https://ntrs.nasa.gov/search.jsp?R=19810010553 2020-03-21T13:39:43+00:00Z

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Light Transport and General Aviation Aircraft Icing Research Requirements

R. K. Breeze, G. M. Clark
North American Aircraft Division
Rockwell International Corporation
El Segundo, California

Prepared for
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Final Report Project Manager, Peggy L. Evanich, Propulsion Systems Division.
NASA Lewis Research Center, Cleveland, Ohio 44135

16. Abstract

A short term and a long term icing research and technology program plan was drafted for NASA LeRC based on 33 separate research items. The specific items listed in the report resulted from a comprehensive literature search, organized and assisted by a computer management file and an industry/Government agency survey. Assessment of the current facilities and icing technology was accomplished by presenting summaries of ice sensitive components and protection methods; and assessments of penalty evaluation, the experimental data base, ice accretion prediction methods, research facilities, new protection methods, ice protection requirements, and icing instrumentation. The intent of the research plan was to determine what icing research NASA LeRC must do or sponsor to ultimately provide for increased utilization and safety of light transport and general aviation aircraft.

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Icing Technology Bibliography		

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FOREWORD

Work accomplished in the performance of the ten tasks of NASA Contract NAS3-22186, "Light Transport and General Aviation Aircraft Icing Research Requirements Program," is presented in this document. The resultant research requirements program plan is intended to contribute to an overall research program for the NASA Lewis Research Center (LeRC) in the field of icing technology. The objectives of the study program were accomplished by addressing ten specific tasks (the tenth being a reporting task) through a very comprehensive literature search and industrywide survey/questionnaire.

This research study was conducted by the Thermodynamics Group of the North American Aircraft Division of Rockwell International Corporation. Mr. R. K. Breeze of the Rockwell Thermodynamics Group served as the Rockwell Program Manager. Ms. Peggy Evanich of the Safety Technology Section, NASA Lewis Research Center served as the NASA Technical Monitor. The authors of this report wish to acknowledge the excellent support given by Ms. Evanich and also by Mr. Jack Reinmann, Section Head, NASA LeRC Safety Technology Section, Mr. Roger Luidens, Branch Chief, NASA LeRC Low Speed Aerodynamics Branch, and all of those industry, Government agency, and university representatives who so generously offered their contributions through the questionnaire.

ABSTRACT

A short term and a long term icing research and technology program plan was drafted for NASA LeRC based on 33 separate research items. The specific items listed in the report resulted from a comprehensive literature search, organized and assisted by a computer management file and an industry/Government agency survey. Assessment of the current facilities and icing technology was accomplished by presenting summaries of ice sensitive components and protection methods; and assessments of penalty evaluation, the experimental data base, ice accretion prediction methods, research facilities, new protection methods, ice protection requirements, and icing instrumentation. The intent of the research plan was to determine what icing research NASA LeRC must do or sponsor to ultimately provide for increased utilization and safety of light transport and general aviation aircraft.

KEY WORDS

Icing Research Requirements
Data Base Assessment
Ice Sensitive Components
Icing Technology Bibliography
Ice Protection Systems
Icing Instrumentation
Icing Weather Prediction
General Aviation and Light Transport Aircraft
Aircraft Meteorology Research

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Section I

SUMMARY

A study was conducted to define for the NASA Lewis Research Center, both a long term and a short term icing research and tecnnology program which is responsive to the needs and desires of members of the light transport and general aviation industry. Included were assessments of the current state-of-the-art in prediction and test techniques and facilities, as well as the adequacy of the existing data base and aircraft instrumentation under icing conditions.

In order to facilitate the overall objectives, the program was divided into ten separate but related tasks as follows:

1. Identify ice sensitive components.
2. List existing ice protection systems for components.
3. Assess ice protection system penalties.
4. Assess experimental data base.
5. Assess ice accretion prediction methods.
6. Assess new ice protection methods.
7. Define a reduced ice protection system requirement.
8. Assess NASA LeRC icing research facilities and recommend improvements.
9. Summarize results and recommend research program.
10. Reporting effort.

The study was accomplished utilizing a comprehensive literature search to obtain the current published information and an industrywide survey to solicit highly specific opinions and answers to questions directly related to the program tasks.

In order to aid the implementation of the specific program tasks and to organize the material obtained from the literature search, a computerized data management file was used for both the storing and retrieving of information. The bibliography of references assembled from the literature search, the lists of ice sensitive components and current methods of ice protection, and tables of codes used for data storage and interrogation were directly used in the report.

The results of the study program revealed that the techniques and methods developed in the 1940 and 1950's are still being used today throughout the general aviation industry. The major improvement has been in the use of computer codes (mostly individually company developed) for calculating flow fields about wings and body shapes, droplet trajectories, ice accretion quantities, and subsequent heat transfer characteristics involved with ice protection system design and certification. Further research is required to develop codes beyond the 2-D programs and also codes for ice shedding, ice shapes, accretion with ice buildup, and aircraft penalties.

Ice protection systems currently used are the same conventional systems that have been used over the past 20 to 30 years, with perhaps some improvements in design and utilization. New systems such as icephobics, electro-impulse, microwave, and acoustic are only in the conceptual and research phases.

A very great concern has been shown throughout the general aviation industry for improvements in instrumentation, icing forecasting, quantitative icing definitions that can be related to G/A aircraft, standard certification required for all FAA regions, and a reevaluation of the FAR 25 Appendix C envelopes.

An assessment of the NASA (LeRC) icing facilities i made including a list of fourteen suggested improvements summarized from the industry survey.

From the results of the study, a list of thirty three research items were assembled for laying out a short term and long term research program. For purposes of the program, the short term is three to five years and the long term five to ten years. The starting times and program costs were coordinated with probable facilities refurbishing dates and estimated reasonable budgets. Research and technology areas are ranked in accordance with the most needed listed first.

Section II

INTRODUCTION

BACKGROUND

The nature of icing problems and advances in technology related to icing and ice protection methods have changed considerably since the 1950's, when the last major thrust in icing research by NACA (now NASA) was terminated. Although industry has accomplished some work in applied R&D, most of the effort has been directed to specific designs for certification of large transport aircraft. More recently, expansion in the use of private business and commuter aircraft has emphasized the problems that result from applying the icing requirements of large commercial aircraft to the smaller, light transport segment of the industry. General aviation and light transport aircraft have operational and utilization problems resulting in relatively higher exposure to icing conditions and greater penalties for ice protection systems. These are due to: (1) the smaller physical dimensions, which produce relatively heavier ice accretions and, thus, aerodynamic performance degradation, (2) weight and cost penalties of icing systems relative to their payload and cost baselines, and (3) the perceived inappropriateness of weather forecasting methods, and (4) lack of partial/limited type certification requirements to this calss of aircraft.

Current icing problems result from increased air traffic volume, more extensive worldwide and seasonal operations, proliferation of low-altitude shuttle operations where icing is more likely for both civil and industrial use, and an increased threat to general populace from accidents that occur in highly populated areas.

In the meantime, advances in technology have been extensive in many areas and particularly in electronics and optics with the proliferation of microprocessors, computers, new types of sensors, radar, lasers, holography, and microwave. A major effort is needed to resolve the icing problems with the aid of these new technologies. Recognition of these factors has resulted in NASA reestablishing an icing research function dedicated to both short and long term research programs, including updating of icing tunnel and instrumentation capabilities.

The research problem is not entirely new, since many techniques evolved in the 1950's, refined since that time, and applied primarily to large transports, are accurate. In particular, the correlation of ice collection equations, as well as heat and mass transfer equations over airfoils and windshields, has been quite good. Since these quantities are also required for light transport and general aviation, some commonality exists. This commonality lies in the areas of the following.

1. The same ice sensitive components, such as flight surface leading edges, engine inlets, pitots, etc. The similarity exists in the areas of function, shapes, and certain ice protection methods.

2. Icing physics associated with ice accumulation and heat and mass transfer are identical and can be related by common scaling parameters.

3. Operational exposure in those regions of operational space which are common, i.e., during transitional flight and at lower altitudes.

Most of the differences result from size, performance, mission, and payload differences, where the general aviation and light transport aircraft are penalized in all these respects.

It is seen that the major problems which need to be resolved are: (1) reduction in operational (certification requirements) constraints in order to improve the use of the existing and growing body of general aviation and light transport aircraft, (2) improvement in safety while operating in icing conditions, and (3) reduction in manufacturing and maintenance costs of ice protection systems as a basis for improving the operational opportunities of short distance shuttle services. It is evident that to solve these problems, a new, concerted effort must be initiated to combine the advancements in instrumentation, ice protection capabilities and methods, weather forecasting techniques, etc., so as to provide a sound and current technological basis for the design and certification of light transport and general aviation aircraft.

OBJECTIVE

The objectives of this program were to define for NASA both a long and a short term icing research and technology program responsive to the needs and desires of members of the light transport and general aviation industry. Included are assessments of the current state-of-the-art in prediction and test techniques and facilities, as well as the adequacy of the existing data base and aircraft instrumentation under icing operation.

SCOPE AND APPROACH

The program was accomplished by laying out a detailed and relevant foundation for accumulation of data which defines the current and future icing prediction, testing, protection methods, and instrumentation that are applicable to the problems of light transport and general aviation aircraft. This foundation established a basis for determining the requirements for future icing research and technology efforts.

As shown in figure 1, the program consisted of ten separate, but related tasks. The first six of these are related, in that the results of each task correspond on a one-to-one basis with the list of ice sensitive components defined in task I. The outputs of these tasks are similar in format, each generating parameter lists which apply to the task I components. The results of the first six tasks were used with the additional assessments of tasks VII and VIII to provide the conclusions and recommendations of task IX. Task X is a reporting task.

The general approach consisted of the division of each task into an initial definition phase and a final assessment phase, including conclusions and recommendations for each task. The intermediate effort, which involved data gathering, data relating, sorting, and interim evaluation was accomplished concurrently by means of a computerized data management system. This step permitted a major increase in program analysis efficiency by: (1) data search and recording of all parameters concurrently, and (2) data combinations, sorting, relating, etc., by computer, based on the use of specialized parameters derived from the objectives of each task. Additional data were obtained from the results of a survey of Government and industry relating to the objectives of this program.

For the purposes of the study program, light transport is defined as fixed wing aircraft of up to 30 passengers, having an annual utilization of about 2500 hours in scheduled operations, and operating primarily at altitudes below 10,000 feet. General aviation refers to fixed wing aircraft utilized in non-military and unscheduled airline operations. Aircraft with the following types of engines are being considered: jet and fan engines, turboprops, and piston engines.

PROGRAM PAYOFF

The intent of this program is to provide guidance regarding areas for icing research and technology which have the greatest potential for advancement of the ice protection state-of-the-art as applicable to light transport and general aviation aircraft. The short term and long term icing research programs developed from the results of the literature search, questionnaire returns, and task studies of this program, along with discussions with other icing authorities will help define a large scale effort for NASA facility improvement and for NASA in-house and/or contracted research and technology activity. These efforts should culminate in an increased utilization of general aviation and light transport aircraft with attendant improvements in safety and economy of operation.

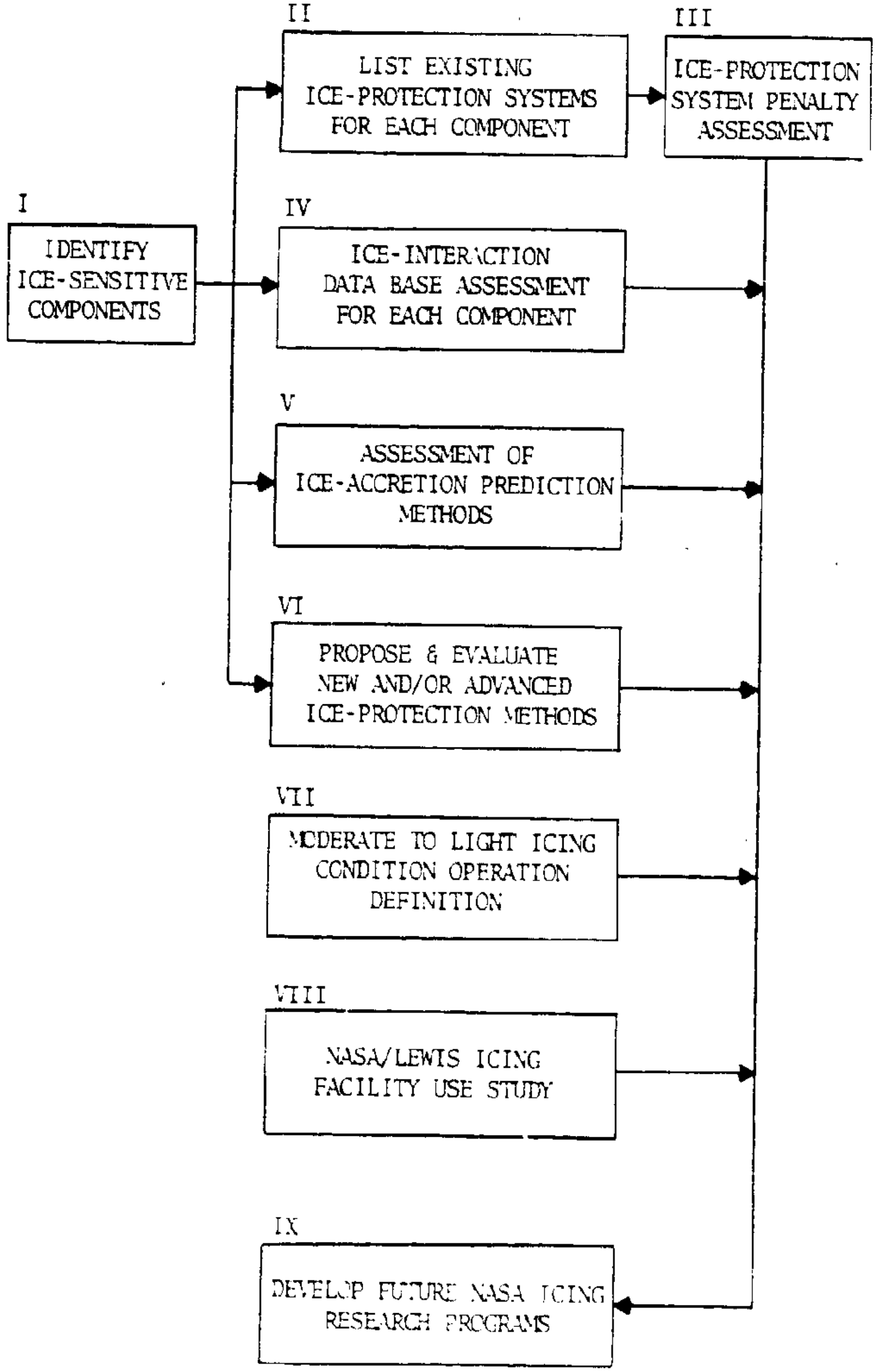

Figure 1. Task Flow Description

Section III

RESEARCH DATA ACQUISITION

LITERATURE SEARCH

From the very beginning of this study, it was recognized that a fairly extensive search of the literature would be required to provide a basis for assessing the current state of icing technology and future icing research requirements. As noted in the introduction, the last major efforts in this field were spearheaded by NACA in the early 1950's. Most of the literature resulting from those efforts has been in circulation for some time, and reviewing such documents would not result in information of which we are not already well aware. (For example, Rockwell already has an in-house file of about 100 icing related documents published circa this period, mostly by NACA.) On the other hand, a search of the more recent literature would provide an indication of the problems and solutions which currently exist in the general aviation and light transport industry. As a result, the search was limited to documents published since 1968, and to subjects concerning aircraft related icing only. Helicopters were explicitly omitted since it was felt that this area would be studied under a similar but separate NASA sponsored contract.

The scope and effort of the search was quite large, since it was intended that the literature would provide the support required for the research program recommendations. Three search sources were utilized - NASA, National Technical Information Service (NTIS), and the Defense Documentation Center (DDC). Abstracts were requested of all documents in these files which addressed aircraft icing and anti-icing.

Figure 2 presents a sample page from the NASA literature search. A total of 221 references were cited by NASA as pertinent to aircraft icing and anti-icing methods. Note that abstracts were not available for all of the references, although in many cases, at least a partial description of the contents was included. Documents published in a foreign language (excluding translations) were not considered for the purposes of this contract, due to time and man power constraints. However, it was noted that eight of these would pertain to the objectives of this program and might be included in future studies. Based on the abstracts, 79 references were determined to be of further interest to this program, and were ordered.

The DDC search turned up only 37 documents which met the search constraints. Table I presents the "first" and "second level search terms" used by DDC to extract documents of interest from its files. In essence, the search requires that at least one term from each level appear in the descriptors for each document. This may be seen to be the case in the DDC search sample of figure 3. Thirteen documents were ordered from the DDC for further examination.

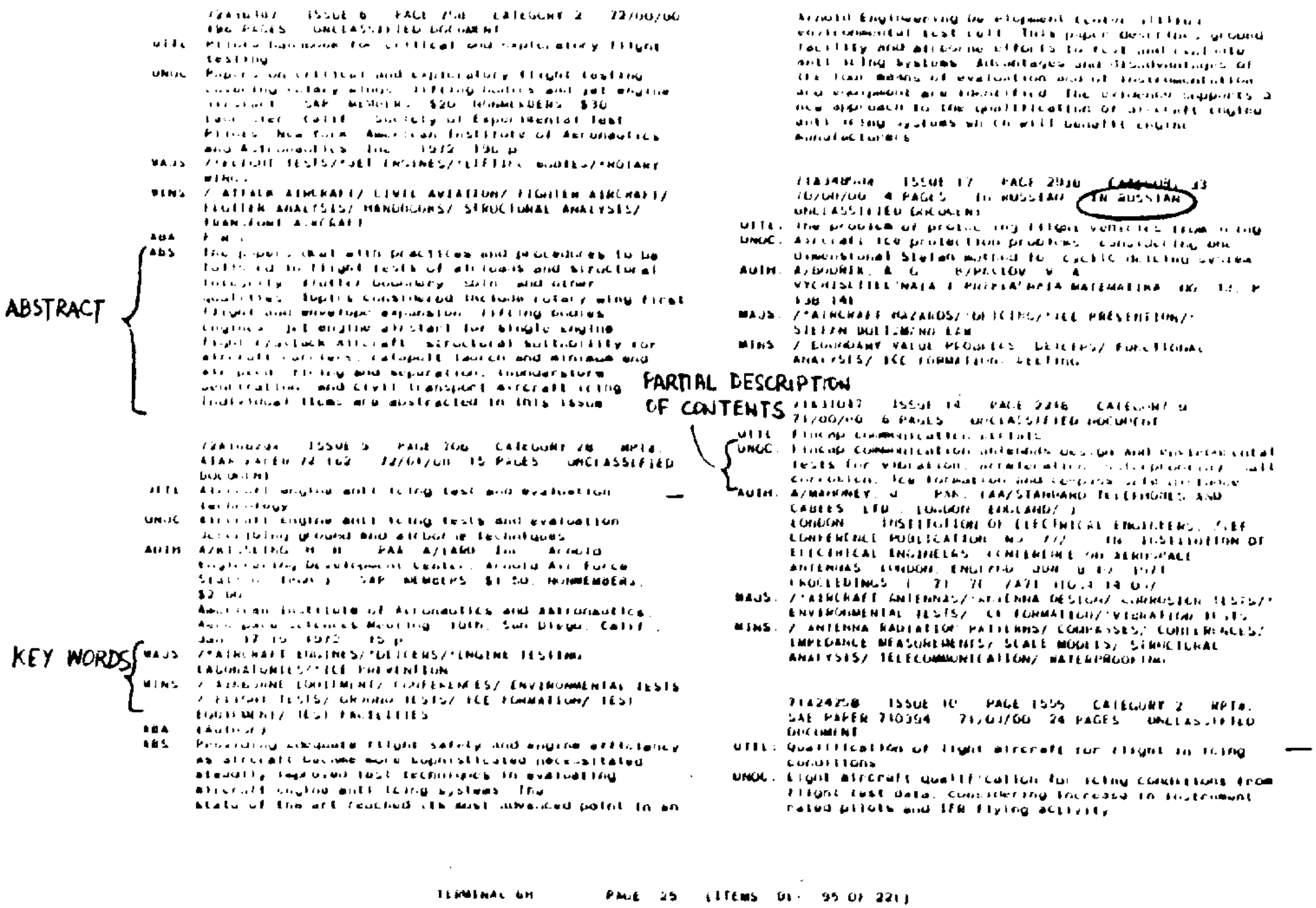

Figure 2. Sample Page From NASA Search

TABLE I

SEARCH TERMS FOR THE DDC SEARCH

SEARCH CONTROL NUMBER 090433

SEARCH STRATEGY

THE TERMS BELOW WERE SEARCHED BY THE COMPUTER. ASTERISK TERMS REPRESENT WEIGHTED RETRIEVAL TERMS. TRUNCATED RETRIEVAL TERMS INDICATE THAT ALL TERMS WITH THE DEPICTED ROOT HAVE BEEN SEARCHED. COORDINATE SEARCHES ARE PORTRAYED AS SEARCH TERMS LISTED ON VARIOUS LEVELS. EXCLUDED RETRIEVAL TERMS ARE DISPLAYED UNDER AN EXCLUDE LISTING.

