigated in the tests have varying degrees of influence on the wavefront movement; parameters that appear to have a strong influence are exposure time and the initial fluid depth.

Hoechst 1704 and Kilfrost ABC fluids at a 50/50 concentration were exposed to a temperature of -7°C (20°F) for five minutes. While the wavefront movement appeared to be somewhat greater for the Hoechst fluid, it was difficult to accurately determine a wavefront location for the Kilfrost fluid under certain conditions, because a single, identifiable wavefront was not apparent. This implies that Kilfrost and Hoechst fluids have some different physical characteristics.

A simulation of the full-scale fluid depth profile at rotation was attempted. The rotation speed, ambient temperature, and fluid concentration were held constant, while the initial fluid depth and the time required to accelerate from zero to the rotation speed were varied. The goal was to determine an initial fluid depth and a time to a 120-knot rotation speed (acceleration rate) that would produce a wavefront at the same location (95 percent aft of the leading edge) and the same number of waves as that determined from the flight test photograph. The fluid used for this was a concentrated Hoechst 1704 at -7°C (20°F). The fluid was allowed to sit for five minutes prior to takeoff. The test was run at three acceleration rates. A fast rate of 15 seconds to V_R, a normal rate of 25 seconds to V_R and a slow rate of 45 seconds to V_R. The fast rotation enabled the greatest number of waves to appear between the 72 percent and 91 percent chordwise location. These waves were also the shallowest for the tests. It appears that these modeling criteria can be satisfied with very small initial fluid depths and very slow acceleration rates (long times to V_R).

Photographs and fluid depth profiles obtained in test A2, with the modified AEA Type II fluids at 35°C (95°F), support the conclusion from test A3 that little or no fluid leaves the airfoil until it reaches the trailing edge. The wave pattern development for a takeoff simulation from test A2 with a rotation speed of 124 knots and the wave pattern development for an actual AEA Type II fluid reveals similar wavefront formation and movement, but a different spanwise structure to the wave pattern. Fluid motion is slower in the modified fluid because it was developed to simulate a fluid temperature of -18°C (0°F) while the actual fluid was tested at -7°C (20°F). The modified AEA Type II fluid and the AEA Type II fluid reveal one aspect of the fluid motion that was observed repeatedly in these tests. Between the initial fluid application and the time when the wavefront just reaches the trailing edge, the area under the fluid depth profile curve does not change appreciably. This leads Boeing to the conclusion that hardly any fluid leaves the wing until the advancing wavefront reaches the trailing edge. Since the flight test pictures

provided by Hoechst show that the wavefront has not yet reached the trailing edge at rotation, Boeing concluded that little, if any, of the AEA Type II fluid applied to the airplane has sheared off the wing at rotation.

The effect of the modified Hoechst 1704 on the lift and drag of the model in test A2 was determined for initial fluid depths and elapsed times. The degradation of lifting force was analyzed after applying the modified Hoechst 1704 fluid, exposed for five minutes at 35°C (95°F). The angle of attack for the climbout portion of the takeoff simulation is normally 11 degrees. The airfoil's lifting force was measured without fluid on the model and with initial fluid depths of 0.01, 0.02 and 0.036 inch. The lift was represented at various times typical of ground roll, rotation, and climbout. The 0.036-inch initial fluid depth test resulted in the greatest loss of lift in all phases of the simulation, followed by the 0.01-inch initial fluid depth test. The corresponding loss of lift and estimated increase of drag for the 0.036-inch test showed a loss of 10 percent in lift capabilities accompanied by an increase in drag of more than 7 percent. The 0.01-inch initial fluid depth test showed a maximum degradation of lift of approximately 6 percent and a minimum increase in drag of just over 4 percent. The lift losses and drag increases, evaluated at a typical "V_2+15" angle of attack of 11 degrees, were for the modified Hoechst 1704 fluid. The model angle of attack of 11 degrees corresponds approximately to an angle of attack of 13 degrees for a B-737-200 airplane. The increase in total airplane drag has been estimated by assuming that the wing upper surface skin friction coefficient would increase by the same proportion as the total drag increase on the 2D airfoil model. These measurements show that fluid residues on a model airfoil can have a significant effect on its lift and drag characteristics.

These tests suggest that, while the residues that remain on the leading edge may be small, the AEA Type II fluids do tend to accumulate on the aft portions of the wing, and that little fluid, if any, shears off the wing during the takeoff ground roll. Wind tunnel measurements show a loss of lift and an increase of drag for even small accumulations of fluid residue. Boeing engineers have concluded that a cautious approach to the use of AEA Type II fluids is justified. They recommend further research into the behavior of AEA Type II fluids, particularly under actual flight conditions.

8.3 KLM/KILFROST RESEARCH TO DETERMINE ICE PROTECTION PROPERTIES OF ADFS

In an article published by McDonnell Douglas Corporation, K. van der Schaff of KLM Royal Dutch Airlines describes a joint effort by KLM and Kilfrost, Ltd (see Bibliography) during which four experiments were conducted with six ADFs to obtain an insight into the ice protection properties of these fluids. These tests, conducted in the Simulated Winter Environment Test Chamber (SWET) of Kilfrost, Ltd., were specifically designed to determine the ice protection properties of the selected ADFs.

The SWET chamber is a walk-in room with a minimum temperature of -45°C (-49°F). The relative humidity can be set between 25 and 100 percent. The temperature of the test panel, which is placed at a 10° angle of incidence, can be controlled down to -10°C (14°F), independent of the chamber temperature. Six test areas are available on the test panel thus enabling the simultaneous testing of different ADFs.

The first test compared the freezing point and holdovertime of the ADFs under the following conditions: SWET chamber temperature of 0°C (32°F), panel temperature of -5°C (23°F), and relative humidity of 100 percent. In these experiments, holdovertime is the time between application of the ADF and the moment that 15 percent of the test area is frozen. The freezing points of the ADFs ranged from -37°C (-35°F) to -26°C (-15°F). Holdovertime ranged from 18 minutes to over four hours.

The second test was designed to determine the freezing point holdovertime of three of the fluids in 70/30 and 60/40 concentrations. The test chamber conditions during this test were SWET chamber temperature of -37°C (-35°F), panel temperature of -5°C (23°F), and relative humidity of 100 percent. The 70/30 solutions demonstrated freezing points ranging from -10°C (14°F) to -5°C (23°F) and holdovertimes from 0 to 65 minutes. The 60/40 solution demonstrated freezing points ranging from -17°C (1°F) to -7.5°C (19°F) and holdovertimes ranging from 73 to 88 minutes.

The third test used the same three ADFs as the second test at 50/50 and 70/30 concentrations. The conditions were SWET chamber temperature of -5°C (23°F), panel temperature of -10°C (14°F), and relative humidity of 100 percent. The demonstrated freezing points ranged from -27°C (-17°F) to -9°C (16°F) for the 70/30 concentrations. The holdovertime ranged from 0 to 35 minutes for the 50/50 concentrations and 15 minutes to 5.5 hours for the 70/30 concentrations.

The fourth experiment tested the performance of five ADFs at a 50/50 concentration in simulated freezing rain. The test conditions were SWET chamber temperature of 0°C (32°F), panel temperature of -4°C (25°F), rain temperature of 0.5°C (33°F), and rain rate of 2.7 mm/hour for a duration of 5.5 minutes. Three of the five ADFs were completely covered by ice after the 5.5 minute test period. The remaining two fluids had begun to freeze. In all cases, ice had started to adhere to the test panel.

KLM engineers determined from the results of these experiments that four factors affect holdovertime: type of ADF, concentration of ADF, panel temperature rather than outside ambient temperature, and amount of precipitation. However, they acknowledge that these were static experiments, conducted under controlled conditions and that during actual winter conditions other factors play an important role. These include type of precipitation, amount of wind, thickness of ADF layer, spraying technique used to apply the ADF, and temperature of fuel in tanks.

The Dutch National Aerospace Laboratory (NLR), under contract to KLM, performed a study for the following purposes:

- To obtain insight into factors associated with protection of aircraft against the formation of ice on external surfaces

- To review safety and adequacy of the procedures presently in use at KLM

- To identify areas for further research in order to optimize holdovertimes during winter operations without compromising safety

NLR, upon completion of this research, developed an analytical expression to relate holdovertime to precipitation rate, aircraft skin temperature, thickness of ADF layer, and spraying techniques. Researchers then used this expression to determine that the situation in which a relatively large mass of ADF and water moves rapidly from the leading edge to the rear of the wing is not directly harmful to the operating wing trailing and edge devices. However, if the ADF becomes trapped inside the mechanical driving system, it may later freeze and a hazardous situation may arise. NLR recognizes that although this analytical expression may help to predict holdovertimes more accurately in the future than can be done presently, the various parameters of the model must be further studied and quantified to effectively model actual operational weather conditions.

CHAPTER NINE

SUMMARY

Deicing is the removal of ice, snow, or frost from the surface of an aircraft. It is best accomplished by use of a heated fluid, which can be an ADF, water, or a mixture of the two. The heat of the fluid breaks the bond between the contaminant accumulation and the aircraft surface and also melts the accumulation. Anti-icing is the prevention of precipitation from freezing and adhering to a clean aircraft. The ADF reduces the freezing point of the residual fluid on aircraft to below that of ambient temperature, and therefore behaves more like an anti-icer than a deicer. During periods of freezing precipitation, it is difficult to predict the ADF's holdovertime or, in other words, how long the ADF will protect the aircraft surfaces from freezing.