FIRST LEVEL SEARCH TERMS

* AEROSPACE CRAFT
* AEROSPACE PLANES
* AIR CUSHION VEHICLES
* AIR SUPERIORITY FIGHTERS
* AIRCRAFT
* AIRPLANES
* AIRSHIPS
* ALL WING PLANES
* AMPHIBIOUS AIRCRAFT
* ANTISUBMARINE AIRCRAFT
* ARMY AIRCRAFT
* ATTACK AIRCRAFT
* ATTACK BOMBERS
* ATTACK HELICOPTERS
* AUTOGYROS
* BALLOONS
* BOMBER AIRCRAFT
* BOOST GLIDE VEHICLES
* CAPTIVE AIRSPACE CRAFT
* CARRIER BASED AIRCRAFT
* COMMERCIAL AIRCRAFT
* COMPOSITE PLANES
* CONVERTIBLE PLANES
* DOWNED AIRCRAFT
* DRONE CONTROL PLANES
* DRONES
* ELECTRONIC AIRCRAFT
* FIGHTER AIRCRAFT
* FIGHTER BOMBERS
* FIXED WING AIRCRAFT
* FLYING BOATS
* FLYING PLATFORMS
* GLIDERS
* GROUND EFFECT MACHINES
* GUNSHIPS
* HELICOPTERS
* HYPERSONIC AIRCRAFT
* JET AIRCRAFT
* JET BOMBERS
* JET FIGHTERS
* JET FLYING BOATS
* JET SEAPLANES
* JET TRAINING PLANES
* JET TRANSPORT PLANES
* METEOROLOGICAL BALLOONS
* MILITARY AIRCRAFT
* NAVAL AIRCRAFT
* OBSERVATION AIRCRAFT
* PARASITE PLANES
* PASSENGER AIRCRAFT
* PATROL AIRCRAFT
* POWERED BALLOONS
* RECONNAISSANCE AIRCRAFT
* REMOTELY PILOTED VEHICLES
* RESEARCH AIRCRAFT
* RESEARCH PLANES
* ROCKET PLANES
* ROTARY WING AIRCRAFT
* SEAPLANES
* SHORT TAKEOFF AIRCRAFT
* SUPERSONIC AIRCRAFT
* SUPERSONIC TRANSPORTS
* SURVEILLANCE DRONES
* TACTICAL AIRCRAFT
* TAILLESS PLANES
* TANKER PLANES
* TARGET DRONES
* TOWED PLANES
* TOWING PLANES
* TRAINING PLANES
* TRANSONIC AIRCRAFT
* TRANSPORT AIRCRAFT
* UTILITY AIRCRAFT
* VARIABLE STABILITY AIRCRAFT
* VERTICAL TAKEOFF AIRCRAFT
* WATER BASED PLANES
* WEATHER RECONNAISSANCE AIRCRAFT

SECOND LEVEL SEARCH TERMS

DEICING
ICE DETECTORS
ICE FORMATION
ICE FORMATION INDICATORS
ICING
ICING FLIGHT TRAILS
ICING TUNNEL

EXCLUDE TERMS

C
S

DDC REPORT BIBLIOGRAPHY . SEARCH CONTROL NO. 089439

AD-A046 852 1/1 8/12 11/3
ARMY AVIATION ENGINEERING FLIGHT ACTIVITY EDWARDS AFB CALIF

Icing Evaluation, U-21A Airplane with Low Reflective Paint. ✓(U)

DESCRIPTIVE NOTE: Final rept.,
MAY 77 28P Thomas,Charles L. ;Stewart, Robert L. ;Benson,Tom P. ;Woratschek,Ralph ;

REPT. NO. USAAEFA-77-05

LEVEL 1

UNCLASSIFIED REPORT

LEVEL 2

DESCRIPTORS: *Utility aircraft, Ice formation, *Paints, Reflectance, Low level, Problem areas, Deicing systems, Jet engine inlets, Leading edges, Jet flaps, Aerodynamic drag (U)
IDENTIFIERS: U-21A aircraft, U-21 aircraft, LPN-DA-20-7-R-0083-02-20-EJ (U)

An evaluation was conducted of the icing characteristics of a U-21A airplane painted with low reflective paint. Test flights were made in trace, light, and moderate icing conditions. During these tests four shortcomings were noted. The shortcomings were ineffectiveness of the deice boots with rime ice accumulation, inability of the engine air inlet anti-ice system to prevent formation of ice in the engine air inlet, lack of an engine inlet lip boot anti-ice system preflight test, and lack of anti-ice/deice capability for the wing area outboard of the pneumatic boots. From the evaluation it was concluded that the low reflective paint does not significantly affect the ice accumulation characteristics of the U-21A airplane, and also that, regardless of the type paint, in moderate icing conditions at constant power, airspeed will be reduced by 20 to 30 knots. (U)

DDC REPORT BIBLIOGRAPHY SEARCH CONTROL NO. 089439

AD-A034 458 1/3 1/4
LOCKHEED-CALIFORNIA CO BURBANK

Ottawa Spray Rig Tests of an Ice Protection System Applied to the UH-1H Helicopter. (U)

DESCRIPTIVE NOTE: Final rept. 20 Jan-30 May 76,
NOV 76 97P Cotton,R. H. ;
REPT. NO. LR-27694
CONTRACT: DAAJ02-76-C-0012
PROJ: 1F263209DB38
TASK: C0
MONITOR: USAAMRDL TR-76-32

UNCLASSIFIED REPORT

DESCRIPTORS: *Helicopters, *Deicing systems, *Ice prevention, *Tail helicopter rotors, Snow, Flight testing, Advanced systems, Heaters, Cold weather tests, Rotor blades(Rotary wings), Ice, Test equipment, Environmental tests, Sprays, Tail rotors, Ice formation indicators (U)
IDENTIFIERS: *H-1 aircraft, UH-1H aircraft, Ice protection system, Electrothermal deicing, PE63209A, ASB38, WU022 (U)

Simulated icing flight tests were conducted on an advanced ice protection system as applied to an Army UH-1H helicopter in the NRC spray rig at Ottawa, Canada. The system provides for electrothermal cyclic deicing of the main and tail rotor blades, electrically heated windshield and stabilizer bar, and ice detectors. The aircraft had been tested previously in simulated icing conditions behind the CH-47 HISS. A total of 18.1 hours of testing were accomplished in 54 days at Ottawa. Test conditions ranged from 0 deg C to -20 C and liquid water contents equivalent to the recommended atmospheric icing criterion for continuous maximum. The deicing controller system demonstrated excellent functioning and reliability characteristics. In general, the deicing of the rotor blades was considered to be good. Test results were obtained to define recommended heater-on times for deicing as well as heater-off time between cycles. Limited tail rotor icing and deicing were evaluated. Natural icing flights were planned after system readiness was established but none were made due to the lack of proper weather conditions. It (U)

Figure 3. Sample Page from DDC Search

ORIGINAL PAGE IS OF POOR QUALITY

The NTIS cited 122 documents. Thirty seven were considered of interest to the program. Seven were found to be duplicates, so thirty documents were ordered.

In all, 380 documents were cited by the three services, and 122 were ordered. However, the number actually reviewed totalled 141, since: (1) some of the documents which were received contain a number of separately referenceable articles of interest to the program, and (2) there were documents not listed in any of the searches which were already in Rockwell's possession.

A computerized bibliography of the references which have been reviewed as part of this program was developed. This file stores the reference titles in standard bibliography format, but also keeps track of the year of publication, the source of the document (e.g., USAF, USN, company, country, etc.), a subject (assigned by the user), and the Government accession number (NASA, DDC, NTIS, or other). The most current output of the bibliography is presented in Appendix A.

A manipulation of this reference file was made to sort the above reports by subject. This was done in order to identify those areas where icing work and studies are currently being conducted which have application to NASA research objectives. It would also point to areas where such work is lacking. The results of this file search are presented in Appendix A. It was found that in general, there was good balance among the separate subjects. As expected, the bulk of the references could be classified as pertaining to general aircraft icing. There were also quite a few concerning anti-icing and deicing systems. Only three accident reports relating to icing were reviewed, plus three on fuel additives, and three on carburetor icing. Only five out of the 141 reports dealt entirely with an analytical model for aircraft icing. The literature searches turned up a number of documents on helicopter icing, but these were not ordered unless they appeared to have application to the general aviation segment of the industry as well. As a result, only six documents are listed under "helicopter icing" in Appendix B. Some reports such as the accident reports which were not specifically sought, turned up in the literature search due to the key code words used in the search. They were reviewed for their possible contribution to the program and recorded. It is suspected, from the review of many documents, that much good data may remain hidden due to: (1) the use of nondescript titles, or (2) the fact that a report may contain icing data which is not properly identified via either the title or key search terms.

DATA MANAGEMENT FILE

Review of the literature has to be accomplished in a consistent, repeatable manner, with certain questions being asked of each document which related explicitly to the objectives of the program. In the process, the reviewer obtains a feel for the content of the literature and its application potential for the various tasks of the program. However, after reviewing more than 100 documents, it becomes difficult to efficiently remember or sort out which of the documents was applicable to what purpose. Also, this procedure almost requires that the reviewer also be the primary investigator for the effort, if he is to know what is contained in each document.

In order to get around this problem, a computerized data management system was used in this program. The idea behind this system is to provide a means of storing the information found in the literature into an easily retrievable file. In this way, the reviewer quickly scans and reviews each document, answering a number of pertinent questions in code form on computer data sheets. The data sheet information is then punched into cards and entered into the icing research data file.

For this study, the MARK IV File Management System was used. This is a system proprietary to Informatics, Inc., but which is on line as part of the Rockwell computer system. As the name implies, the primary concept of MARK IV is the ability to manipulate files of data. Basically, what the user must do when starting out, is to decide what information he wants to store from each record (or reference), how he wants to store it, and in what format he wants to input the data into the system. This "file creation" process is depicted in figure 4, and can be broken down into "file definition," "transaction definition" (input format), and "file creation" phases. It is important to choose the categories of information to be stored carefully when first developing the file because it becomes increasingly difficult to go back and restructure the file as the number of records (or references) inserted into the file grows.

Once the files and their transactions have been defined, the user has the ability to solve his information management requirements. In MARK IV, this is done through the use of "requests." In general, requests are the means by which a user selects records from a file, selects specified data from the records for computation and logical processing, and specifies the desired output. This output normally takes the form of reports, intermediate result files, subsets of the original file, or combinations of all of these.

A very simplified scheme for a MARK IV file is shown in figure 5. In this example, the total file length allocated for data storage is 27 locations per record, or reference. The first three are allocated to the reference number, and the next fifteen to the aircraft type discussed in that reference. The last three sets of three locations are for filing the ice sensitive component, if any, addressed in the reference, the anti-ice system discussed, and the data base (i.e., wind tunnel testing, analytical, etc.). Note that for the latter three, a code number is stored, instead of a word description. This is done to reduce the file size requirements. For example, if each of those three parameters were allocated 20 locations each in the file, then the file length would be 78 per reference, instead of the 27

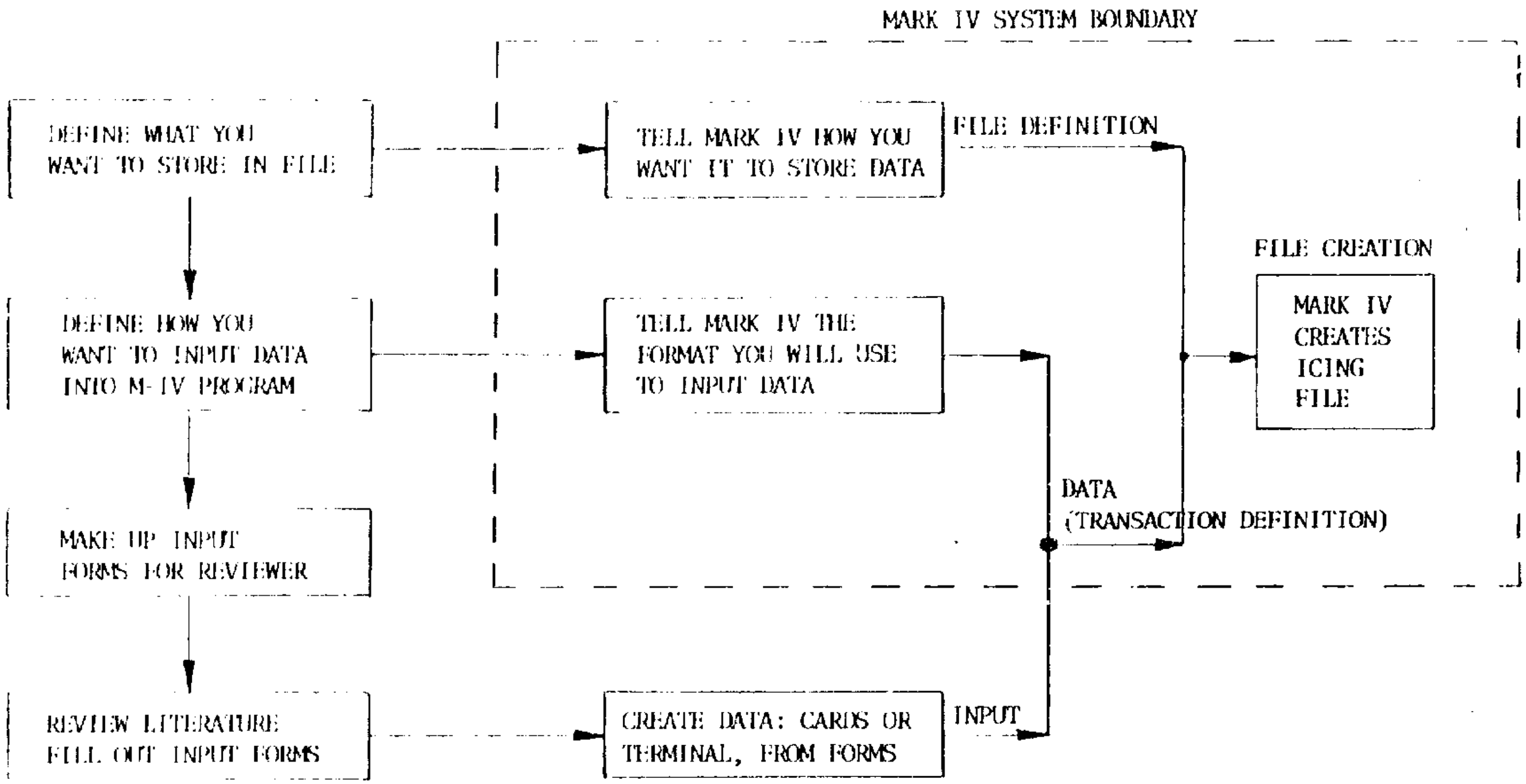

Figure 4. How to Create A File Using Mark IV System

REFERENCE NUMBER	AIRCRAFT	COMPONENT	ANTI-ICE SYSTEM	DATA BASE
1	L-1011	500	40	2
2	SABRELINER	300	10	1
3	NONE	300	30	1

Table of Components

100	NONE
200	WINDSHIELDS
300	AIRFOILS
400	RADOMES
500	MANY

Table of Anti-ice Systems

10	HOT AIR
20	THERMO-ELECTRIC
30	NONE
40	MANY

Table for Data Base

1	WIND TUNNEL
2	FLIGHT TEST
3	ANALYTICAL
4	NONE

Figure 5. A Sample Mark IV Icing File

locations shown in the figure. The code numbers are chosen from tables of components, anti-ice systems, and data base which the analyst constructs at task initiation.

The file used to actually accomplish this effort was much larger than the sample file in figure 5, but the basic principles are the same. A number of questions were developed for classifying and storing the information found in the references. These questions were based on the investigator's interpretations of the task objectives, and deal with a number of items required by these tasks.

Figure 6 presents a typical work sheet used during the review of the literature. The work sheet breaks down into four different parts. The first part deals with the reference in general, and includes codes for a reference number, the component types, anti-ice methods, and the availability of the reference. The tables of codes which were used are presented in Appendix B. The "data base" describes the type of data in the report, such as commentary, statistical, operational experience reporting, type of test facility, computer program, etc. The "method of expression" describes or classifies any specific equations, or notes whether there are computer programs/data or experimental measurements included. The "research status" allows the reviewer to note whether the reference suggests that research is either needed or not needed, as well as how badly it is needed. A code is included for the "icing conditions" discussed in the reference, such as liquid water content, altitude, drop size, flight test under natural or tanker icing, combinations, flight profiles, certification data, and many others. The "state-of-the-art" code really applies to the method of anti-icing or instruments which measure icing. Using this code, the reviewer assesses where the state-of-the-art lies; i.e., off the shelf, new concept, etc. Provision is made for indicating the aircraft discussed in each reference, if applicable. Finally, up to four lines of comments are allowed regarding the overall reference. Here the reviewer can rate the source, or simply provide a mini-abstract, if he wishes.

The second part of the work sheet deals with the icing phenomena in the reference, such as heat transfer analyses, water drop trajectory/collection efficiencies, ice shedding, aircraft effects, etc. Once the phenomenon has been coded, questions regarding its data base, method of expression, research status, and icing conditions are considered. If icing phenomena are not discussed, all the attendant codes and comments which follow may be left blank.

The third part of the work sheet addresses the penalties discussed in the reference. These are coded to signify whether they address components, or are aircraft associated (weight, speed, drag, range, etc.). A rating of the penalty is also coded: no effect, small effect, moderate effect, severe effect, etc.

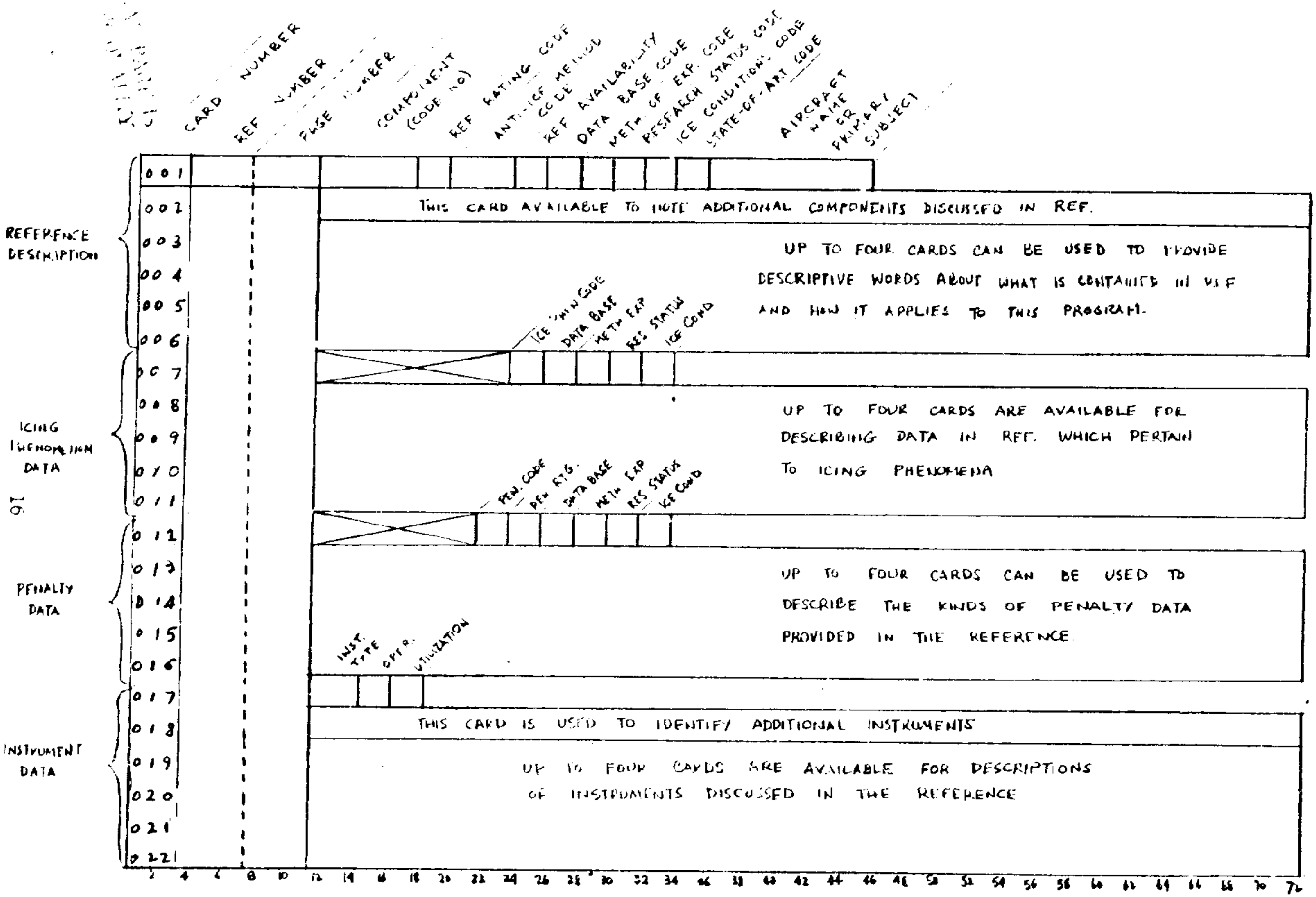

Figure 6. Sample Input Sheet

The same questions are asked in the penalty section as were asked in previous ones. The data base, method of expression, research status and icing conditions are noted. Up to four lines of comment regarding the penalty information in the reference are allowed. Again, if penalty information is not discussed, all the attendant codes and comments are omitted.

The fourth part of the work sheet, which was an addition made after a considerable number of references had been reviewed, addresses the instrumentation associated with icing which are discussed in each reference. Again, the same questions are asked in the instrumentation section as were asked in the previous ones. Allowances are made for additional instrumentation when "more than one" code is used. The principle of operation and utilization of the instruments are also indicated by code number. Again, up to four lines of comments regarding the instrument information are allowed. A component code number in the first part of the work sheet immediately indicates to the computer and reviewer when the main subject of the reference is instrumentation.

The questions and codes used are meant to reflect the task requirements. Some additions or changes were made, such as the addition of a section regarding instrumentation. However, as more and more of the literature was reviewed, it became more difficult to make changes, since one would then have to go back and rereview the documents already incorporated into the files.

All 141 references were reviewed from the standpoint of these questions, and the resulting information was input into the MARK IV system to create a file of data pertaining to icing research requirements. The entire process, including the literature search, file creation, and file manipulation is schematically depicted in figure 7. As expected, the file was an efficient tool for manipulating the findings of the literature so as to address the requirements of the various program tasks.

During the course of this effort, the computer file was interrogated in a number of different ways, and the results were used in the fulfillment of each task, as required. The computer outputs from these interrogations are included in this report as Appendix C.

INDUSTRY/GOVERNMENT/UNIVERSITY SURVEY QUESTIONNAIRE

Early in the program, it was decided by the NASA that a ver worthwhile addition to the program would be a survey of the general aviation industry and those concerned Government agencies involved in aircraft icing technology, to solicit their views with regard to a number of the program tasks.

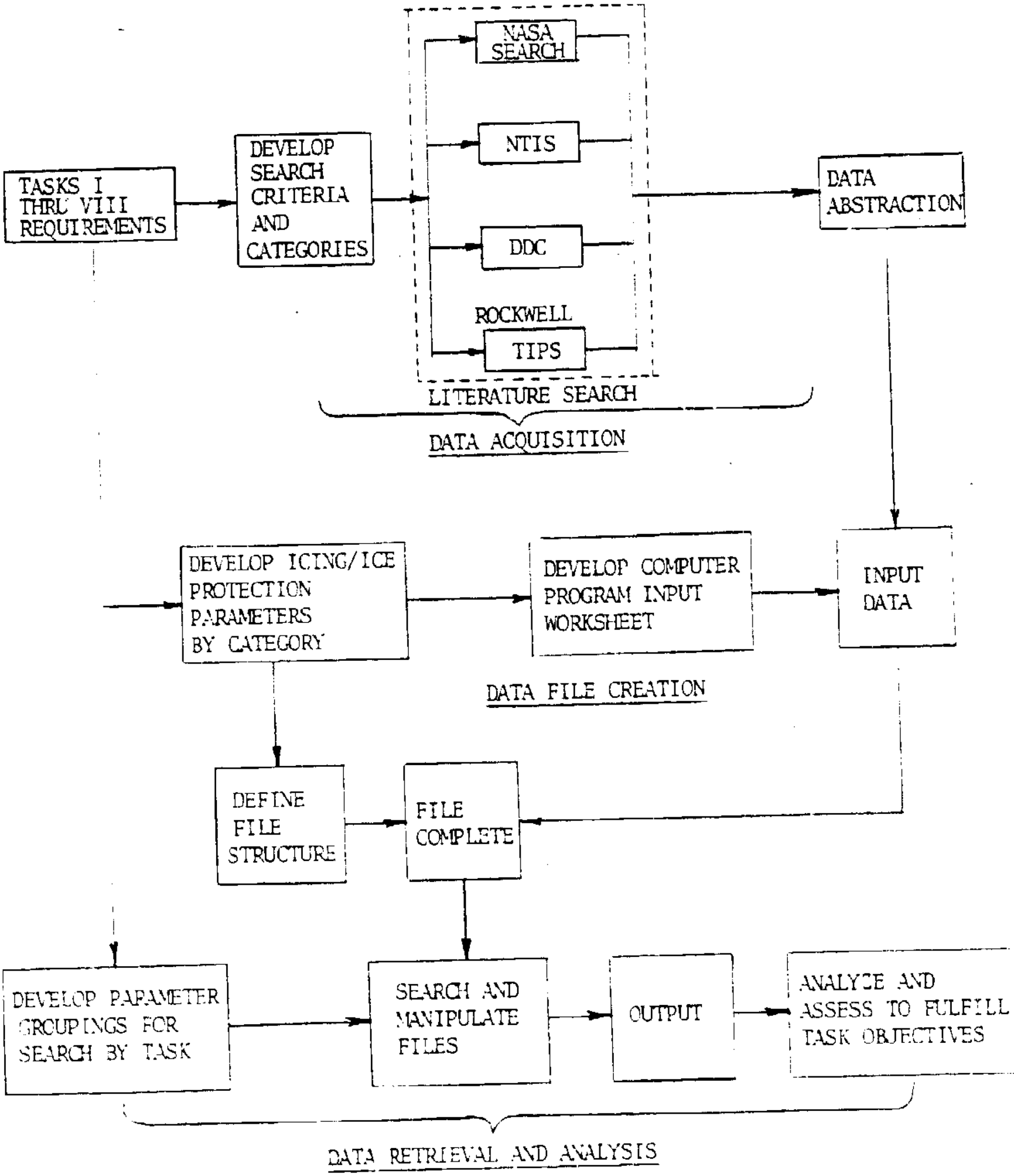

Figure 7. Use of Data Management to Accomplish Tasks

The major objectives of the survey/questionnaire were threefold, as follows:

1. To solicit the latest up-to-the-minute information on many different aspects of icing technology including ice protection system design and operational techniques used by the general aviation aircraft industry and related Government agencies.

2. To solicit the views, comments and recommendations from the experts in industry and Government, concerned with icing problems and their resolution.

3. To give the icing technology experts in industry and Government an opportunity to voice their concerns relating to icing and icing protection and to influence the direction of future NASA research. These inputs would allow the reflection of the broader view of the general aviation industry in the recommendations given to NASA for short and long term research plans.

A copy of the survey/questionnaire and the letter of transmittal sent to industry and Government agencies is contained within the report in Appendix D. The survey/questionnaire was sent to eight Government agencies and fifty-two general aviation aircraft companies and universities.

The questions in the survey were grouped into eight basic sections dealing with:

1. Ice Protection Systems

2. Ice Protection Penalties

3. Propulsion System Icing

4. Airframe Icing

5. Testing Techniques

6. Calculation Techniques

7. Weather Data

8. Final Recommendations

These eight sections went right to the heart of the important material of the study program in an effort, not only to obtain the most current information available from those experts from industry and Government agencies working in the aircraft icing field, but in the case of penalties data, to obtain data not readily available in the general literature. An initial review of the literature obtained in the study program indicated that there was only a limited amount of icing, icing component, or anti-icing system penalty data available in usable form. Anti-icing protection system penalty data is usually aircraft model oriented and system oriented rather than anti-iced component oriented.

Also noted in the general literature was a lack of specific data base information regarding specific computer codes used for analysis. This may, of course, be due to the proprietary nature of many computer programs developed in the private industry sector. Specific information on data base was requested, not only to obtain direct and current information on the subject, but also due to the fact that in much of the literature reviewed the data base was poorly defined or merely inferred.

Each questionnaire was sent out with a letter of transmittal. Two basic letters were used, differing only in one or two sentences depending upon whether the letter was being sent to a representative of the aviation industry or to a Government agency. In general, the questionnaires were not necessarily sent directly to the icing expert, but to a company official who would be in a position to see that any information presented was in accordance with the individual company policies.

Approximately 35 percent of the companies, universities, and Government agencies receiving the questionnaire responded. A list of the respondents is shown in table II, which indicates that a good cross section of both industry and Government contributed generously to the program.

Penalty data presented in the responses were in the form of tabulations on ice protection systems and components. Most of the data were relative ranking of penalties with respect to the various aircraft models listed. All of the other data presented were primarily in the form of written answers to the specific questions. Most organizations were extremely helpful by presenting their answers directly in the same format as they were asked.

The information from the survey was carefully evaluated and then folded into the applicable sections of the report. Since many of the respondents presented similar answers and ideas to many of the same question , no attempt was made to single out an individual in the body of the report for credits. Rather, a summary of the data and information from an evaluation of the survey was assembled and is presented in Appendix E of the report.

TABLE II

LOG OF QUESTIONNAIRE RESPONSES

DATE RECEIVED	FIRM	TYPE
06/11/80	Rockwell, General Aviation Division	Aircraft
07/28/80	Key Industries Corporation	Systems, Operations
08/01/80	Teledyne-Ryan Aeronautical	Systems, Operations
08/01/80	General Dynamics, Convair Division	Aircraft
08/07/80	Cessna Aircraft	Aircraft
08/11/80	Crew Systems Consultants	Systmes, Operations
08/14/80	Gulfstream American	Aircraft
08/14/80	AiResearch Mfg. Co. of Arizona	Engines
08/15/80	Bendix Avionics Division	Systems, Operations
08/15/80	Beech Aircraft Corporation	Aircraft
08/15/80	University of Kansas	University
08/12/80	Dept. of Transportation, FAA	Government
08/22/80	B. F. Goodrich	Systems, Operations
08/22/80	A. F. Wright Aeronautical Labs	Government
08/29/80	Lockheed-Georgia Company	Aircraft
09/02/80	AVCO-Lycoming Division	Engines
09/03/80	Piper Aircraft Corp., Lakeland Division	Aircraft
09/08/80	Detroit Diesel Allison	Engines
09/11/80	NASA, Marshal Space Flight Center (MSFC)	Government
09/16/80	Douglas Aircraft Company	Aircraft
10/20/80	Piper Aircraft Corp., Santa Maria, Calif.	Aircraft
12/04/80	Boeing Commercial Airplane, Co., Seattle, Washington	Aircraft
12/04/80	The De Havilland Aircraft of Canada, Ontario, Canada	Aircraft

Section IV

TECHNICAL DISCUSSION OF TASKS

In the following technical discussions, are the assessments and evaluations of the many facets of icing technology referred to in the specific program study tasks. It was the considered opinion of both NASA and Rockwell that these assessments and evaluations would play a very necessary part in the development of the requirements for a short term and long term icing research program.

ICE SENSITIVE COMPONENT CATEGORIZATION (TASK 1)

The logical first task requirement in this program was to identify and list all light transport and general aviation aircraft components which are ice sensitive, particularly those which need to be considered with respect to ice protection. Ice sensitive refers to those components which:

1. Accumulate ice in the presence of an icing conducive atmosphere.

2. Are "problem oriented" with respect to aircraft performance, safety, maintenance, design cost, life cycle cost, or other type of penalty.

The ice sensitive component list developed for the study program is one of the primary codes for the data file and is shown in its entirety in Appendix B as the first table in the series of 15 "lookup" tables. This code list not only lists the ice sensitive component but also gives answers to the following questions for each component.

1. Where and/or how does the ice form?

2. When does the ice form?

3. Is it a problem? Why?

The list is considered quite definitive and was updated several times during the program. The component list is the basis for all of the other tasks of the program. Each succeeding task concerns all, or at least several of the components on the list, depending upon the technology subject and the availability of the data.

Table III is a matrix of components versus ice protection methods. The components are listed under several general titles which divide them into natural categories as follows: jet engines, fan jet (engines), turboprop (engines), piston engines, aircraft instruments (flight), fuselage, tail surfaces (empennage), and wings.

TABLE III

MATRIX OF COMPONENTS VS ICE PROTECTION METHODS

CODE: 1 Continuous
2 Cyclic
3 Intermittent
4 "One-Shot"

COMPONENT	ICE-PROTECTION METHOD: HOT AIR: INTERNAL	HOT AIR: EXTERNAL - BNDRY LAYER POROUS	ELEC.: INTERNAL	ELEC.: EXTERNAL	FLUID: ALCOHOLS, GYLCERIN	FLUID: 'TKS' SYSTEM	FLUID: OIL (HOT ENGINE)	FLUID: FUEL ADDITIVE	OTHER: PNEUMATIC	OTHER: ACOUSTIC	OTHER: MICROWAVE	OTHER: ICEPHOBICS	OTHER: VIBRATORY
JET ENGINES													
1. Main Inlet	1		1						2,3				
2. Blow In Doors													
3. Inlet Noise Suppression													
4. Nose Caps	1			1									
5. Screens													
6. Inlet Guide Vanes	1												
7. Rotor Blades	1												
8. Frame Struts	1						1						
FAN JET													
Items 1 To 4 And 6 To 7 From Jet Engines													
Fan	1												
Bypass													
TURBOPROP													
Items 1, 4, And 6 To 8 From Jet Engines													
Particle Separators	1			1									
Screens													
Pull Propellers				1,2	3							1	
Push Propellers				1,2	3							1	
Engine Cowling	1			1,2									
PISTON ENGINES													
Carburetor							1	1					
Pull Propellers				1,2	3							1	
Push Propellers				1,2	3							1	
Engine Cowling	1												

TABLE III MATRIX OF COMPONENTS VS ICE PROTECTION METHODS
(continued)

CODE: 1 Continuous
2 Cyclic
3 Intermittent
4 "One-Shot"

COMPONENT	ICE-PROTECTION METHOD: HOT AIR		ELEC.		FLUID				OTHER				
	INTERNAL	EXTERNAL - BNDRY LAYER POROUS	INTERNAL	EXTERNAL	ALCOHOLS, GYLERIN	'TKS' SYSTEM	OIL (HOT ENGINE)	FUEL ADDITIVE	PNEUMATIC	ACOUSTIC	MICROWAVE	ICEPHOBICS	VIBRATORY
A/C INSTRUMENTS													
Pitot Static Tube			1										
Alt. Rate-of-Climb Orifice			1										
Yaw Vanes			1										
Total Head Probe			1										
Total Temp Probe			1,2										
FUSELAGE													
Windshield	1	1	1		3	3							
Wing/Fuselage Juncture	1,2												
Static Vents													
Scoops				1									
Drains													
Other Junctures													
Antennas													
Radomes	1	1			3	3							
Electro-Optical Transpar.			1										
TAIL SURFACES													
Horizontal, Elevator	1,2,3,4			1,2	3	3			2,3				
Vertical, Rudder	↓			1,2	3	3			2,3				
T-Tail	↓												
V-Tail	↓												
WINGS													
Swept, Straight	1,2,3			1,2	3	3			2,3	3	3		3
Ailerons													
Flaps													
Slats	1,2,3												
Slots													
Fences & Vortex Gen.			1,2										
Canard	1,2,3			1,2									

The ice protection method or methods used with each of the ice sensitive components is shown on the matrix and is discussed in the next section of the report. The effects of ice on the unheated components and the penalties associated with the ice protection systems are the subjects of discussion in subsequent sections of the report.

ICE PROTECTION METHODS CATEGORIZATION (TASK 2)

Ice protection methods for the ice sensitive components identified for Task I were itemized and utilized for the matrix of combinations shown in table III. A list of all of the various ice protection methods currently used or in research and development stages have been included in the second table of Appendix B. There is a computer file code number for each method and there is a column parameter established for the code in the data file.

The ice protection methods shown in the matrix of table III have been further detailed in that they have been coded to indicate the type of system such as continuous, cyclic, intermittent, or "one shot," that are normally used for a specific component.