Various ADFs are available to help deice and anti-ice aircraft in North America and Europe. The ADFs used in North America are ethylene glycol-based fluids produced by manufacturers such as Dow, Texaco, and Union Carbide. The ADFs used in Europe are designed to specifications provided by the AEA. Those fluids are produced by Hoechst, Kilfrost, British Petroleum, and Shell. Some of the fluids contain propylene glycol as a main ingredient; others contain diethylene glycol. The U.S. military has issued a specification, MIL-A-8243C, which describes the composition of ADFs used by the Army, Navy, and Air Force. These fluids are produced by Texaco, Union Carbide, Dow, and others.

There are two important issues surrounding the ADFs used in North America and Europe. First, FAA AC 20-117 stresses the clean aircraft concept which, some argue, is violated by the AEA Type II thixotropic fluids. The AEA states that the fluids are shed from the wing when an aircraft reaches a rotation speed of at least 85 knots; however, this is questioned by some members of the North American deicing community. Second, the environmental and health effects that may result from the use of various glycols, especially ethylene glycol, contained in ADFs is a subject of controversy. Although the ethylene glycol used in most North American ADFs is more toxic than the propylene glycol used in most European ADFs, there is some question as to whether deicing personnel could possibly ingest toxic doses during normal deicing operations.

Deicing is usually conducted from truck-mounted deicing units, but brooms and brushes are sometimes used to help remove contaminant accumulation. The fluid capacity of deicing vehicles ranges from 700 to 1800 gallons. Smaller, portable tank units are also available that can be carried on carts or trailers. The more complex deicing vehicles contain elaborate heating and mixing systems that allow the operator to modify the ADF concentration of the deicing mixture as necessary during the operation. Some manufacturers offer mixing systems capable of handling AEA Type II fluids without any degradation of their psudo-plastic characteristics.

Operational procedures employed to accomplish on-ground aircraft deicing vary according to the type of accumulation on the surface of the aircraft. The procedures used by most airlines are based on the recommendations of the aircraft manufacturers. The airlines provide guidelines to help deicing personnel determine the appropriate amount if ADF to be used in the deicing mixture.

Most deicing operations are conducted at the gate; however, central or remote locations are sometimes used. Central facilities exist at Dorval Airport and Mirabel Airport, both in Montreal, Canada; Charles de Gaulle Airport, Paris, France; and Kallax Airport, Luela, Sweden. The facility at Mirabel is not operating currently. Remote deicing facilities are sometimes employed during periods of heavy frozen precipitation. These facilities are composed of two or more deicing vehicles situated in a car-wash type arrangement. The aircraft are parked between the vehicles to be deiced. Central and remote deicing facilities can be especially effective when located near the end of the runway so that the time between deicing and takeoff is minimal.

Interviews were conducted with commercial airline maintenance personnel and pilots and with general aviation FBOs, maintenance personnel and pilots regarding procedures used for the on-ground deicing and anti-icing of aircraft. These interviews resulted in several observations:

- Deicing procedures do not vary much among airlines.

- Some airlines use premixed deicing solutions; others use proportional mixing systems available on some deicing vehicles.

- Pilots and deicing personnel in North America are not very aware of AEA Type II fluids.

- One airline reported that the landing gear of its aircraft are deiced, especially when slush is present on the runway.

- GA pilots would like better training regarding the hazards associated with icing.

On-site observations of deicing operations verified that the information accumulated during the interview process provides an accurate description of the deicing procedures followed by members of both the commercial aviation and GA communities.

A review of data bases maintained by the FAA, IATA, ICAO, NTSB, USN, and USAF revealed that 40 accidents/incidents related to on-ground icing were reported between 1977 and 1982. Thirteen of these accidents were fatal, with a total of 113 fatalities reported. Of the 40 accidents/ incidents, 14 occurred while the aircraft was operating under FAR part 91, nine occurred while the aircraft was operating under FAR part 135, eight aircraft were on USN missions, two were on USAF missions and one was operating for the Canadian military. The causes and contributing factors cited for these accidents verified concerns and problems revealed during the interviews of deicing personnel conducted as part of this effort and described above.

Research related to on-ground deicing technology is currently being conducted by the AEA and NASA Lewis Research Center. Recently, Boeing Commercial Airplane Company and KLM Royal Dutch Airlines completed other related research efforts. The AEA is currently sponsoring an aircraft anti-icing research program to study the effects of AEA Type I and II fluids on aircraft aerodynamics or flight characteristics. The Boeing Commercial Airplane Company conducted wind tunnel tests to investigate the possible aerodynamic effects of AEA Type II fluids when used on commercial jet transports. Finally, KLM Royal Dutch Airlines and Kilfrost, Ltd., have conducted experiments with various ADFs in an attempt to obtain insight into the ice protection properties of these fluids.