In general, ice protection systems fall into the following categories:

1. Hot Air

2. Electrical

3. Fluid

4. Pneumatic

5. Other (Acoustic, Microwave, Vibratory, Icephobics)

The first four categories are in common use today and have been for some time in the past. The systems under the heading "other" are still in the conceptual and/or research and development stages.

All of these categories of systems fall into one or both of two possible types of protection systems: (1) deicing systems, or (2) anti-icing systems. Deicing refers to the removal of ice accretion after it has built up. Deicing can be accomplished by any of the categories of systems listed. Anti-icing refers to the prevention of ice formation before it can start to build up. In general, anti-icing can only be accomplished by the first three categories of systems, basically fluid or thermal means. It may be noted here that all of the new conceptual and research and development systems are deicing system types. This is not considered unusual since one of the main concerns is to reduce the power requirements of these new systems. Deicing systems, by the nature of their operational characteristics, which are always intermittent, use less power than anti-icing systems.

Descriptions and discussions of the conventional methods of ice protection and of ice protection systems may be found in many of the documents listed in the bibliography of references herein. In particular, references 75, 105, and 108 contain design data, descriptions and discussions of both deicing and anti-icing systems.

COMPONENT AND ICE PROTECTION METHOD PENALTY ASSESSMENT AND EVALUATION (TASK 3)

GENERAL

The objectives of this section are to identify ice protection systems and related factors which have the greatest payoff for improving the icing condition operational capability of general aviation and light transport aircraft.

In order to achieve the objectives that are desired, an assessment of the penalties associated with the ice sensitive aircraft components and the ice protection systems utilized or contemplated for these components was made insofar as data were available. A literature search was conducted to obtain data with respect to penalty data associated with the ice sensitive components or ice protection systems. Five lines (12 through 16) were allowed for penalty associated data on the computerized master file computer code form. Questions and fill-in charts were included with the industry/Government survey questionnaire in order to solicit the desired information from general aviation aircraft manufacturers, universities, and experts in Government agencies associated with aircraft icing problems and technology.

The literature search was conducted for penalty factors which concerned both unprotected aircraft ice sensitive components and ice protection systems such as the following:

1. Power Requirements
2. Initial Cost
3. Maintenance Time and Costs
4. Impact on Aircraft Performance
    a. Aerodynamics, ΔC_D, ΔC_L, Stall Speed, etc.
    b. Weight
    c. Range/Payload
    d. Speeds, Maximum, Cruise, etc.
5. Reliability
6. Safety

The literature search was disappointing in that very little information on penalties is published in the general literature, particularly under the general title of component penalties. Certain types of information, such as electrical power requirements and heat requirements can be extracted from published analyses made on specific systems for specific aircraft. However, specific penalties such as electrical power required or heat required (which is sometimes translated into an engine bleed air flow available) are difficult to assign a relative ranking because they are intimately involved with the type, size, and capabilities of the specific aircraft/engine type involved. The ice protection system requirement for a particular ice sensitive component which may impose a severe penalty to one type of aircraft may impose only a minor penalty to another type of aircraft.

It is logical, then, to make penalty assessments on a basis of ice protection system(s) for a specific aircraft and/or type of aircraft where ice protection systems are provided and data are available. Different kinds of ice protection systems for the same ice sensitive component are evaluated with respect to each other. The same logic holds true with respect to ice accretion on unprotected components regarding the impact on aircraft aerodynamic performance. The impact of icing on aircraft performance due to icing of unheated surfaces such as the leading edges of the wings, horizontal and vertical stabilizers, wing struts, engine cowl propeller, etc. is in the form of increased drag, reduced lift and rate of climb, and increased stall speed. Flight tests have indicated that only 1/4 inch of glaze ice on the leading edges of the wing can reduce climb speed by 300 fpm (reference 1). This same reference indicates that wing icing can contribute 40 to 60 percent of the total icing drag on an airplane. Propeller efficiency on a typical G/A aircraft can be reduced by as much as 10 to 19 percent (reference 1 and NACA TN 1598) by ice buildups. For business jet type aircraft with new wing (approximating supercritical) cross sections, less than 1/4 inch of ice on the leading edge "hi-lite" or stagnation point can increase the stall speed by 10-15 knots. Propeller driven G/A aircraft also exhibit the same 10-15 knot stall speed increase for 1/8 to 1/4 inch ice buildup on the wing leading edge. Icing accretions on the engine cowl, aircraft nose, miscellaneous antenna, and other protuberances can contribute as much as 20-25 percent of the total increased drag due to aircraft icing.

Recent tests with simulated ice representing 10 minutes of moderate (0.5 gms/m^3) icing on the leading edges of the Sabreliner 65 wing, increased the stall speed by 15 knots. Although handling qualities of the aircraft were very satisfactory, some buffeting was experienced with the ice shapes.

Data on a JU-21D aircraft taken from reference 41 indicate that at 170 KCAS, an ice accumulation of 0.5 to 1.0 inches (moderate icing) on the flight surface leading edges will result in a 20-30 knot loss in speed at the same power setting.

A very excellent study of the effects of simulated hoar frost and ice on three basic wing configurations of the NACA 65A215 wing section is contained in reference 53 by Sundberg and Trunov. Figure 8, taken from reference 53, shows the effect of simulated hoar frost on maximum lift. The loss in C_{Lmax} can be greatly reduced by cleaning the first 18 percent of the chord. The effects on maximum lift and cruise drag of simulated large leading edge ice shapes considered of importance for light aircraft are shown in figure 9, taken from reference 53. The effects on $C_L(\alpha)$ and C_{Lmax} of ice shapes simulating cruise conditions for no flap and for trailing edge flaps extended are shown in figures 10 and 11, taken from reference 53. A third configuration with leading edge slats was tested, but is not shown here since most all general aviation aircraft and most light transports do not use leading edge slats, whereas, many use flaps of one type or another. Of key interest in these figures, is the fact that the big reduction in $C_L(\alpha)$ or C_{Lmax} at the higher angles of attack occurs with a minimum accretion (hoar frost simulation) and increase somewhat from that point. At low angles of attack for the no flap configuration and at negative angles of attack for the flaps extended configuration, very little change occurs in $C_L(\alpha)$ or C_{Lmax} for any of the simulated ice shapes. For sustained exposure to icing conditions, an aircraft loitering with a relatively high angle of attack must have an ice protection system that keeps the flight surfaces relatively clean in order for the system to be effective.

RELATIVE PENALTIES DUE TO EFFECTS OF ICING/ICE PROTECTION SYSTEMS

Data from the results of the questionnaire were reviewed and selected penalty data on the icing effects on aircraft or components or penalties due to ice protection systems were tabulated. Table IV lists the aircraft penalties and table V the components, by the manufacturer's name, aircraft model, and by component name. The penalties are given a relative ranking as: (1) severe penalty, (2) moderate penalty, and (3) small penalty. The majority of the rankings for both total aircraft and components were either moderate or small. The only severe penalties were related to the effects of icing of wing leading edge surfaces.

Table VI is a penalty assessment of the protection systems based on data from the results of the survey/questionnaire. Penalty rankings are given for both aircraft and components in terms of power, cost, weight, range reduction, etc. The table lists the data by the manufacturer's name and aircraft name and/or model number. In some instances, actual values for the power or engine bleed data are given.

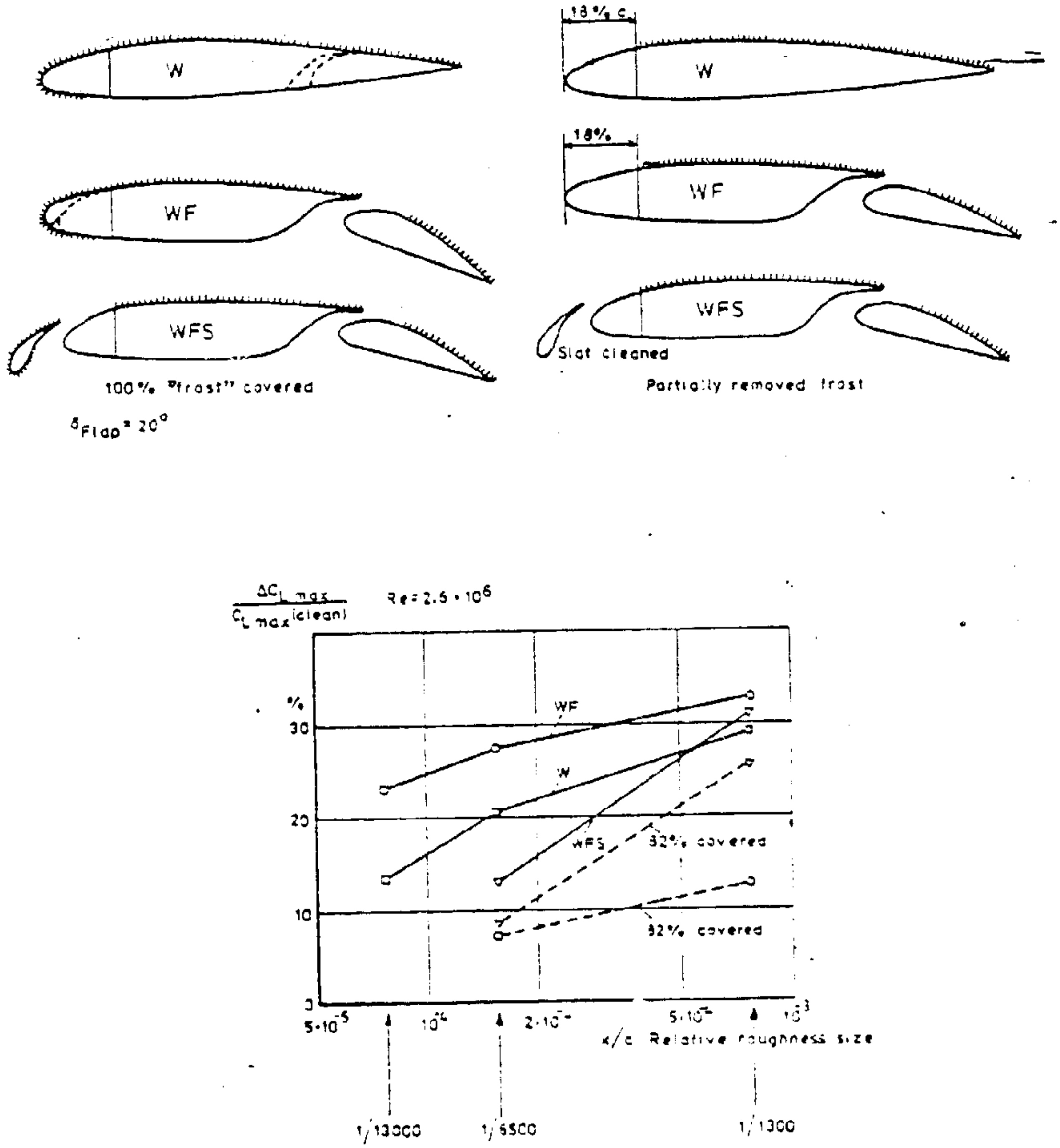

Figure 8. Effect of Simulated Hoar Frost on the Maximum Lift for NACA 65 A 215 Wing Section, From Reference 53

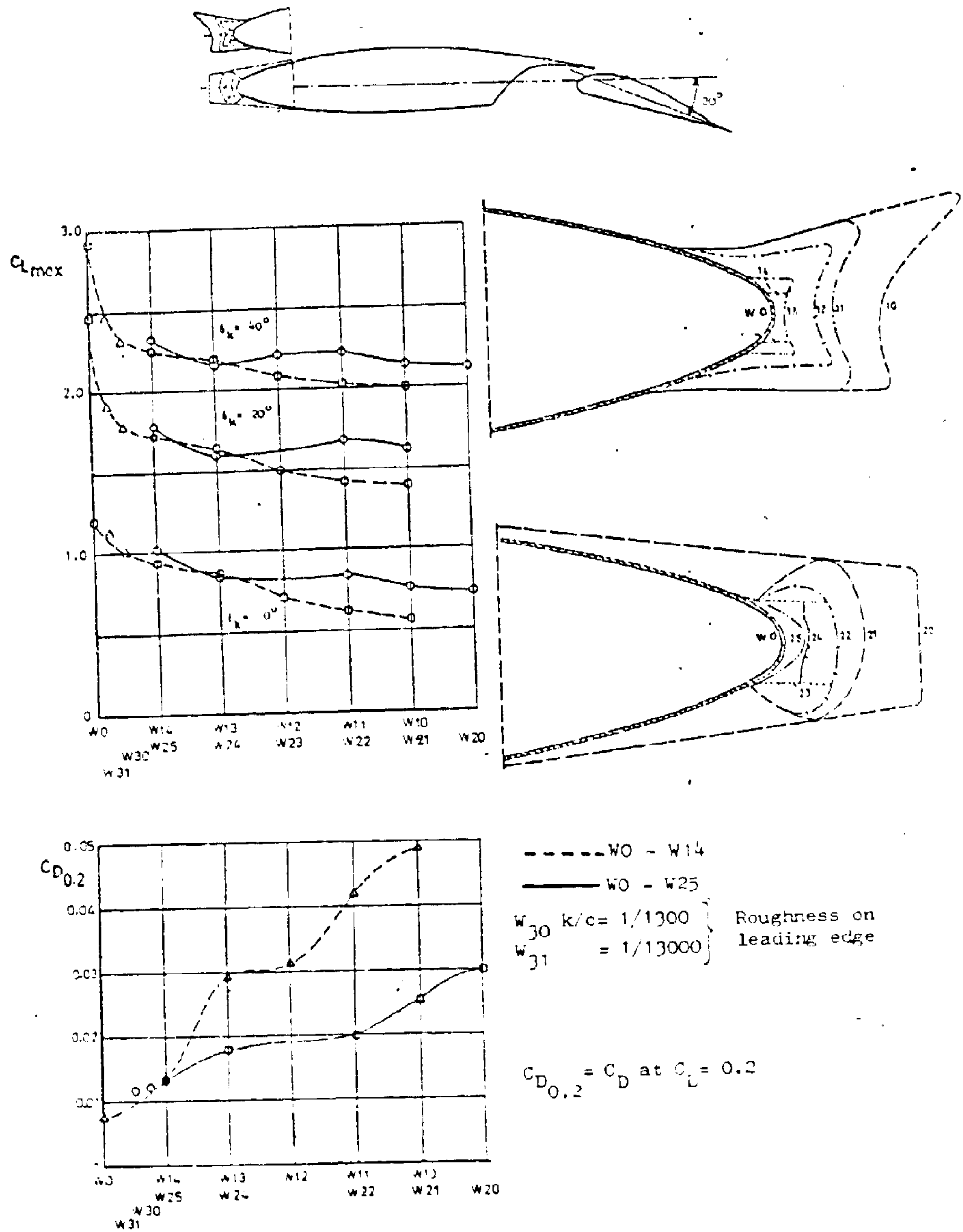

Figure 9. Effects on Maximum Lift and Cruise Drag of Simulated Large Leading Edge Ice Shapes Considered of Importance for Light A/C. Ref 55

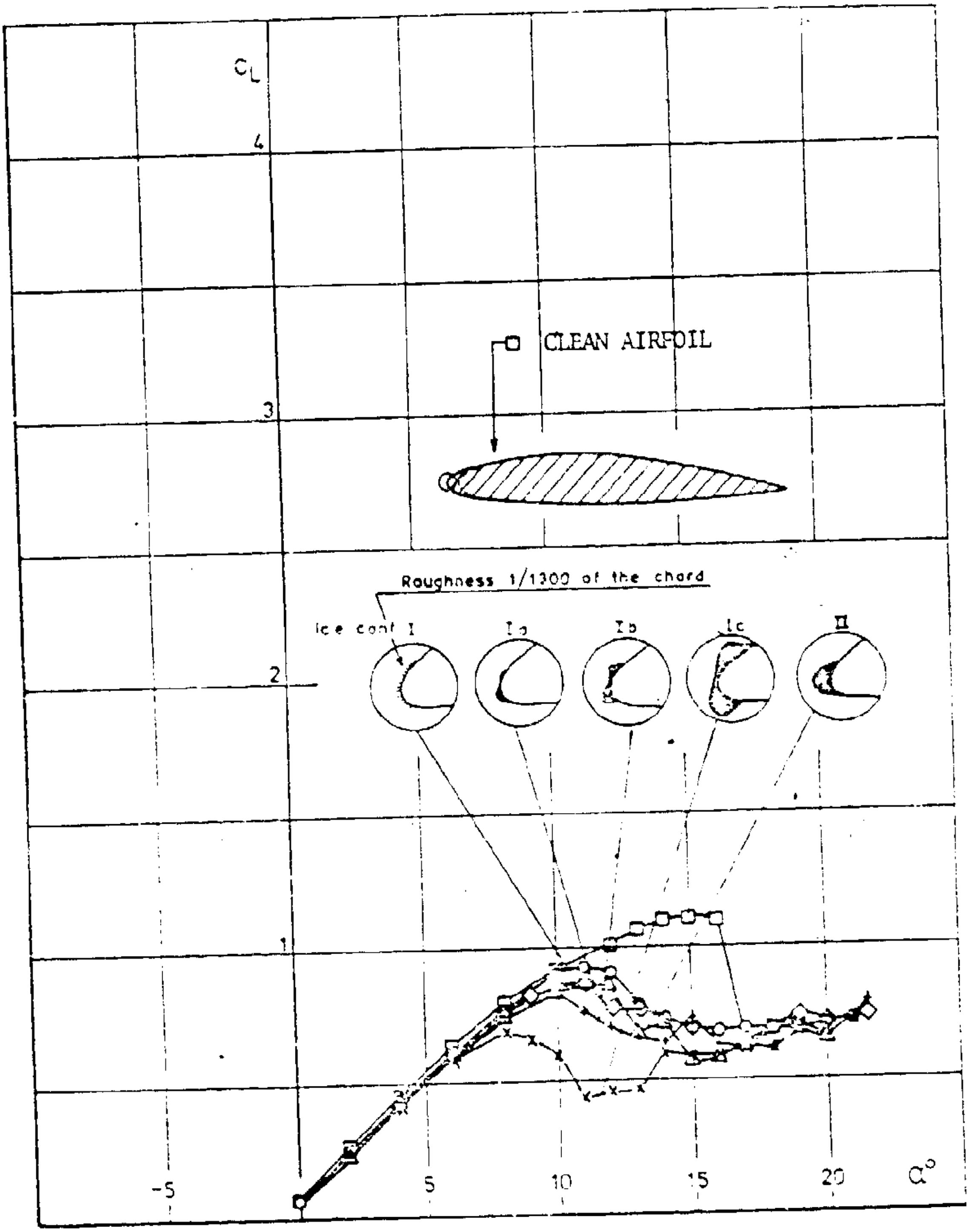

Figure 10. The Effect on C_L α and $C_{L\,max}$ of Ice Shapes From the Icing Tunnel Corresponding to Icing in Cruise for the No Flap Configuration, Ref 53

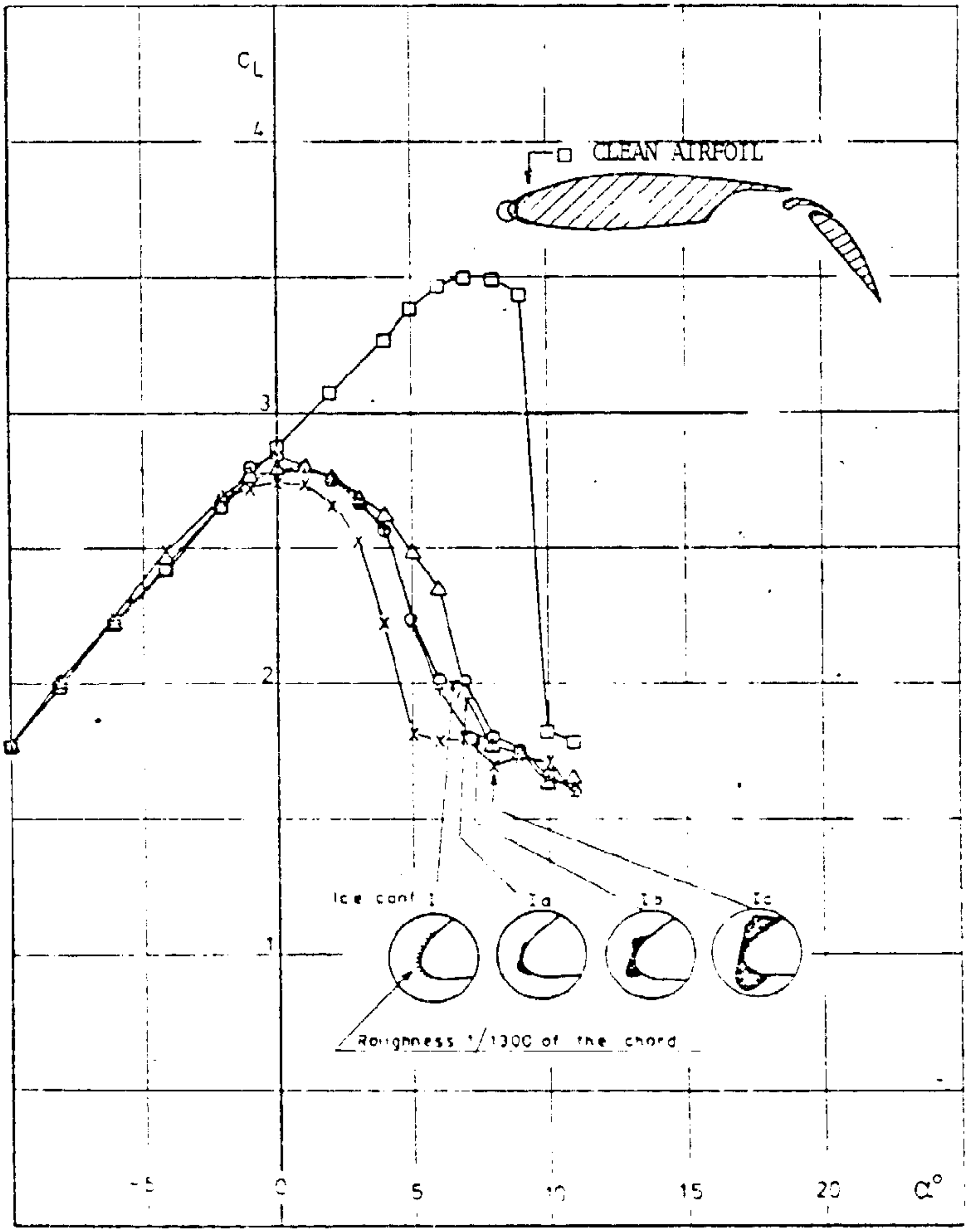

Figure 11. The Effect on $C_L(\alpha)$ and $C_{L\,max}$ of Ice Shapes From the Icing Tunnel Corresponding to Icing in Cruise but With Trailing Edge Flap Extended, Ref 53

TABLE IV

II.1 PENALTIES OF ICING EFFECTS ON AIRCRAFT BY MODEL

AIRCRAFT OR COMPONENT	PENALTIES DUE TO ICING Use Actual Values or Relative Penalties: 1=Severe Penalty; 2=Moderate; 3=Small						
	WT	Δ MAX SPEED	Δ LIFT	Δ DRAG	Δ STALL SPEED	Δ RANGE	SAFETY
ROCKWELL							
Model 700	2	1	2	1	1	1	2
Model 690 Series	3	2	1	2	1	2	2
CESSNA							
CE-441	2	2	2	2	2	2	2
CE-500	2	2	2	2	2	2	2
CE-550	2	2	2	2	2	2	2
Engine Pylons, Wing Fillet, Wing Tip, Radome	In general detailed research on these unprotected areas needs to be accomplished in all areas of question 5 in Section IV.						
Antennas: VOR/LOC GS, ADF (sense & Loop) UHF, VLF/OMEGA	More research on performance penalties required.						
Cessna 421	2*	2	2	2	2	2	2
Wing & Empennage Boots	3						
Prop Deice Boots	3						
Heated W/S	3						
Heated Pitot	3						
Heated Stall Vane	3						
All unprotected surfaces including nose caps, nacelles, wing tips,	Very little information available on performance degradation due to ice accumulation.						
*Each component by itself has a small wt penalty but with them combined the wt penalty becomes significant.							
GULFSTREAM AMERICAN							
Gulfstream II/III	3	2	2	2	2	3	3
Gulfstream I/IC	3	2	2	2	2	3	3
PIPER							
PA31T Series	3	3	3	2	2	2	3
DETROIT-ALLISON							
T56 501 Engine	3	3	-	-	-	3	2
T63 250 Engine	3	3	-	-	-	3	2

TABLE V

II.1 PENALTIES OF ICING EFFECTS ON AIRCRAFT BY COMPONENTS

AIRCRAFT OR COMPONENT	PENALTIES DUE TO ICING ASSUME NO ICE PROTECTION Use Actual Values or Relative Penalties: 1=Severe Penalty; 2=Moderate; 3=Small						
	WT	Δ MAX SPEED	Δ LIFT	Δ DRAG	Δ STALL SPEED	Δ RANGE	SAFETY
BEECH							
Wing Surface	1	1	1	1	1	1	1
Tail Surface	3	3	3	2	3	3	2
Engine Inlets	3	1*	3	3	3	1	1
Windshield	3	3	3	3	3	3	2
Radome	3	3	3	3	3	3	3
Propeller	3	2	3	3	-	-	2
Antenna	3	3	3	3	3	3	2
Control Surface Balance Horn	3	3	3	3	3	3	1
*Considers the potential of engine loss. All relative penalties assume no ice protection.							
NASA - MSFC							
Frost on Airfoil				2	2		2
DOUGLAS AIRCRAFT							
Horizontal Tail		3	3(A)	3	3(A)	3	3(A)
Vertical Tail		3	3	3	3	3	3
Inboard Span of Wing		3	2-3(B)	3	2-3(B)	3	2-3(B)
Pylon		3	3	3	3	3	3
Flap Hinge Fairings		3	3	3	3	3	3
Wing Tips		3	3	3	3	3	3
Miscellaneous Antenna & Lights		3	3	3	3	3	3(C)
Outer Wing Panels		3	1	2	1	2	1
Gear Extended		2	3	2	3	2	3
(A) If designed to include ice effects, if not the penalties are severe.							
(B) Strong function of spanwise extent and leading edge geometry.							
(C) If shed ice clears aircraft.							
TELEDYNE-RYAN AERO							
Wings	2	1	1	1	1	2	2
Carburetion	2	1	-	-	-	1	1

TABLE VI

II.2 PENALTY ASSESSMENT OF THE PROTECTION SYSTEMS

List Aircraft and Check Components Protected From Icing
Note Actual or Relative Penalties of Individual Components or for Total Aircraft

	CHECK COMPONENTS THAT ARE ANTI-ICED/DEICED										ANTI-ICING SYSTEM PENALTIES OF INDIVIDUAL COMPONENTS FOR TOTAL AIRCRAFT — Use Actual Values or Relative Ranking: 1 = Severe Penalty to Aircraft; 2 = Moderate; 3 = Small						
AIRCRAFT TYPE, NAME, OR MODEL	WINDSHIELD	WING LEADING EDGE	TAIL LEADING EDGE	PROPELLER	ENGINE INLET	NACELLE	PITOT	ICE DETECTOR	BALANCE HORN	OTHER	POWER REQD BY SYSTEM	INITIAL COST	WEIGHT	RANGE REDUCTION IMPACT	CRUISE SPEED IMPACT	MAX SPEED IMPACT	RELIABILITY IMPACT
ROCKWELL																	
Sabreliner 65	X	X			X	X	X				3	2	2	3	3	3	3
Sabreliner by Component	X										~3100 watts						
		X									1% eng bleed						
						X					2% eng bleed	2	3				
Model 700	X	X	X	X			X					3	2	2	3	3	3
Model 690 Series	X	X	X	X	X		X		X			3	2	2	3	3	3
PIPER AIRCRAFT																	
Cheyenne I & II	X	X	X	X	X		X		X	X	3 watts	2	3	2	2	2	3
By Component	X										350 W						
		X									---	2	3	2	2	2	3
			X								---	2	3	2	2	2	3
				X							900 W	2	3	2	2	2	3
					X						900 W	2	3	3	3	3	2
							X				25 W	2	3	3	3	3	3
									X		---	3	3	3	3	3	3
										X	25 W	3	3	3	3	3	3
Piper Aerostar Model 600 Series	X	X	X	X			X				1271 W	2	3	3	3	3	3
By Component	X										431 W	2	3	3	2	3	2
		X									---	2	2	3	3	3	3
			X								---	2	2	3	3	3	3
				X							504 W	2	2	3	3	3	3
							X				336 W	2	3	3	3	3	3
DETROIT ALLISON																	
T56/501 Engine					X						2	2	3	2	3	3	2
T56/501 Engine					X						3% bleed						
T63/250 Engine					X						2	2	2	2	3	3	2
T63/250 Engine					X						12% bleed						
*250-C30 Engine					X						4% bleed						
*Latest production model 250 engine with 9:1 pressure ratio (earlier models = 7:1)																	
DOUGLAS AIRCRAFT																	
DC-9 & DC-10	X										3	2	3	3	3	3	2
		X									2	2	2	3	3	3	3
(DC-9 Only)			X								3	2	2	3	3	3	3
					X						2	2	2	3	3	3	3
						X					3	3	3	3	3	3	3
							X				3	3	3	3	3	3	3
								X			3	3	3	3	3	3	3
(Misc. Antenna)										X	3	3	3	3	3	3	3
LOCKHEED - GEORGIA																	
Jet Star	X	X	X		X	X	X										
Jet Star II	X	X				X	X										
	X																
		X									Boots	2	2	3	3	3	3
						X					3% bleed	2	2	2	3	3	2
C-141	X	X	X		X	X	X	X									
C-5	X				X	X	X	X									
C-130	X	X	X	X	X	X	X	X									

TABLE VI (continued)

II.2 PENALTY ASSESSMENT OF THE PROTECTION SYSTEMS

List Aircraft and Check Components Protected From Icing
Note Actual or Relative Penalties of Individual Components or for Total Aircraft

AIRCRAFT TYPE, NAME, OR MODEL	CHECK COMPONENTS THAT ARE ANTI-ICED/DEICED: WINDSHIELD	WING LEADING EDGE	TAIL LEADING EDGE	PROPELLER	ENGINE INLET	NACELLE	PITOT	ICE DETECTOR	BALANCE HORN	OTHER	ANTI-ICING SYSTEM PENALTIES OF INDIVIDUAL COMPONENTS FOR TOTAL AIRCRAFT (Use Actual Values or Relative Ranking: 1 = Severe Penalty to Aircraft; 2 = Moderate; 3 = Small): POWER REQD BY SYSTEM	INITIAL COST	WEIGHT	RANGE REDUCTION IMPACT	CRUISE SPEED IMPACT	MAX SPEED IMPACT	RELIABILITY IMPACT
CESSNA																	
Citation I & II	X	X	X	NA	X	X	X				3	2	2	3	3	3	2
	X										2% eng bleed						
		X									7557 watts						
		X	X								<1% eng bleed						
					X	X					2% eng bleed						
Conquest (CE-441)	X	X	X	X	X		X				3	2	2	3	3	3	2
	X										3% eng bleed						
		X	X								<1% eng bleed						
				X							234 watts						
					X						2% eng bleed						
Cessna 421	X	X	X	X			X				3	2	2	3	3	3	2
	X										*1470 watts						
		X	X								3						
				X							3						
							X				3						
*Installation of the windshield requires 100 amp alternators versus 50 amp alternators. With typical aircraft delivered 100 amp alternators are required ∴ increased electrical loads are not significant.																	
GULFSTREAM AMERICAN																	
Gulfstream II/III	X	X				X	X	X			3	2	3	3	3	3	3
Gulfstream I/IC	X	X	X	X	X		X				3	2	3	3	3	3	3
BEECH																	
58P, 58TC, 60	X	X	X	X	X		X			X	3	3	2	2	2	2	2
*Ditto by Component	X										3	2	3	3	3	3	2
		X									3	3	2	3	3	3	2
			X								3	3	2	3	3	3	2
				X							3	2	3	3	3	3	3
					X						3	2	3	2-3	2-3	2-3	3
							X				3	3	3	3	3	3	3
										X	3	3	3	3	3	3	3
C90, E90, F90, A100	X	X	X	X	X		X			X	2	2	2	2	1	1	2
*Ditto by Component	X										3	2	3	3	3	3	2
		X									3	3	2	3	3	3	2
			X								3	3	2	3	3	3	2
				X							3	2	3	3	3	3	3
					X						2	2	2-3	2	1	1	2-3
							X				3	3	3	3	3	3	3
										X	3	3	3	3	3	3	3
*200 by Component					X						2	2	2	2	1	1	3
*The Model 200 is the same as Models C90, E90, F90, and A100 except the inlet lip on the Model 200 is heated by engine exhaust where the other models have an electric heated inlet lip.																	
B100	X	X	X	X	X		X			X	2	2	2	2	2	2	2
Ditto by Component	X										3	2	3	3	3	3	2
		X									3	3	2	3	3	3	2
			X								3	3	2	3	3	3	2
				X							3	2	2	3	3	3	3
					X						2	2	3	2	2	2	3
							X				3	3	3	3	3	3	3
										X	3	3	3	3	3	3	3

ICE PROTECTION SYSTEM WEIGHT PENALTY

Ice protection system weight depends upon the type of system used, the ice sensitive components protected, the extent or area of each component protected and the design of each protective system that is provided.

It has been found that in general the ice protection system weight of all aircraft except large wide body transports ranges from 0.2 to 1.5 percent of the vehicle empty weight. This ice protection system weight for piston engine aircraft ranges from 0.6 to 1.0 percent of the aircraft takeoff weight. Also, it has been calculated that in general, ice protection systems weigh in the order of 0.4 to 1.6 pounds per square foot of protected area (reference 102).

Because of the discrepancies in the "bookkeeping" used to assign ice protection system weights and those associated systems weight that may have a portion attributed to ice protection, exact weights are sometimes difficult to come by.

In percentage ratios of ice protection system weight to aircraft weight from heaviest to lightest, the sequence is as follows:

1. General Aviation (Piston or Turboprop Engines)
2. Business Jets
3. ASW Patrols and Trainers
4. Commercial Transports and Helicopters
5. Fighters and Bombers
6. Jumbojets

A survey was made of general aviation and light transport aircraft to determine the weight of the standard or optional ice protection systems used on each aircraft. Each aircraft chosen was representative of a particular class of aircraft. In figure 12, the ice protection system weights are plotted against the aircraft total gross weight for each type of aircraft for which data were available. Table VI presents in code form, the protection systems which were used to determine these weights, and table VII defines these codes, giving the type of system and component protected.

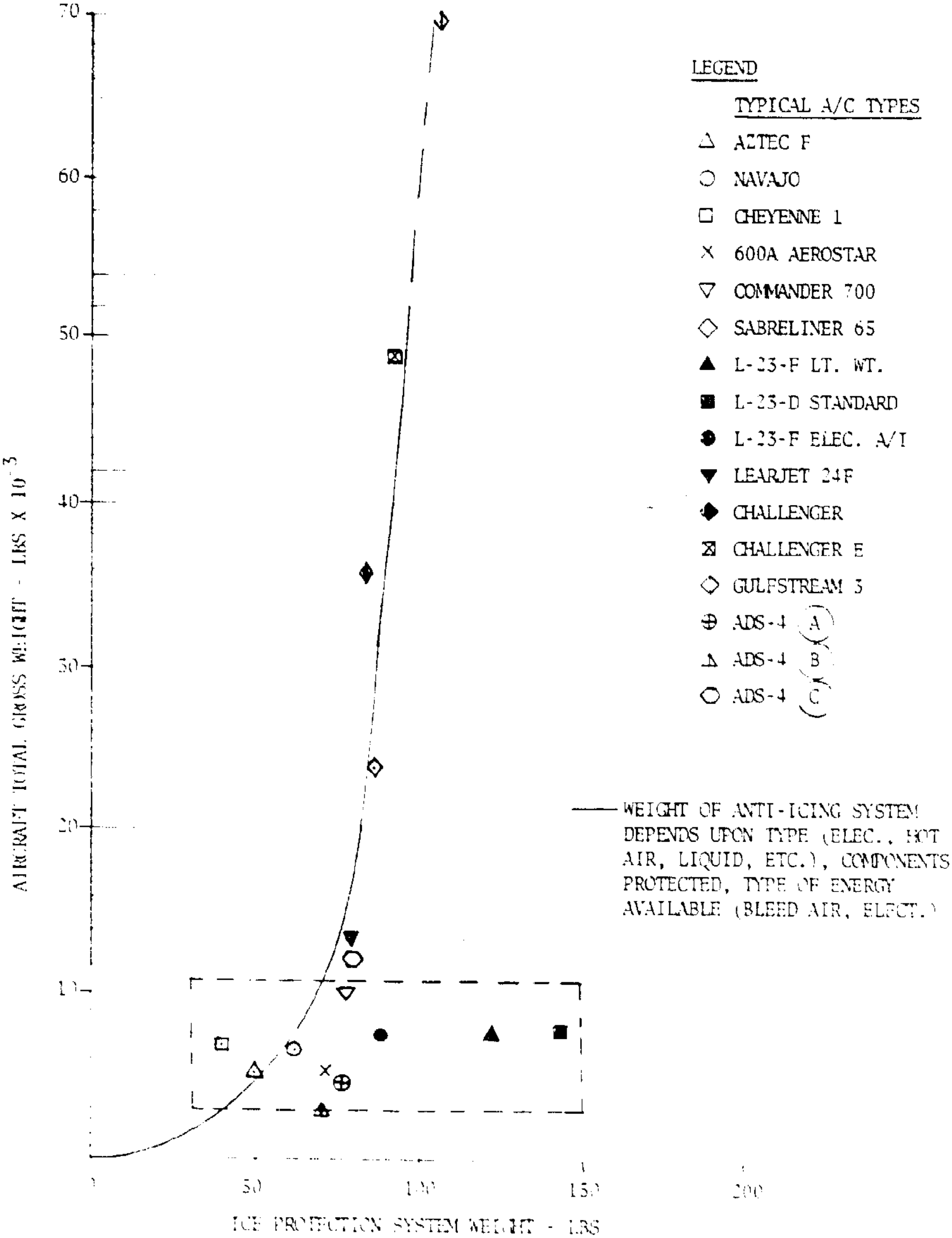

Figure 12. Ice Protection System Weight Penalty

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TABLE VII

AIRCRAFT TYPE (TYPICAL EXAMPLES OF WEIGHT CLASS)