APPENDIX A

BIBLIOGRAPHY

AEA De-icing/Anti-icing Task Force, Association of European Airlines Recommendations for De-icing/Anti-icing of Aircraft on Ground, 2nd Edition, September 1, 1983.

AOPA Newsletter, "Results of 1983-84 AOPA Icing Survey," November 1984.

AOPA Pilot, "Legally Speaking," April 1980, March and May 1982, February 1983.

AOPA Pilot, "Washington Counsel," November 1980, April 1982, February 1984.

Abbott, William Y., Floyd L. Dominick, and Stuart Arthur, Ice Phobics Blade Tracking and Comparison of Vibration Analysis Techniques, Final Report, Edwards AFB, May 1981.

Air Canada, "Seasonal Preparedness and Operation - Winter Operation," November 7, 1984.

Air Wisconsin, "Deicing Training and ADF Testing Procedures Manual," September 7, 1984, Sections 1-4.

Albright, A. E. and D. L. Kohlman, "An Improved Method of Predicting Anti-icing Flow Rates for a Fluid Ice Protection System," AIAA 22nd Aerospace Sciences Meeting, AIAA paper 84-0023, January 9-12, 1984.

American Airlines, "General Maintenance Manual, Deicing Aircraft," December 15, 1983, pp. 1-12.

Bernhart, W. D. and G. W. Zumwalt, "Electro-Impulse Deicing: Structural Dynamic Studies, Icing Tunnel Tests and Applications," AIAA 22nd Aerospace Sciences Meeting, AIAA paper 84-0022, January 9-12, 1984.

Billiard, Frank J, "Cold Weather Operation," Boeing Airliner, October-December 1982.

Boeing Aircraft Corporation, "Boeing 737 Maintenance Manual, Cold Weather Maintenance," October 20, 1983, pp. 201-218.

Boeing Aircraft Corporation, "Boeing 747 Maintenance Manual, Airplane-Servicing (Cold Weather Maintenance)," August 25, 1983, pp. 301-313.

Boeing Airliner, "Preparation For Winter Operations," October-December 1984.

Bragg, M. B, "Effect of Geometry on Airfoil Icing Characteristics," Journal of Aircraft, Vol. 21, No. 7, July 1984, pp. 505-511.

Bragg, M. B, "Predicting Airfoil Performance with Rime and Glaze Ice Accretions," AIAA 22nd Aerospace Sciences Meeting, AIAA paper 84-0106, January 9-12, 1984.

Bragg, M. B, and W. J. Coirer, "Detailed Measurements of the Flow-Field in the Vicinity of an Airfoil with Glaze Ice," AIAA 23rd Aerospace Sciences Meeting, January 14-17, 1985, AIAA paper 85-0409.

British Airways, "Operation in Snow and Ice Conditions," September 1984, pp. 1-59.

Canada Water Act, "Guidelines for Effluent Quality and Wastewater Treatment at Federal Establishments," April 1976.

Coffman, Jr., H. J., "Review of Helicopter Icing Protection Systems," AIAA Aircraft Design, Systems and Technology Meeting, October 17-19, 1983, AIAA paper 83-2529.

Cooper, W. A., W. R. Sand, M. K. Politovitch, and D. L. Veal, "Effects of Icing on Performance of a Research Airplane," Journal of Aircraft, Vol. 21, No. 9, September 1984, pp. 708-715.

De-icing/Anti-icing Procedures of European and North American Airlines, Transport Canada Preliminary Report, January 1985.

De Witt, K. J., T. G. Keith, D. F. Chao, and K. C. Masiulaniec, "Numerical Simulation of Electrothermal Deicing Systems," AIAA 21st Aerospace Sciences Meeting, AIAA paper 83-0114, January 10-13, 1983.

Delta Airlines, "Defrosting and Deicing Aircraft," August 30, 1982, pp. 1-18.

Dietenberger, Mark A., "A Model for Nocturnal Frost Formation on a Wing Section," October 1983, NASA Contractor Report 3733.

Federal Express, "Memphis Winter Operations Manual," Winter season 1984-85.

Frontier Airlines B-737 Flight Standards Manual, "Cold Weather Operation," April 4, 1984, pp. III-9 to III-16.

Frontier Airlines, "Anti-icing Deicing Manual," September 9, 1984, p. 1-28.

Hendrickson, G. S., "Wind Tunnel Investigation of the Aerodynamic Effects of Type II Anti-icing Fluids When Applied to Airfoils," Boeing Commercial Airplane Company, December 12, 1983.

Hewko, Ginny, "Deicing/Anti-icing Procedures of European and North American Airlines," Preliminary Report, Transport Canada, November 1984.

IATA Accident Data Base,"Ice Snow Accretion-Airframe Engine," World Airlines Accident Summary, January 4, 1977 to January 13, 1982.