NO.	SYMBOL	MANUFACTURER - NAME	ICE PROTECTION SYSTEM CODES (See Table VIII)	IPS WT (lbs)
1	△	Piper - Aztec F	BW,EW/S,EP	48.8
2	○	Piper - Navajo	HDF,EW/S,WW,BW,BV,BH,EP	62.0
3	□	Piper - Cheyenne 1	BW,BH,BV,Lights	39.4
4	×	Piper - 600A Aerostar	HDF,BW,BH,BV,EP,EW/S,EPT, Lights	73.9
5	▽	Rockwell - Commander 700	EW/S,EPT,EP,WW,BW,BH,BV, Lights	78.3
6	◇	Rockwell - Sabreliner 65	EW/S,HW,HE,EPT,WW/S	86.0
7	▲	Beech - L-23F	BW,BH,BV,EW/S,EP	123.0
8	■	Beech - L-23D	BW,BH,BV,EW/S,EP	144.0
9	●	Beech L-23F	EW,EH,EV,EW/S,EP	107.0
10	▼	Gates - Learjet 24F	HW,EH,EV,FR,EPT,HE,FW/S,HDF	80.0
11	◆	Canadair - Challenger	EW/S,HW,HV,HH,HE,EPT	83.1
12	⊠	Canadair - Challenger E	EW/S,HW,HV,HH,HE,EPT	93.1
13	⇳	Grumman - Gulfstream 3	EW/S,HW,EPT (Est.)	108.0
14	8	ADS-4 - *HYP A/C Ⓐ	BW,BH,BV,EW/S,EP	75.0
15	△	ADS-4 - *HYP A/C Ⓑ	BW,BH,BV,EW/S,EP	70.0
16	○	ADS-4 - *HYP A/C Ⓒ	BW,BH,BV,EW/S,HE	80.0

*Hypothetical aircraft for ice protection system penalty assessment, ref. FAA ADS-4

TABLE VIII

AIRCRAFT ICE PROTECTION SYSTEM CODES

TYPE SYSTEM	COMPONENT	CODE
Pneumatic Boots	Wing	BW
	Horizontal Stabilizer	BH
	Vertical Stabilizer	BV
Hot Air	Wing	HW
	Horizontal Stabilizer	HH
	Vertical Stabilizer	HV
	Wingshield A/I	HW/S
	W/S Defrost	HDF
	Engine Inlet	HE
Electrothermal	Wing	EN
	Horizontal Stabilizer	EH
	Vertical Stabilizer	EV
	Windshield	EW/S
	Propeller	EP
	Pitot	EPT
	Ice Detector	EID
	Carburetor	EC
	Engine Inlet	EI
Fluid IPS	Wing	FW
	Windshield	FW/S
	Horizontal Stabilizer	FH
	Vertical Stabilizer	FV
	Radome	FR
	Propeller	FP
Wipers	Windshield	WW/S

References: 8, 77, 88, 89, 105
Mini-survey, Canadair Telecon
Sabreliner Weights Group

It can be noted in figure 12 that the ice protection system weight for jet aircraft does not change appreciably with aircraft size/weight in the range of aircraft of interest in this study. The biggest scatter in ice protection system weight is for the smaller aircraft. This is due to the fact that there is a variation in types of ice protection systems used, there is a variation in which components are provided with protection between types of aircraft, and variations due to the state-of-the art changes.

For new ice protection systems, considerable weight savings are anticipated as well as great savings in power penalties. Reference 134 shows the following advantages of a microwave ice protection concept relative to an electrothermal concept for the same component:

1. Power, 80 percent less.

2. Weight, 17 to 36 percent less.

3. Ice detection is inherent in the microwave system.

4. Reduced complexity.

5. Cost, 27 percent less.

The latter two items require the proof that stems from a complete research and development program estimated to require about 7 to 8 years time. Maintainability, durability, and adaptability all need to be proven as yet, with this system.

Another new ice protection system, the electroimpulse system, has also been shown to have considerable advantage over the electrothermal system relative to weight and power penalties and other aspects as follows:

1. Power, 90 percent less.

2. Weight, 3 to 28 percent less.

3. Cost, 29 percent less.

4. Less complex.

5. Simple modification kits can be used for many applications.

This system will require from three to four years to develop in this country. So far, only the Russians have actually used these systems on aircraft. A typical system (reference 29) compares an electrothermal system with an electroimpulse system for deicing power requirements. The electrothermal system uses 3.25 to 13.0 watts/in.^{2} compared to 0.016 to 0.032

watts/in.^{2} for the electroimpulse system. The payoffs for the development of systems with this sort of power savings are obviously very good provided that the concepts are proven to be feasibly sound for fixed wing general aviation aircraft.

MAINTENANCE

In assessing the overall penalties associated with ice protection systems, the probability of failure and complexity of the systems must be considered. The probability of hot air thermal systems failing is very small. Malfunctioning of the valves and associated controls are about the only possibility. The electrothermal systems are much more complex with all of their contactors and controls, therefore, their failure is more probable. Electrothermal systems are more efficient generally, thus causing less power loss to the engine than the aerothermal systems. Maintenance is less on aerothermal systems, therefore, maintenance costs are less. However, the possibility of burnout and damage to the electrical heating elements has not been completely eliminated by design as yet. An excellent listing of ice protection system components showing mean time between failures (MTBF), mean time between unscheduled replacements (MTUR), and corrective maintenance man hours (CM) that are at 90 percent confidence level (C_L) for windshield defogging/anti-icing, wing and empennage anti-icing, empennage deicing, propeller deicing, and engine inlet anti-icing are contained in reference 102. Examples of these data, shown here in tables IX through XVI, point out problem areas and places where improvements should be made with ice protection subsystem components.

SAFETY

Carburetor icing caused 360 general aviation accidents in a five year period (reference 2) with 40 fatalities, 160 injured, and 47 aircraft destroyed. Some 613 persons were exposed to death and injury and 313 aircraft were damaged. Carburetor icing caused 44 accidents in 1966-67 time period (reference 4). These statistics indicate the seriousness of carburetor icing problems and their effects on aircraft safety. It also helps to emphasize the requirement for continued research into the carburetor icing problem. At present, research is continuing on the use of fuel additives such as ethylene glycol monomethylether (EGME) for ice protection. The use of carburetor heat can cause a 15 percent loss in power in light aircraft, so methods and techniques which do not extract from the already minimum power availability of small aircraft are much needed.

The windshield of an aircraft may hold a charge of several thousand volts relative to its mounting structure (reference 72). The electrostatic charge can be induced onto the surface of the windshield by certain types of precipitation including ice crystals. If the windshield is provided with an electrically heated anti-icing system (conductive coating or wires) it is

TABLE IX

WINDSHIELD DEFOG/ANTI-ICING RELIABILITY

SUBSYSTEM: WINDSHIELD DEFOGGING/ANTI-ICING (ELECTRICAL)				
Component Description	MTBM (Hr)	MTUR (Hr)	MMH/CA @ 90% C_L	MTBF (Hr)
Relay	85,638	256,916	16.5	513,832
Rheostat	128,458	-	1.0	128,458
Thermistor	4,429	-	2.5	4,429
Transformer	10,704	32,114	12.0	64,329
Control Box	1,735	51,383	3.1	55,000
Heating Element	1,167	-	3.1	100,000
Other	14,273	-	3.6	14,273
Subsystem Complete	543	18,518	6.0	55,500
Relay, High/Norm	96,280	320,936	3.3	Infin
Control Box	5,842	26,163	2.8	60,175
Transformer	35,397	200,585	6.3	601,755
Wiring	6,656	19,969	5.5	19,969
Heating Element	1,163	74,468	4.7	Infin
Subsystem Complete	2,785	10,416	4.5	>14,492
Switch	6,656	-	13.8	Infin
Control Box (Side)	19,969	39,938	7.6	Infin
Control Box (Windshield)	59,907	-	2.5	Infin
Xfmr. (Side)	13,313	39,938	11.7	39,938
Xfmr. (Windshield)	19,969	39,938	10.1	Infin
Relay	19,969	-	5.9	Infin
Wiring & Connectors	1,996	-	5.4	Infin
Other	19,969	19,969	18.0	Infin
Sub System Complete	1,060	8,000	9.4	39,938

MTBM - mean time between maintenance
MTUR - mean time between unscheduled replacements
MTBF - mean time between failure
MMH/CA @ 90% C_L - man-hours per corrective action at 90% confidence level

Data From Reference 102

TABLE X

WING/EMPENNAGE BLEED AIR ANTI-ICING RELIABILITY

SUBSYSTEM: BLEED AIR DISTRIBUTION - WING ANTI-ICING AND EMPENNAGE ANTI-ICING				
Component Description	MTBM* (Hr)	MTUR* (Hr)	MMH/CA* @ 90% C_L	MTBF* (Hr)
Valve-Isolation	1,173	7,556	8.2	25,691
Valve-Anti-Icing, Wing	4,714	10,932	8.9	22,340
Valve-Check	17,718	32,114	12.4	128,458
Valve Anti-Icing, Empennage	3,425	11,170	7.7	32,114
Expansion Bellows	18,351	128,458	9.1	Infin
Insulation Blanket	3,471	39,525	3.5	Infin
Ducting	340	1,976	11.6	25,691
Tubing	4,757	64,229	6.9	Infin
Compensator	45,877	214,096	8.6	Infin
Subsystem Complete	202	1,107	8.5	6,173
Valve, Check	137,544	481,404	4.1	Infin
Valve, Wing Isolation	2,407	5,470	7.5	17,193
Valve, Modulating	4,689	1,668	5.5	42,476
Sensor, Temp. Control	80,234	103,158	5.5	361,053
Duct, Diffuser	112,327	1,684,914	3.3	Infin
Camp, Duct	29,176	148,124	4.7	213,957
Insulation Blanket	5,014	12,035	3.8	30,087
Ducting	54,705	200,585	10.9	601,755
Subsystem Complete	1,102	2,710	5.7	8,000

*See table IX for definitions.

TABLE XI ELECTRICAL EMPENNAGE DEICING RELIABILITY

SUBSYSTEM: EMPENNAGE DEICING (ELECTRICAL)				
Component Description	MTBM* (Hr)	MTUR* (Hr)	MMH/CA* @ 90% C_L	MTBF* (Hr)
Controller	530	1,972	2.8	8,596
Heater, Leading Edge	9,347	26,744	8.4	962,808
Relay	962,808	962,808	1.7	925,616
Indicator Light Assy & Wiring	6,334	60,175	7.2	Infin
Subsystem Complete	464	1,779	5.0	8,475

* See table IX for definitions.

TABLE XII BLEED AIR ENGINE INLET ANTI-ICING RELIABILITY

SUBSYSTEM: ENGINE INLET ANTI-ICING (BLEED AIR)				
Component Description	MTBM* (Hr)	MTUR* (Hr)	MMH/CA* @ 90% C_L	MTBF* (Hr)
Valve	28,546	64,229	6.2	128,458
Probe/Ice Detector	12,234	27,043	4.3	42,819
Shut-Off Valve (Motor Oper)	64,229	171,277	9.7	Infin
Duct	36,702	513,832	5.5	Infin
Other	64,229	-	4.4	Infin
Subsystem Complete	5,681	16,393	6.0	32,258
Valve, Anti-Ice	3,902	13,539	5.7	31,915
Duct, Nacelle Nose Cowl	15,677	74,468	10.0	393,620
Relay	127,660	Infin	1.9	
Rectifier, Engine A/I	223,406	Infin	4.2	
Actuator, Valve Eng. Inlet	3,786	10,154	6.7	24,822
Actuator, Nacelle A/I	29,787	[illegible]1,238	5.1	223,405
Ducting	7,415	223,405	2.7	
Subsystem Complete	1,307	4,975	5.2	

Data From Reference 102

TABLE XIII ELECTRICAL PROPELLER DEICING RELIABILITY

SUBSYSTEM: PROPELLER, ANTI-TORQUE AND DEICING SYSTEM (ELECTRICAL)				
Component Description	MTBM * (Hr)	MTUR * (Hr)	MMH/CA* @ 90% C_L	MTBF * (Hr)
Element Assy., Nose			1.0	Infin
Heater Assy., Cuff			1.0	Infin
Element-Heater, Spinner	18,351	128,458	4.8	Infin
Control Panel	64,229	-	2.0	140,658
Transformer	128,458		2.0	Infin
Relay	856,386		7.6	Infin
Timer	64,229		2.2	35,164
Boot - Blade	5,677	293,618	5.9	Infin
Subsystem Complete	3,584	90,900	3.3	28,131

* See table IX for definitions.

TABLE XIV ICE DETECTION SYSTEM RELIABILITY

SUBSYSTEM: ICE DETECTION SYSTEM				
Component Description	MTBM * (Hr)	MTUR * (Hr)	MMH/CA* @ 90% C_L	MTBF * (Hr)
Relay	214,076	321,145	2.8	
Interpreter	32,114	64,229	8.9	85,638
Rectifier	256,916	770,748	8.5	Infin
Detector	10,276	21,409	4.6	28,546
Other	64,229	-	18.8	-
Detector	613	1654		3723
Switch, Control	31,915	111,702		223,405
Subsystem Total	376	1573	3.9	3603
Detector	799	3117		5195
Switch, Test	10,391	31,175		-
Subsystem Total	465	2834	7.0	5195

Data From Reference 102

TABLE XV PNEUMATIC RADOME ANTI-ICING RELIABILITY

SUBSYSTEM: RADOME ANTI-ICING (PNEUMATIC)				
Component Description	MTBM* (Hr)	MTUR* (Hr)	MMH/CA* @ 90% C_L	MTBF* (Hr)
Valve, Pressure Relief	21,409	128,458	2.9	128,458
Valve Modulating	2,214	6,760	5.9	25,691
Regulator	6,760	64,229	6.3	Infin
Thermostat	15,112	85,638	8.1	Infin
Ejector	18,351	128,458	3.2	Infin
Subsystem Complete	1,153	5,208	5.3	21,276

* See table IX for definitions.

TABLE XVI BLEED AIR ON ENGINE COMPONENTS - RELIABILITY

SUBSYSTEM: COMPRESSOR BLEED AIR, ENGINE COMPONENTS				
Component Description	MTBM* (Hr)	MTUR* (Hr)	MMH/CA* @ 90% C_L	MTBF* (Hr)
Valve, Sensitive	502,032	Infin.	4.4	Infin.
Valve, Speed Sensitive	1,649	2305	7.3	3091
Valve, Comp Bleed	20,838	112,426	4.8	Infin.
Valve, Bleed Control	33,096	187,544	[illegible]	Infin.
Valve, Solenoid, 3-Way	251,316	502,032	-	Infin.
Valve, Solenoid	56,263	251,316	4.1	251,316
Valve, Anti-Ice	[illegible]	[illegible]	[illegible]	[illegible]
Miscellaneous	[illegible]	Infin.	[illegible]	Infin.
Subsystem Complete	[illegible]	[illegible]		[illegible]

Data From Reference [illegible]

possible that the windshield will act as a two plate capacitor connected to the power supply. If there is sufficient static charge, the resistance to current flow may breakdown and the charge will be discharged into the aircraft electrical system by way of the windshield heating element connectors, causing a failure. It is possible to reproduce this complete electrical phenomena in the laboratory icing research tunnel at modest costs. Research in this area is recommended in order to learn more about the "mechanics" of windshield electrification by ice crystals.

Current solutions to the problem have been through the use of anti-static coatings, which are metal oxides, and the use of suppression devices such as air cored chokes, capacitors, and resistors. The chokes are not easy to install and are often omitted which shortens windshield service life, theoretically.

Icing of the flight control surfaces exposed to direct impingement of water droplets or to runback ice can impose a severe safety problem if careful design consideration has not been given to such possibilities during the conceptual design stages of the aircraft. One example is in the design of elevator balance horns. Ice accretion on the leading edges of the horns may prevent further up or down movement of the elevators, with possible disasterous results. Common design practice has been to leave a substantial gap between the fixed and moveable parts of the horizontal stabilizer in the vicinity of the balance horns. Heated and nonheated shields have also been utilized with success, however, the problem has not been completely solved to date, and research is still required if a completely satisfactory answer is to be found.

ASSESSMENT OF THE EXPERIMENTAL DATA BASE (TASK 4)

The experimental data base was assessed for the ice sensitive components identified in task 1 and listed in tables XVII, XVIII, and XIX and in Appendix D, insofar as data were available from the literature search and from the results of the industry survey. Information, with regard to the extent of published data, was recorded in the computer file program through the utilization of a table of source data categories - data base/facility type (Appendix D). This lookup table contains codes for the source of the data presented, e.g., whether based on wind tunnel or flight testing, computer programs, laboratory testing, commentary, etc. These codes establish the known data base for the following:

1. Droplet collection efficiencies.

2. Ice accretion size and shape as a function of cloud characteristics, time in cloud, and aircraft flight parameters.

3. Ice shedding, conditions and fragment sizes.

TABLE XVII

MATRIX OF COMPONENTS VS DATA BASE/FACILITY TYPE

OBJECTIVES OF TESTS:

1. Nature & Extent of Icing
2. IPS Performance
3. A/C Performance Penalties

COMPONENT	DATA BASE/FACILITY TYPE: FULL SCALE ENGINE ICING FACILITY OR FULL SCALE ICING WIND TUNNEL	SUBSCALE ICING WIND TUNNEL	IN-FLIGHT SPRAY TANKER	GROUND SPRAY SYSTEM	IN-FLIGHT NATURAL ICING	DIRECT CONNECT ENGINE WIND TUNNEL	ANALYTICAL TECHNIQUES	DRY AIR FLIGHT TEST SIMULATED ICE	OPERATIONAL EXPERIENCE	STATISTICAL SURVEY
JET ENGINES										
Main Inlet	X		X		X		O			
Blow-In Doors	X		X		O				X	X
Inlet Noise Suppression	X		X		X	O				
Nose Caps			X		X	O	X			
Screens	X		X		X	O				
Inlet Guide Vanes	X		X		X	O	X			
Rotor Blades	X		X		X	O	X			
Frame Struts	X		X		X	O	X			
FAN JET										
Main Inlet	O		X		X		O			
Blow-In Doors			X		X				X	X
Inlet Noise Suppression	X				X	O				
Nose Caps	X		X		X	O	X			
Inlet Guide Vanes	X		X		X	O	X			
Rotor Blades	X		X		X	O	X			
Fan	O		X		O	X				
Bypass	O		X		O	X				

O - Primary Data Base
X - Data Base Contributor

TABLE XVIII

MATRIX OF COMPONENTS VS DATA BASE/FACILITY TYPE

OBJECTIVES OF TESTS:

1. Nature & Extent of Icing
2. IPS Performance
3. A/C Performance Penalties

COMPONENT	DATA BASE/FACILITY TYPE: FULL SCALE ENGINE ICING FACILITY OR FULL SCALE ICING WIND TUNNEL	SUBSCALE ICING WIND TUNNEL	IN-FLIGHT SPRAY TANKER	GROUND SPRAY SYSTEM	IN-FLIGHT NATURAL ICING	DIRECT CONNECT ENGINE WIND TUNNEL	ANALYTICAL TECHNIQUES	DRY AIR FLIGHT TEST SIMULATED ICE	OPERATIONAL EXPERIENCE	STATISTICAL SURVEY
TURBOPROP										
Main Inlet	X		X		X	O	X			
Nose Caps	X		X		X	O				
Inlet Guide Vanes	X		X		X	O	X			
Rotor Blades			X		X	O	X			
Frame Struts			X		X	O				
Particle Separators	X		X		X	O				
Screens	X		O		X					
Pull Propellers			O		X					
Push Propellers			O		X					
Engine Cowling			O		X		X			
PISTON ENGINES										
Carburetor	X	X	X	X	O				X	X
Pull Propellers			O	X	O					
Push Propellers			O	X	O					
Engine Cowling			O	X	O					
WINGS										
Swept Straight	X	X	X	X	O		O	X		
Ailerons	X		X		O					
Flaps	X		O		O		X			
Slats	X		X		O		O	X		
Slots	X		O		X		X			
Fences & Vortex Gen.	X		X		X		O	X		
Canard	X		X		X		O	X		

O - Primary Data Base
X - Data Base Contributor

TABLE XIX

MATRIX OF COMPONENTS VS DATA BASE/FACILITY TYPE

OBJECTIVES OF TESTS:

1. Nature & Extent of Icing
2. IPS Performance
3. A/C Performance Penalties

COMPONENT	FULL SCALE ENGINE ICING FACILITY OR FULL SCALE ICING WIND TUNNEL	SUBSCALE ICING WIND TUNNEL	IN-FLIGHT SPRAY TANKER	GROUND SPRAY SYSTEM	IN-FLIGHT NATURAL ICING	DIRECT CONNECT ENGINE WIND TUNNEL	ANALYTICAL TECHNIQUES	DRY AIR FLIGHT TEST SIMULATED ICE	OPERATIONAL EXPERIENCE	STATISTICAL SURVEY
TAIL SURFACES										
Horizontal, Elevator	X	X	X		O		O	X		
Vertical, Rudder	X	X	X		O		O	X		
T-Tail			O		O		X	X		
V-Tail			O		O		X	X		
Balance Horns	X		X		O				X	
FUSELAGE										
Windshield	X		O		O		O			
Wing/Fuselage Juncture			O	X	O			X		
Static Vents			O		O				X	X
Scoops	O		X		O		X		X	X
Drains			X		X				O	X
Other Junctures	X		O	X	X			X		
Antennas			O		X		X		X	
Radomes			O		O		X	X		
Electro-optical	X		X		X		X			
Transparencies										
A/C INSTRUMENTS										
Pitot Static Tube	O		X		X					
Alt. & Rate of Climb	X				X					
Orifices	O		X		X					
Yaw Vanes	O		X		X		X			
Total Head Probe	O		X		X				X	
Total Temp. Probe	O		X		X				X	

O - Primary Data Base
X - Data Base Contributor

4. Effects of ice accretion on the aerodynamic characteristics of the components.

The last item (4) is also discussed in the previous section which assesses the available information on aircraft penalties due to ice accretion on unheated surfaces or aircraft penalties due to the energy and weight requirements of the ice protection systems provided.

The data base associated primarily with ice accretion is also the subject of the section on ice accretion size and shape.

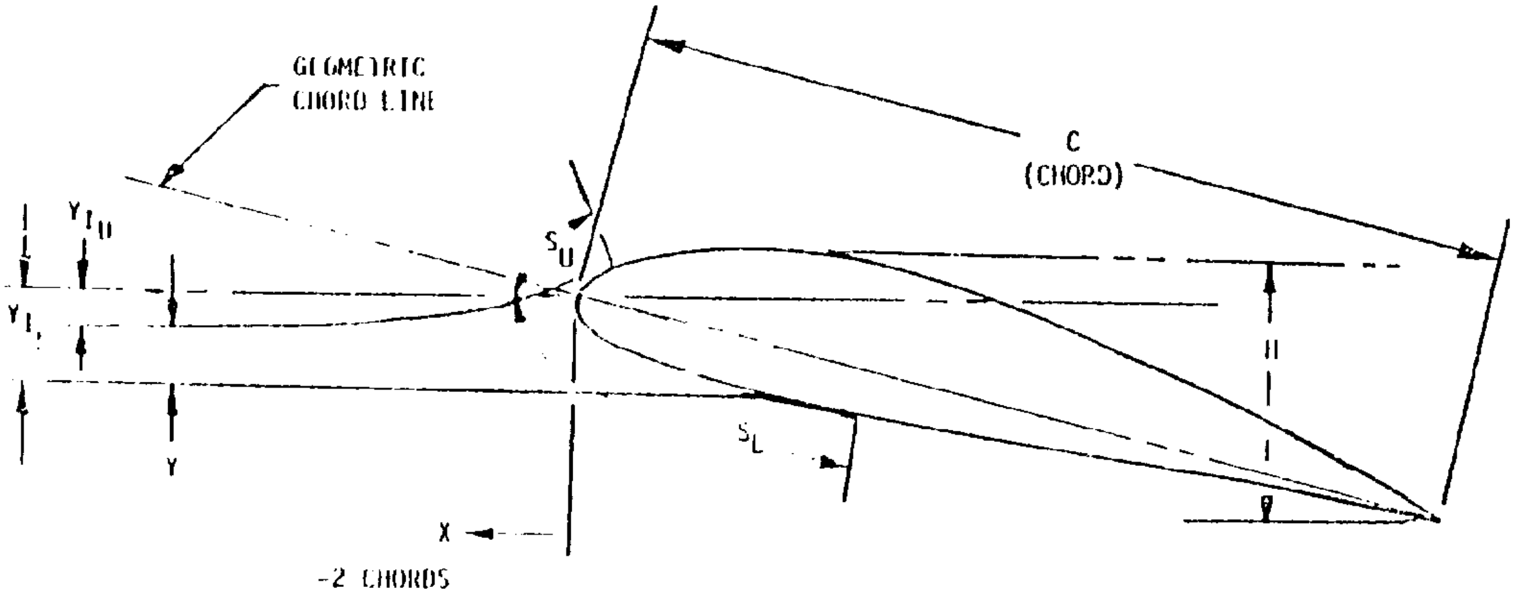
DROPLET COLLECTION EFFICIENCIES

The collection efficiency, E_m, is defined (from reference 105) as the ratio of the actual water impingement stream tube thickness to the maximum value that could occur (straight line trajectories). The actual water impingement stream tube thickness (Y) is determined from the difference between the starting Y-values (YI_U and YI_L) of the particle trajectories that are tangent to the upper (S_U) and lower (S_L) body surface, respectively (see figure 13). The straight line trajectories (very heavy drops) stream tube thickness is merely the projected height of the body.

Very little quantitative experimental data, with regard to droplet collection efficiency, has ever been acquired with any facility other than an icing research tunnel. The majority of this data, as far as the data that are published is concerned, were obtained by work accomplished in the 6 ft x 9 ft IRT at NASA Lewis Research Center. Quantitative data on collection effiency have been obtained with multicylinder instrumentation during flights in natural icing which have been used many times to confirm the theoretical collection efficiencies for cylinders. In a similar fashion, collection efficiencies on other conventional body shapes (spheres, ellipsoids, i.e., bodies of revolution) have been determined, but not to the same extent as with the cylinder. Quantitative data on collection efficiency for airfoils from flight in natural ice is extremely difficult to obtain, so consequently, little is in existence.

Collection efficiency is a function of flight speed, droplet size, body geometry, ambient temperature, and pressure. In the literature, E_m is presented versus various dimensionless parameters, but most generally it is correlated with the dimensionless modified inertia parameter K_0. The use of this parameter results in essentially a single valued curve of E_m versus K_0 for bodies of the same geometrical shape. The error involved in the use of the K_0 parameter for correlation of E_m is less than ±10 percent for most airfoils and bodies, for the normal range of flight conditions (reference 105).

An excellent discussion of a comparison between theoretical and experimental data on efficiency of catch may be found in the bibliography references 102, 105, and 124. These references summarize experimental data



TOTAL IMPINGEMENT EFFICIENCY $E_m = \frac{(Y_{I_L} - Y_{I_U})}{H} = \frac{Y}{H}$

WIDTH OF STREAM TUBE OF DROPLET IMPINGEMENT LIMITS $Y = Y_{I_L} - Y_{I_U}$

S_U UPPER SURFACE IMPINGEMENT LIMIT

S_L LOWER SURFACE IMPINGEMENT LIMIT

$\frac{Y_I}{C}$ = DIMENSIONLESS WIDTH OF LOWER IMPINGEMENT STREAM TUBE

$\frac{X}{C}$ = DIMENSIONLESS DISTANCE AHEAD (OFF) OF AIRFOIL

$\frac{Y}{C}$ = DIMENSIONLESS WIDTH OF STREAM TUBE (DROPLET IMPINGEMENT LIMITS)

$\frac{S}{C}$ = DIMENSIONLESS SURFACE DISTANCE

Figure 13. Definition of Analysis Parameters, Ref 105

largely obtained in icing tests conducted by the NACA during the 1950's in the 6 ft x 9 ft IRT at NASA LeRC.

Many investigators solved the water drop trajectory equations and determined the impingement limits and the collection efficiencies for a variety of airfoil shapes. It was found that the accuracy of their solutions was very much dependent on how accurately they could predict the flow field. For Joukowski airfoils, cylinders, ellipses, and spheres, exact potential flow solutions exist and the agreement between analytical and experimental data is good. However, a great majority of practical airfoils do not have exact potential flow solutions, and the agreement between analytical and experimental data was not as good, indicating that water catch calculations are very sensitive to the airflow field.

Computerized techniques are utilized for solving the water drop trajectories equations for reasonably shaped, 2-D and swept airfoils, and axisymmetric engine inlets at angles of attack. They solve the water droplet trajectory equations by a numerical technique and then use the water drop trajectory results to calculate the water catch data; i.e., local efficiency distributions, local water catch distribution, impingement limits, total collection efficiency, and the total water catch. These methods output all of the water catch data discussed above, given the body coordinates, angle of attack, free-stream velocity, altitude, free-stream temperature, chord length, thickness of the body, droplet size, and liquid water content.

Many respondents to the survey questionnaire indicated that they use computer techniques to solve the droplet trajectory equations and for subsequent calculations including collection efficiency. The computer programs, although similar in function, are generally proprietary to the individual companies. In other instances, some respondents indicate that they use the techniques of ADS-4 with charts and curves of data to simplify hand calculations. Many indicated that ADS-4 should be updated to include many new airfoils designed in recent years. The collection efficiency versus K_0 for the new airfoils calculated by computer analysis and backed by icing tunnel test data is a much needed improvement to the data base.

Techniques are also required for the experimental determination of droplet collection efficiency change as ice accretes on an airfoil or other body configuration. Some attempts at correlating actual ice accretion with theoretical accretion was accomplished in NACA TN 4151, but more effort is required since all of this work was on just one airfoil at various angles of attack. Also, this work was on an unswept airfoil. Very little data of the same type are available on swept airfoil configurations in the published literature.

ICE ACCRETION SIZE AND SHAPE

Ice accretion will occur on any object (ice sensitive component) moving through a cloud when the temperature is below freezing.

The rate of ice buildup will vary with the following:

1. The water density of the cloud, i.e., liquid water content (LWC).

2. The velocity of the object with respect to the air.

3. The size and shape of the object (component).

4. The temperature of the air and the temperature of the object/component.

5. Duration of the encounter.

The shape and consistency of the ice buildup will vary with the following:

1. Temperature of the object (component), the cloud, and the water drop size.

2. The velocity of the object, as it affects the surface temperature (adiabatic temperature rise).

3. Thickness ratio of the object (collection efficiency) and "sweep" with respect to the free-stream.

4. Angle of attack of the object.

Ice shapes are generally classified as glaze (mushroom), intermediate, and rime. A correlation of ice shape in terms of liquid water content, ambient temperature, and flight speed was developed by Tom Dickey using the "freezing fraction" concept developed by Messinger. A general discussion of the correlation for ice shape is found in reference 105. In general terms, it can be stated that rime ice is likely to occur at total air temperatures of about 10°F and below, while glaze ice usually occurs at total temperatures of 25°F to 32°F. Between 10°F and 25°F, a glaze-rime formation will usually occur, with clear glaze ice at the stagnation region and milky white rime ice in the aft regions.

Correlation of ice accretion size and shape has never been experimentally verified for the full range of values for the associated parameters. Also, even though a large number of photographs of ice shapes on unheated bodies have been taken and are available in the literature, very few cross sections of the ice are shown, or critical dimensions given. Rime ice forms in a manner that is more easily predicable than glaze ice. The drops freeze on impact and the rate of growth is generally linear because the ice shape does not alter the flow field significantly. The glaze ice exhibits the typical "double horn" shape that results from water flow in the stagnation region. The exact shape of glaze ice is difficult to predict and the growth is nonlinear because the ice affects the flow field (NACA TN 4151).

On highly swept airfoils, glaze ice tends to form as a series of discontinued cusps (cup shapes), sometimes referred to as "lobster tails." These shapes are repeatable for tests using the same conditions all around, but there is no empirical equation or theoretical prediction method for determining the size and shape of this type of ice configuration.

The ice accretion information available from published data for determining the ice shapes is applicable to unswept airfoils at limited angles of attack, for the most part. However, reference 121 does contain a discussion of the Boeing Aircraft Company program (sponsored by the FAA and conducted in the NASA 6 ft x 9 ft IRT) to obtain basic ice accretion and ice shedding data on typical jet transport swept airfoils.

Ice accretion tests were conducted on two swept airfoil sections representative of the inboard and outboard wing or horizontal stabilizer airfoil sections of typical jet transports. The size and shape of these ice accretions were measured through photographs and actual plaster casts of the ice cap. Tests were conducted over a range of simulated flights and icing conditions designed to give the rough or glaze shape, which results in the highest drag penalty. The test results were satisfactorily correlated with theoretical water impingement parameters obtained from a digital computer program. Ice accretion characteristics and test data were found comparable to limited published data which include NACA TN 4151 and NASA TN D-2166.

Although this work was conducted for large transport aircraft wing sections, the technology is applicable to general aviation and light transport aircraft. The empirical relationships developed which correlate measured ice accretion rates with theoretical impingement parameters are not restricted to any particular size of airfoil, although the complex trends of the data preclude a general ice accretion relationship with other airfoil shapes (involving camber, angle of attack, etc.).

Future research is required to obtain the same type of data on many other airfoils and body shapes to update the limited data base which exists at the present time.

Photographs and qualitative data have been obtained over the years for ice accretion tests utilizing aircraft flying in natural icing conditions, aircraft flying behind tanker aircraft, and for full scale and subscale models in icing wind tunnels. Quantitative data, to a limited extent, were obtained by specially equipped aircraft with instrumented airfoil shapes extending vertically from the fuselage section of the aircraft (i.e., Canadian "ice wagon" and USAF B-24 test aircraft). These aircraft were flown in natural icing conditions. Considerable data in natural icing conditions related to ice accretion were obtained with multiple cylinders in order to relate the airfoil catch characteristics with the multiple cylinder accretion characteristics. However, the bulk of the published quantitative data on ice accretion on airfoils and all other body shapes tested have been obtained from icing wind tunnel tests.

ICE SHEDDING

Ice shedding from aircraft components on which ice has been accreted is a function of many, many variables and sometimes occurs in a totally random fashion. Ice shedding is some function of the shape or configuration of the body or airfoil to which the ice has adhered. It is a function of the type and shape of ice, which in turn, is a function of temperature, LWC, droplet size, airstream velocity, and duration of exposure. The angle of attack and the sweep angle play an extensive role in both the shape and si·· of the ice accretion. Any discussion of ice shedding must necessarily address ice shed from unprotected surfaces, passively protected surfaces, and surfaces protected with active ice protection systems.

For those surfaces which are unprotected, the accreted ice or some portion of it will shed for the following reasons:

1. Some portion of the ice buildup is weaker than the aerodynamic forces acting upon it.

2. Natural flexing and/or vibration of the ice accreted surface is sufficient to break the bond with the ice.

3. The aircraft, due to acceleration, altitude change, or meteorological changes, flies into an area where the air temperature and subsequent component surface temperature reach 32°F or above.

For those surfaces which are passively protected by having a surface which either has an icephobic material covering it, or itself is icephobic in nature, the ice will shed for the same reasons given in the previous paragraph. The main difference is that the ice will probably shed before it builds to the same size, because the adhesive forces are much less, thus requiring less aerodynamic force for ice removal.

For the ice accreted surfaces which are protected by active ice protection systems, only deicing systems are of concern. For these surfaces, some portion of the ice will shed for the following reasons:

1. The bond between the ice and the surface is disturbed by mechanically changing the surface by vibrating it or expanding it, as with pneumatic boots. Aerodynamic forces assist in the final removal of the ice.

2. The layer of ice being brittle, fractures due to vibration or change in surface area.

3. The temperature of the interface between the ice and the body surface is made to exceed 32°F by a heating system, thus eliminating the ice adhesion. Aerodynamic forces then remove the ice.

The experimental data that has been published on ice shedding is extremely limited, particularly that which is related to fragment sizes. The majority of the data or information is related to qualitative assessments as to what component the ice sheds from, and how soon did it shed after leaving the icing cloud which was penetrated. Testing for ice shedding has been accomplished during flight in natural icing conditions, flight behind tanker aircraft, and in icing wind tunnels. The majority of the testing for which quantitative data have been obtained has been by tanker tests and from icing wind tunnel tests.

Reference 121 contains a discussion of a Boeing Aircraft Company method of calculating the airfoil/ice interface temperature and predicting the time at which the ice will shed. This method was developed using icing tunnel test data in conjunction with a heat transfer analysis. The ice shedding calculation procedure was demonstrated and shown to be conservative from natural icing flight test data. Subsequently, a computer program was developed by the Boeing Aircraft Company to compute the leading edge skin temperature beneath ice accreted on unheated airfoil surfaces. This program also determined from the calculated transient temperature profiles (reference 103) the altitudes at which shedding would occur during a descent.

Ice shedding characteristics are of interest in determining the required frequency of application of the deicing system. Also, ice shedding predictions can be used to determine the need for ice protection due to the hazard to downstream structure and/or aft-mounted engines. Shed ice from wings, etc. may strike the tail section or be ingested by aft-mounted jet engines. Therefore a knowledge of the size and trajectories of shed ice from the forward sections of the aircraft are required. Reference 128 discusses 1:16 scale model tests of shed ice trajectories from the unprotected radome of a VFW 614. The results matched theoretical calculations. Dynamic similarity and scaling factors were used in the scale model tests.

Ice shed from the leading edges of the wings or tail in an unsymmetrical manner may cause aircraft control problems which could be hazardous if it occurred during landing. Testing of such a situation is extremely difficult or impossible in natural ice, but can be simulated with tanker tests, dry air tests with simulated ice shapes, or in large icing wind tunnels such as the NASA Altitude Wind Tunnel (AWT), after the planned rehabilitation is completed.

There is very little published data on ice shedding including the conditions for shedding, ice fragment sizes, and the trajectories of the fragments. Although the effects of ice shedding can be different for each aircraft, depending on its design configuration, there is a requirement for more research to build up the experimental data base of general information on these factors. There is a need for expanding methods for determining ice shedding characteristics for straight and swept airfoils and other body shapes based on the various types of accreted ice, including the maximum and average size of the ice fragments. Theoretical methods for determining trajectories and impact velocities of shed ice are required which can account for the shape and size of the ice fragments.