ICAO Accident Data Base, "Occurrences with A/C Icing as a Factor," February 4, 1970 to February 21, 1984.

KLM Royal Dutch Airlines, General Aircraft Maintenance Manual: Servicing, Cold Weather Ground Handling, November 1, 1983. pp. 201-223.

Keith Jr., T. G., K. J. DeWitt, K. C. Masiulaniec, and D. Chao, "Predicted Electrothermal Deicing of Aircraft Blades," AIAA 22nd Aerospace Sciences Meeting, AIAA paper 84-0110, January 9-12, 1984.

Kendrick, Fred, "PT-2 Engine Inlet Probe Icing," Boeing Airliner, October-December 1982.

Kilfrost, Ltd, Kilfrost A.B.C. De-icing Operations Manual.

Lacagnina, Mark M., "Collisions," AOPA Pilot, December 1982.

MIL-A-8243C Admendment 1, Military Specification Anti-Icing and Deicing-Defrosting Fluids, January 17, 1984.

MIL-A-8243C, Military Specification: Anti-icing and Deicing-Defrosting Fluids, November 17, 1980.

Magenheim, B. and J. Rocks, A Microwave Ice Accretion Measurement Instrument (Miami), AIAA 20th Aerospace Sciences Meeting, January 1982.

McDonnell Douglas Corporation, DC-10 Maintenance Manual, Cold Weather Protection-Servicing, May 1, 1984. pp. 301-313.

McDonnell Douglas, Aerodynamics and Cold Weather Operations.

McDonnell Douglas, Flight Phase Thoughts.

McDonnell Douglas, Ground De-icing Solutions and Application.

McDonnell Douglas, Power Plant Operations in Cold Weather.

McDonnell Douglas, Protection After De-/Anti-Icing Treatment.

Monroe, Jr., Robert L. and Thomas F. Tibbals, A-10A MIL-H-83282 Hydraulic Fluid and Airframe Icing Tests, Final Report, Edwards AFB, March 1982.

Mulally, A. R., M. D. Shirkey, and C. R. Higgins, "Winter Operations - Keep It Clean," Boeing Airliner, October-December 1983.

NASA ASRS Data Base, Ground Deicing Procedures, December 1978 to April 1984.

NASA Tech Briefs, "Modified Antifreeze Liquids for Use on Surfaces," Spring 1983, Vol. 7, No. 3, MFS-25741.

NTSB Accident Data Base, "Accidents/Incidents Involving Icing Conditions as Cause/Factor," November 18, 1979 to February 27, 1983.

Northwest Orient Airlines, Procedures - Cold Weather Operations, December 12, 1984, pp. 1-14.

Pan American World Airways, Winterization Protection of Aircraft, November 29, 1983, pp. 1-7.

Potapczuk, M. G. and P. M. Gerhart, "Progress in Development of a Navier-Stokes Solver for Evaluation of Iced Airfoil Performance," AIAA 23rd Aerospace Sciences Meeting, AIAA paper 85-0410, January 14-17, 1985.

Reinmann, J., R. J. Shaw, and W. A. Olsen, Jr., "NASA Lewis Research Center's Program on Icing Research," AIAA 21st Aerospace Sciences Meeting, AIAA paper 83-0204, January 10-13, 1983.

Republic Airlines, Aircraft Servicing - Ice, Snow and Frost Removal, December 10, 1982, pp. 12-72 to 12-7-41.

Ross, R., "Thermodynamic Performance of an Airplane Wing Leading Edge Anti-Icing System," Journal of Aircraft, Vol. 21, No. 7, July 1984, pp. 536-537.

Royal Norwegian Air Force, Royal Norwegian Air Force Technical Order for Aircraft Anti-icing/De-icing, January 1985.

Salvador, Rene, Aircraft De-/Anti-icing Hoechst 1704 ADF Properties-Application-New Development, October 1984.

Salvador, Rene, Ecological and Toxical Aspects of De-icing Agents for Aircraft and Runways, October 1984.

Scandinavian Airlines System, Aircraft Ground Servicing: Snow and Ice Elimination - De-/Anti-icing on Ground, November 1, 1983, pp. 1-10.

Schrag, R. L., and G. W. Zumwalt, "Electro-Impulse Deicing: Concept and Electrodynamic Studies," AIAA 22nd Aerospace Sciences Meeting, AIAA paper 84-0021, January 9-12, 1984.

Skidmore, F. W., and G. F. Pearce, Cloud Liquid Water Content Measuring Equipment for the Nomad N24 Aircraft Flight Icing Trials of 1978-1979, Department of Defense Support - Aeronautical Research Labs, Australia, September 1981.

Society of Automative Engineers, Deicing/Anti-Icing Fluid, Aircraft Ethylene-Glycol Base, AMS 1425A, April 1, 1982.

Transport Canada, The Environmental Effects of De-icing Fluids.

Transport Canada, Transport Canada's Interest in Aircraft De-icing.

U.S. Air Force Data Base, Icing Condition Mishaps, 1974 to present.

U.S. Army Data Base, Statistics Related to Icing Mishaps, October 1, 1973 to present.

U.S. Department of Transportation, Federal Aviation Administration, Airplane Service and Anti-Ice Systems, AC 91-51, September 15, 1977.

U.S. Department of Transportation, Federal Aviation Administration, Hazards Following Ground Deicing and Ground Operations in Conditions Conducive to Aircraft Icing, AC 20-117, December 17, 1982.

U.S. Environmental Protection Agency, Office of Ground Water Protection, Ground Water Protection Strategy, August 1984.

U.S. Environmental Protection Agency, Office of Ground Water Protection. "Protecting Ground Water: The Hidden Resource," EPA Journal, Vol. 10, No. 6, July/August 1984.

U.S. Navy Data Base, Mishaps Related to Icing.

Union Carbide Corporation, Ethylene Oxide/Glycol Division, Technical Service Report: Ecological Aspects of UCAR(R) Aircraft Deicing Fluids and Ethylene Glycol, February 28, 1985, pp. 1-7.

Wilson, G. W., "Helicopter Icing-Testing and Certification," Journal of the American Helicopter Society, Vol. 27, No. 2, April 1982, pp. 66-72.

Yeoman, K. E., and F. L. Stasa, "Finite Element Thermal Analysis of an Icing Protective System," AIAA 21st Aerospace Sciences Meeting, AIAA paper 83-0113, January 10-13, 1983.

Zumwalt, G. W., and A. A. Mueller, "Flight and Wind Tunnel Tests of an Electro-Impulse De-Icing System," AIAA General Aviation Technical Conference, AIAA paper 84-2234, July 10-12, 1984.

APPENDIX B

LIST OF ABBREVIATIONS

AC	Advisory Circular
ADF	Aircraft Deicing Fluid
AEA	Association of European Airlines
AEADC	Arnold Engineering Air Development Center
ALPA	Air Line Pilots Association
APU	Auxiliary Power Unit
ASRS	Aviation Safety Reporting System
ATA	Air Transport Association
BIT	Boeing Icing Tunnel
BOD	Biochemical Oxygen Demand
BRWT	Boeing Research Wind Tunnel
°C	Degrees Centrigrade
CAA	Civil Aviation Authority
CDG	Charles De Gaulle Roissy Airport
cm	Centimeter
CWT	Cold Wind Tunnel
EPR	Engine Pressure Ratio
°F	Degrees Farenheit
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulations
FBO	Fixed Based Operator
FPD	Freezing Point Depressant
GA	General Aviation
gm	Gram
GPM	Gallons Per Minute
hrs	Hours
IATA	International Air Transport Association
ICAO	International Civil Aeronautics Organization
in.	Inch(es)
IRT	Icing Research Tunnel

kg	Kilogram
l	Liter
LD	Lethal Dose
LWC	Liquid Water Content
mins	Minutes
ml	Milliliter
MPH	Miles Per Hour
NASA	National Aeronautics and Space Administration
NTSB	National Transportation and Safety Board
ppm	Parts Per Million
PSI	Pounds Per Square Inch
SLO	Spring Lockout Operation
SWET	Simulated Winter Environment Test
TLV-TWA	Threshold Limit Value - Time Weighted Average
UCAR	Union Carbide
USA	United States Army
USAF	United States Air Force
USN	United States Navy
VKI	Von Karman Institute

APPENDIX C

COMPANY BROCHURES

The following is a list of the companies that provided brochures describing products related to on-ground aircraft deicing. An address, point of contact, telephone number, and product line are included for each entry.

American Hoechst Corp.
Industrial Chemicals Div., Chemicals Dept.
Rt. 202-206 N., Somerville, NJ 08876
Austin Bishop (201) 231-3647
Product: Aircraft Deicing Fluid

AO Scientific Instruments
Division of Warner-Lambert Tech., Inc.
P.O. Box 123, Buffalo, NY 14240
Distributed by MISCO Products Division
3401 Virginia Rd., Cleveland, OH 44122
(216) 831-1000
Product: Refractometers

ARP Industries, Inc.
36 Bay Drive East, Huntington, NY 11743
Alfred R. Puccinelli (516) 417-1585
Product: ARP Frost and Ice Detectors

B. F. Goodrich
500 S. Main Street, Akron, OH 44318
(216) 374-3600
Product: Aircraft De-Icing Systems

B. F. Goodrich
Aerospace and Defense Division
500 S. Main Street, Akron, OH 44318
David B. Leslie (216) 374-3743
Product: Limited Application Ice Protection Fluid

De-icing System KB
Box 6097
S-102 32 Stockholm, Sweden
Thomas Nilsson, Managing Director (08-32 05 30)
Product: Experimental Deicing Plant at Kallax Airport

Dow Chemical Canada Inc.
1 Westmount Square
Bureau 300 Westmont (Quebec) Canada H3Z 2P9
Michael Greenhill (514) 931-7112
Product: Aircraft Deicing Fluid

Dow Chemical USA
Texas Operations
Freeport, TX 77541
B-1605
Russ Fay (713) 238-2112
Product: Aircraft Deicing Fluid

FMC Corporation
Airline Equipment Div.
7300 Presidents Drive, P.O. Box 13400
Orlando, FL 32859-3400
Pete Compton (305) 851-3377
Product: Ground Support Equipment

Miller-Stephenson Chemical Co.
George Washington Highway
Danbury, Connecticut 06810
(203) 743-4447
Product: Chemicals/Lubricants

Parker Hannifin Corp.
Airborne Division
711 Taylor Street, Elyria, OH 44036
Arthur Livergood (216) 323-4676
Product: Ice Protection System

Robert Mitchell, Inc.
350 Decarie, Montreal, Canada H4L 3K5
Paul Dostie (514) 747-2471
Product: Ground Support Equipment

Sage (Stevens Aircraft Ground Equipment) Corp.
30 N. Prospect Avenue, Lynbrook, NY 11563
Vincent Ventura (212) 656-7982
Product: Ground Support Equipment

Stinar Corp.
3255 Sibley Memorial Hwy., St. Paul, MN 55211
Tom Carlson (612) 454-5112
Product: Ground Support Equipment

The Ted TRUMP Company
P.O. Drawer 308, Elberta, AL 36530
(205) 986-5301
Product: Ground Support Equipment

TEXACO U.S.A.
P.O. Box 52332, Houston, TX 77052
J.S. Willey (713) 650-5055
Product: Aircraft Deicing

Tronair
South 1740 Eber Road, Holland, OH 43528
Ron Dossat (419) 866-6301
Product: Ground Support Equipment

Union Carbide
Ethylene Oxide/Glycol Division
Old Ridgebury Rd., Danbury, CT 06817
(203) 794-5300
Product: Aircraft Deicing Fluid

APPENDIX D

ACKNOWLEDGMENTS

Special appreciation is extended to the following organizations, which contributed to our understanding of aircraft deicing technology:

Aircraft Manufacturers
- Boeing Commercial Airplane Company
- Lockheed-California Company
- Douglas Aircraft Company

Associations and State, Government, and International Agencies
- Air Line Pilots Association
- FAA Denver Flight Service Station
- International Civil Aeronautics Organization
- National Transportation Safety Board
- Ohio State University
- Royal Norwegian Air Force
- Transport Canada
- U.S. Air Force
- U.S. Army
- U.S. Environmental Protection Agency
- U.S. Navy

Chemical Manufacturers
- Dow Chemical USA/Canada
- Hoechst Corporation
- Kilfrost, Ltd.
- Texaco, USA
- Union Carbide Corporation

Fixed-Base Operators
- Aero Associates
- Combs Gates
- Denver Air Center
- Denver Beechcraft, Incorporated
- Hoffman Pilot Center
- Turbo West

Equipment Manufacturers
AO Scientific Instruments
ARP Industries, Incorporated
FMC Corporation
Robert Mitchell, Incorporated
Sage Corporation
Stinar Corporation
The Ted Trump Company
Tronair

We would also like to thank the following airlines for contributing written materials, making time available for their maintenance personnel and pilots to answer questions, their pilots' time to answer our questions either in person or in response to a written questionnaire, and for providing the opportunity to observe their deicing facilities and operations.

Air Canada
Air France
Air Wisconsin
American Airlines
British Airways
Continental Airlines
Delta Airlines
Eastern Airlines
Federal Express
Frontier Airlines
KLM Royal Dutch Airlines
Lufthansa German Airlines
Northwest Orient Airlines
Pan American World Airways
People Express Airlines
Piedmont Airlines
Republic Airlines
Scandinavian Airlines System
Sabena Belgium World Airlines
Saudia (Saudi Arabian Airlines)
U.S. Air

Special acknowledgment is made to J. Eggert of Lufthansa German Airlines, G. Hewko of Transport Canada, J. Meyer of Federal Express and R. Nova of Boeing Commercial Airplane Company.

APPENDIX E

DISTRIBUTION LIST

Region Libraries

Alaska	AAL-64
Central	ACE-66
Eastern	AEA-62
Great Lakes	AGL-60
New England	ANE-40
Northwest-Mountain	ANM-60
Western-Pacific	AWP-60
Southern	ASO-63d
Southwest	ASW-40

Center Libraries

Technical Center	ACT-64
Aeronautical Center	AAC-44.4

Civil Aviation Authority
Aviation House
129 Kingsway
London WC2B 6NN England

Embassy of Australia
Civil Air Attache
1601 Mass Ave. NW
Washington, D. C. 20036

Scientific & Tech. Info FAC
Attn: NASA Rep.
P.O. Box 8757 BWI Aprt
Baltimore, Md. 21240

DOT-FAA AEU-500
American Embassy
APO New York, N. Y. 09667

Headquarters (Wash. DC)

ADL-1
ADL-32 (North)
APM-1
APM-13 (Nigro)
ALG-300
APA-300
API-19
AAT-1
AWS-1
AES-3

OST Headquarters Library

M-493.2 (Bldg. 10A)

University of California
Sers Dpt Inst of Trsp Std Lib
412 McLaughlin Hall
Berkely, CA 94720

British Embassy
Civil Air Attache ATS
3100 Mass Ave. NW
Washington, DC 20008

Dir. DuCentre Exp DE LA
Navigation Aerineene
941 Orly, France

Northwestern University
Trisnet Repository
Transportation Center Lib.
Evanston, Ill. 60201

Mr. Al Hubler
FAA-PHL FSDO
PHL International Airport
Bldg. 1, Cargo Area
Philadelphia, PA 19153

Mr. Charles Smalley
FAA Chicago ACO, ACE-130C
2300 East Devon Avenue
Des Plaines, IL 60018

Mr. Fred Jenkins
FAA Western Region ACO, ANM-130L
4344 Donald Douglas Drive
Long Beach, CA 90808

Mr. Jess Lewis
FAA Central Region Headquarters, ACE-111
601 East 12th STreet
Kansas City, MO 64106

Dr. Kenneth Korkan
Texas A&M University
College of Engineering
College Station, TX 77840

Mr. Nat Moore
Cessna-Wallace Aircraft Division
P. O. Box 7704
Wichita, KS 67277

Mr. Ralph Rissmiller
FAA Wichita ACO, ACE-130W
1801 Airport Road
Wichita, KS 67204

Mr. Robert Kiapprott, Manager
FAA Wichita ACO, ACE-130W
Wichita ACO
1801 Airport Road
Wichita, KS 67209

Mr. Russ Lawton
AOPA Air Safety Foundation
421 Aviation Way
Frederick, MD 21701

Mr. Tom Swift
FAA Los Angeles ACO, ANM-101N
4344 Donald Douglas Drive
Long Beach, CA 90808

Mr. Bill Gaitshill
U.S. Army (AVSCOM)
4300 Goodfellow Blvd.
St. Louis, MO 63120

Mr. David Forgach
BF Goodrich Aerospace
500 South Main Street
Akron, OH 44316

Mr. Harry Chambers
U.S. Army (AVSCOM)
Attn: DRSAV-ED
4300 Goodfellow Blvd.
St. Louis, MO 63120

Mr. Jim Brisco
BF Goodrich
500 South Main Street
Akron, OH 44316

Mr. Mark Quan
FAA Northwest Mountain Region, ANM-112
17900 Pacific Highway South
Seattle, WA 98168

Mr. Norbert A. Weisend, Jr.
BF Goodrich Company
Engineered Products Group
500 S. Main Street, D/1832
Akron, OH 44223

Mr. Richard Adams
Federal Aviation Administration, AWS-104
800 Independence Avenue, S. W.
Washington, DC 20591

Mr. Robert McKnight
NASA-Lewis Research Center
21000 Brookpark Road
Cleveland, OH 44135

Mr. Terence Barnes
FAA Seattle ACO, ANM-150N
P. O. Box C-68966
17900 Pacific Highway South
Seattle, WA 98168

Mr. Warren Green
FAA Capital City GADO
Capital City Airport
New Cumberland, PA 17070

Mr. William Norton
FAA Chicago ACO, ACE-160C
2300 East Devon Avenue
Des Plaines, IL 60018

Mr. Jorg Eggert
Airframe and Airframe Systems
Engineering Department
Lufthansa German Airlines
Dept. HAM IF 1
Weg beim Jager 193
D-2000 Hamburg 63
West Germany

Ms. Ginny Hewko
Facilities and Environment Management
Airport Facilities Branch
Place de Ville
Ottawa, Ontario K1A 0N8
Canada

Mr. William Schweikhard
Kohlman Systems Research
Vice-President Flight Test
319 Perry Street
Lawrence, KS 66044

Ms. Kath George
Development Engineer, Ethylene Oxide/
Glycol
Union Carbide Corporation
P. O. Box 8361, Technical Center
South Charleston, WV 25303

Mr. Brad Phillips
Flight Operations
Federal Express
P. O. Box 727
Memphis, TN 38194-0131

☆U.S. GOVERNMENT PRITNING OFFICE: 1986-605-071/40133