EFFECTS OF ICE ACCRETION ON THE AERODYNAMIC CHARACTERISTICS OF THE COMPONENTS

The experimental data base for the effects of ice accretion on the aerodynamic characteristics of components comes largely from wind tunnel tests. Simulated ice shapes determined from ice accreted during icing wind tunnel tests are used in dry air wind tunnel tests for measuring changes in lift, drag, and pitching moments on the airfoil or body configuration. In this manner quantitative data may be obtained readily without the difficulties involved with below freezing temperatures for the experimenters and other such problems as unexpected ice shedding or melting, etc.

Quantitative data from flight tests in natural icing conditions or tanker tests other than increased angle of attack, increased power to maintain altitude, and mach number, are relatively impossible to obtain. Qualitative data on handling and control characteristics are obtained with flight tests in natural icing conditions or tanker tests. This type of data could be obtained for small aircraft in a large wind tunnel such as the AWT under simulated conditions.

The effects of ice accretion on an aircraft is to increase drag, reduce wing stalling angle and maximum lift coefficient, and create adverse pitching moments. The upper horn of a glaze ice acts as a spoiler to destroy the smooth flow over the upper surface of the wing, causing premature stall. The lower horn serves to increase the drag.

A recent survey (1979) of the state-of-the-art in aerodynamic penalty prediction was made by the Air Force Flight Dynamics Laboratory and referred to in a technical memorandum (reference 125) on Air Force aircraft icing needs. The following conclusions were made:

1. At present, there are no theoretical methods available that can be used to provide numerical lift and drag increment values. There has never been any attempt made in the past to develop the capability from a purely theoretical standpoint.

2. Most of the existing methods are empirical and are based on very limited test data. Drag estimates for other airfoils are extrapolated from these data and the accuracy of the results are unproven.

3. There are numerous references available on the subject of the methods of calculating water droplet trajectories relative to aerodynamic bodies and to determine impingement limits and distribution. There are only very limited attempts to directly relate meteorological data to drag or lift increment numbers. No attempts were made to understand the exact manner in which the ice grows and to develop a detailed geometry description. The capability exists to estimate the rate of water catch (lbs/hr/ft of span) on a given exposed surface.

ASSESSMENT OF THE ICE ACCRETION PREDICTION METHODS (TASK 5)

ANALYTICAL PREDICTION METHODS

The vast majority of work on icing statistics and ice accretion prediction was conducted during the late 1940's and 1950's by the NACA. Most of this material has already been reviewed and summarized as a result of a Federal Aviation Agency study and published in their report ADS-4 (reference 105) in March 1964.

Only a limited amount of work has been done since the publication of ADS-4 that is available to the public. A substantial portion of this most recent work is contained within the reports called out in the bibliography and reference list of Appendix A.

The analysis methods in use today are chiefly based on the above-mentioned NACA icing research conducted under natural icing conditions over a period of many years (late 1940's and early 1950's) as summarized in section I of ADS-4. More recently (1973) the work was updated by Werner (reference 102) to include comparisons with much more recent data taken in Europe and Russia.

The early work was performed by specially equipped research aircraft using rotating multicylinders to measure icing intensity. Later data were obtained by mounting icing rate meters on commercial and military aircraft, thus obtaining icing data related to routine flight operations. These data form the major part of icing statistical data that are still in use today.

The validity of these statistical data, having been recorded more than 30 years ago, have been questioned many times in recent years. Except for a few instances, the NACA data have stood the test of time and are still considered valid. Also, the European and Russian data discussed in reference 102 verify the NACA statistical data. However, the true test awaits the time when new instrumentation is developed and utilized in real time with continuous readout, thus providing a much more complete picture of each icing penetration made for statistical model verification.

The size and shape of an ice accretion are functions of the airfoil or component shape, flight speed, angle of attack, altitude, component surface temperature, and properties of the icing cloud in terms of liquid water content (LWC), drop size, temperature of the air, and horizontal and/or vertical extent.

Section II of ADS-4 presents a summary of droplet impingement data. These data and the icing cloud data of section I of the report can be used to determine rates of water catch and impingement limits for specific flight conditions and airfoil or component geometry. The data are presented in correlated form in a series of graphs. Knowing the airfoil, flight speed, altitude, temperature, droplet size, LWC, and angle of attack, the water catch and impingement limits can be approximated from the various graphs. The data are claimed to be generally accurate within ±10 percent (reference 103).

The method is limited to those airfoils or body shapes for which data have been accumulated and plotted. For any other case, the contour of the airfoil or body must be "matched" to an airfoil of known characteristics, at least in the forward (leading edge) portion. A second method is to match the pressure (or velocity) distribution of the airfoil of interest with the pressure (or velocity) distribution of an airfoil having known characteristics.

Contour matching is not adequate in the case of engine inlets or for highly swept airfoils. Methods have been developed for converting straight wing data to swept wing data, but with limited usefulness.

Engine inlet ice accretion and protection requirements have the identical problems of the other airframe components. Reliable data on water catch and impingement lengths are limited to that which have been verified by previous testing.

Many aircraft companies and Government agencies have developed computer codes to predict water catch and impingement limits for airfoils and other body shapes. The advantage of these programs is that once developed, they can input any 2-dimensional body shape (airfoil) into the program through a given set of X, Y coordinates. Then through the use of a potential flow field program and the resultant physical flow data, an input to a droplet trajectory program is made. Ultimately, the program outputs water catch characteristics, the upper and lower (airfoil) impingement limits, efficiency of catch (by whatever definition is used), and sometimes the modified parameter, K_0.

Some of the known computer programs related to ice accretion and icing technology in general are as follows:

1. Rockwell proprietary program documented in a three volume report, NA-72-849.

   Vol. I A computer program that sets up on-body and off-body points for icing analysis.

   Vol. II Application of the Douglas-Neumann computer program to determine the flow field around a two-dimensional body for icing analysis.

   Vol. III A computer program that calculates the theoretical initial catch characteristics of a two-dimensional body.

2. NASA procured or planned computer codes.

   Water droplet trajectories for water catch rates and impingement limits on:

   - 2-D Lifting Bodies (Wings, Tails, Inlets)
   - 3-D Lifting Bodies (Wings, Tails, Fuselage)
   - 3-D Nonlifting Bodies (Fuselage)
   - Axisymmetric Engine Inlets at Angles of Attack

   Steady state heat transfer for anti-icing analysis.

   Ice accretion modeling on wings, inlets, and rotors.

   Prediction of aerodynamic penalties due to ice accretion.

   Transient heat transfer codes for deicer analysis.

   Prediction of shed ice trajectories.

3. Key Industries Corporation proprietary programs "POT," defines this flow field ahead of and around two-dimensional or axisymmetric models.

   "DROP," utilizes the flow field generated by program "POT" to compute model impingement limits and water loading.

4. Air Force Flight Dynamics Laboratory program, AEROICE (AFFDL-TM-79-91-WE). A computer program which evaluates the aerodynamic penalty due to icing.

5. A two dimensional particle trajectory computer program written by Boeing Military Airplane Co., Kansas for the Bureau of Naval Weapons, 9 March 1965.

Reference 125 discusses many of the general needs for icing research as well as the specific needs of the U. S. Air Force. The need for extending the existing methods of calculating the impingement distribution on aerodynamic bodies and the problems with theoretical methods are given as follows:

1. Exact geometric shapes are difficult to define for some components.

2. Full potential flow equations are nonlinear and cannot yet be solved.

3. Existing linearized equations are not applicable to the leading edges.

4. The solution is accurate for only one instant of time.

Existing aerodynamic prediction codes require a knowledge of the body contour in order to apply the proper boundary conditions. In addition, the geometry (surface coordinates, camber shape, leading edge radius) must remain fixed during the duration of the flow. Thus, a theoretical approach is complicated by the fact that the geometry of an iced airfoil continuously changes with the duration of the exposure and the calculated lift or drag values are true for only one instant of time.

Another factor that complicates the use of analytical methods at this time is the nature of the equations of motion and our present capability to solve them. This problem is true across the entire spectrum of aerodynamic research. The full potential equations for inviscid flow and the full Navier-Stokes equations for viscous flow are highly nonlinear and without the introduction of simplifying assumptions, these equations cannot yet be solved. Existing production type computer codes rely on the linearized forms of these equations. The process of linearization introduces limitations to the applicability of the programs. For example, for inviscid flow the small disturbance theory assumes that the presence of an airfoil offers only a small disturbance to the flow field and the ratio of the perturbation velocity to the free-stream velocity is considerably less than one. Examination of this boundary condition shows that it does not apply in the region close to the airfoil leading edge, where we are primarily interested in an icing investigation.

EXPERIMENTAL PREDICTION METHODS

There are basically four methods of testing aircraft and aircraft components for ice accretion and icing effects. These are icing tests in natural icing conditions, icing tests behind a tanker aircraft, icing tests in icing wind tunnels, and tests using ground spray systems. Two kinds of tests accomplished in icing wind tunnels are full scale model tests and sub-scale model tests.

Current prediction methods for ice accretion are limited due to the difficulties caused by a limited data base, uncertain accuracy, two-dimensional analysis, and uncertain effect of the fuselage nacelles and finite span of the airfoils. All of these difficulties limit the choice to experimental empirical methods. This approach seems to provide the only possible answer to the prediction problem at the present time. In order to enhance the level of confidence, the current data base must be expanded. A systematic investigation of airfoils of different thicknesses must be made to improve the accuracy of the resulting empirical equations and to avoid generalized extrapolations.

The experimental methods also have their own problems that must be resolved before any meaningful tunnel and flight test data correlation is possible. Among the immediate requirements (reference 125) are the following:

1. Fully instrumented tunnel capable of controlling the icing parameters and closely simulating the flight icing conditions. It is often difficult to estimate aerodynamic penalties in icing conditions different from those specifically investigated for a particular airfoil. An accurate control of the parameters in the tunnel may provide greater flexibility in simulating different flight conditions.

2. Understanding of the effects of scaling. Many of the current available data are based on full scale airfoil tests. Though this approach simplifies the problem, full scale testing is not always possible, particularly for complete aircraft configurations. If a smaller scale model is to be tested, the icing parameters may also have to be scaled in some manner. An important question is whether the ice geometry obtained in the tunnel will be identical to the geometry in flight if the meteorological parameters are the same or as close as possible. This again points out the necessity of understanding the manner in which ice builds up on a surface.

Icing tests in natural icing conditions are limited in that it is rarely possible to find actual design icing conditions for adequate testing, even with modern weather satellite pictures, weather radar, etc. A typical icing search will involve 30-60 hours of flight to obtain one to two hours of actual icing experience, resulting in high costs. Thus, because of the high cost and the fact that design conditions are hard to find, the usual procedure is to find icing conditions of whatever severity is available and to use previous analytical and test data to extrapolate the natural icing test data to the design extremes. Also, determination of the characteristics of the icing conditions encountered (LWC, drop size, etc.) is extremely difficult and subject to error. Thus, natural icing tests are of dubious value when weighed against the cost of conducting these tests (McDonnell-Douglas paper "Flight Testing in Dry Air and Icing Cloud," reference 121).

Two methods of tanker icing tests have been employed in the past. The first, which is not used very often, is to mount a water spray rig ahead of the aircraft wing, engine, or other component to be tested. The aircraft is then flown at an altitude with the desired temperature, and water from the spray rig is sprayed over the component to cause icing. This method has many problems associated with it including size, weight, and aero turbulence effects caused by the spray rig.

In the second method, a tanker aircraft equipped with spray nozzles creates an artifical cloud into which the test aircraft is flown to expose portions or the entire aircraft to icing conditions. In most cases the cloud is not large enough to envelop the entire aircraft. This method is limited in its usefulness and accuracy, in that it is difficult to simulate actual design conditions and to accurately measure the conditions that are produced in a spray rig. In many cases the drop sizes produced are excessive and not representative of those encountered in natural conditions. The cloud behind the tanker is turbulent due to the tanker aircraft and the spray rig itself. Research tests have been conducted in the last few years to try to bring the droplet size from tanker spray rigs more in line with desired design limits, but without complete success (reference 61).

Icing wind tunnel testing has been, and still is the best method for determining ice accretion rates and shapes. The icing environment and flight parameters can be carefully controlled and varied as desired to permit data to be obtained at as many conditions as required. In this way, complete data can be obtained for any airfoil, body shape, or other component that will fit into the particular facility. The major limitation, therefore, is the size of the tunnel and the size of the model or component to be tested. Many icing tunnels are atmospheric type meaning that they cannot duplicate altitude conditions, although this is not an extremely important factor in much of the icing testing that is done. Altitude would have a more significant effect for ice protection system performance tests where heat transfer coefficients are affected by density change.

There are several types of ground spray systems that are used in icing tests with jet engines, fixed wing aircraft, and helicopters. The spray systems are either right at ground level (for tests with jet engines) or mounted in a tower for creating an icing cloud for low hovering helicopters. Also, these clouds can be used to simulate ground fog type conditions for fixed wing aircraft. In any case, the systems rely on the seasonal low temperatures to produce below freezing conditions necessary for icing tests. The desired spray cloud conditions are difficult to produce and are often used in conjunction with a large fan or blower to move the cloud over the vehicle being tested. Measurements of the icing parameters is particularly difficult with this type of spray system due to the minimum velocity conditions.

The general literature contains very little data with regard to scaling parameters relating the similarity between a scale model and full scale prototype (aircraft or component) with respect to icing.

Reference 94 introduces the fundamental relationships for dynamic similarity between model and prototype which must be satisfied in order to measure ice catch distribution, airflow, and heat load requirements for an anti-icing system. The report, however, imposes certain limitations as follows:

1. The model is tested at the same pressure altitude and ambient temperature as the airplane flight altitude. This limits investigations to flight altitudes equal to tunnel altitudes.

2. The heat transfer rate on the model is the same as on the prototype.

3. The model is tested at the same water catch per unit area and acquires the same ice accretion thickness on an unheated surface as the prototype. However, even if the above conditions are met, the aerodynamic effects of ice buildup cannot be determined due to the relative difference in size of the formation of prototype versus scale model.

Reference 95 is an extension of the work accomplished in reference 94 and eliminates the model testing limitations by two developmental approaches:

1. The adjustment of variables to test anti-icing models under conditions which account for nearly all altitude effects and allow for any ratio between heat transfer rate on the model to that on the prototype.

2. The adjustment of variables to test unheated models under conditions which allow ice accretion in the proper amount to produce a geometric distortion of the model proportional to that of the prototype.

Reference 130 describes the scale model testing at the French SI Modane Tunnel. The French have had excellent results with scale models down to 1/12 scale when icing similitude laws were respected. Since it is not possible to vary the tunnel altitude or temperature at this wind tunnel, the prototype flight conditions of altitude and temperature have to match the tunnel available conditions. The SI Modane Tunnel uses the winter season low temperature conditions for icing tests. Also, it is an atmospheric type tunnel.

The operating parameters of the experimental facilities are given in the survey of aircraft icing simulation facilities in North America and Europe, found in Appendix E. The tables of data on the facilities contain not only the range of operating parameters, but the size and location of the facilities as well. The types of facilities are defined in sketches accompanying the lists of facilities.

Some of the characteristics of the various test facilities selected from the lists, including icing parameter measuring instrumentation, ranges and accuracy, and general test programs are discussed below.

AEDC Engine Test Facility

In reference 137, data are presented concerning the Arnold Engineering Development Center (AEDC) with regard to aircraft engine testing in icing conditions. All instrumentation and data acquisition systems used by AEDC to document engine performance are described in the AEDC test facilities handbook. All transducer and system calibrations are traceable to the National Bureau of Standards. Specialized instrumentation systems are used to measure the state of the icing cloud at the engine inlet. Heated total temperature and total pressure probes are installed upstream of the engine inlets. Turbine flowmeters measure demineralized water flow rate in spray water systems which determines water loading of the icing cloud. An in-line holography system is used to determine three-dimensional water droplet data, particle size, particle distribution and with double laser pulse, particle velocity. AEDC feels holography methods are superior to all others used for measuring droplet and LWC data.

In reference 21, other factors about the test instrumentation used at AEDC facilities are described having to do with conventional measurements. Conventional instrumentation is used to measure engine speed, temperature, pressures, scale force, and other engine parameters. Special instruments are used for measuring total pressure and temperature in the icing environment of the inlet duct. Multiprobe pressure rake calibrates heated total pressure probes. Electrically heated temperature probes are calibrated to measure inlet total temperature. Special portholes are provided for use in photographing the inaccessible areas. Willbanks and Schulz of AEDC developed a math model of the inlet flow (thermo and kinetic properties) to the engine test article.

Engine icing reserach at AEDC has the following objectives: (1) to develop improved measuring techniques for defining water droplet number, size, and velocity, and (2) to use the measuring techniques to obtain a data base for improving the analytical model. The AEDC program as of 1978 was divided into four phases:

1. Development of an icing research test cell.

2. A survey of available particle size instrumentation systems.

3. Selection of the devices which might meet the measurement requirements.

4. Evaluation of the selected particle measurement devices in the icing research test cell.

Only work on the fourth phase continued after 1978. The first three phases were completed earlier.

The icing instrumentation survey looked for a particle diagnostic system which provided the means to measure particle diameters in the range of 5μ to 100μ at concentrations up to 600 particles/cc. Also, the system would meet the following requirements:

1. Acquisition of data in real time, nearly.

2. Continuous, in situ operation.

3. Nonperturbing to the flow field.

The four systems chosen were:

1. Fiber-optics particle-sizing system (FOPSS).

2. Particle-sizing interferometer (PSI), developed at AEDC.

3. Particle-sizing interferometer (PSI), commercially developed.

4. Backscattering particle-sizing system (BSPSS).

In-line holocamera was selected as the baseline device for the experimental portion of the evaluation.

Icing test measurement uncertainties typical of icing tests at AEDC test cells are:

PARAMETER	UNCERTAINTY, PERCENT
Liquid Water Content, gms/m^3	±15
Mean Effective Droplet Diameter, μ_m	±36
Engine Face Temperature, °K	±1.2

General Electric Engine Test Facilities

Also from reference 137, the instrumentation used at the General Electric, Peebles, Ohio test facilities and comparative accuracies experienced with that instrumentation are discussed below.

Real time measurement of both cloud LWC and drop size/distribution characteristics at the General Electric Peebles, Ohio Test Center Free Jet Engine Ground Test Facility was obtained from two laser driven spectrometers (Knollenberg probes) which were direct-connected to on-line computers for data reduction and display. Water droplet sizes are also determined from 100X photographs of an oil coated slide which is mounted to a retractable boom. Rotating cylinder systems are used to measure LWC (two cylinders - 3 in. diameter and 0.125 in. diameter). With 85 data points, the spread in laser probe, oil slide, and rotating cylinder measurements of drop size and LWC was as follows:

Liquid Water Content	0.1 gms/m^3
Droplet Size	3-4 Microns
Temperature	0.2 °C

In the 10-50μ range, the uncorrected oil slide data are large by a factor of 1.8 (agrees with AEDC test data). The causes of oil slide error are evaporation of small drops, coalescence errors, and impact errors (flattening). Multiple cylinders exhibit run off at high (27°F) temperature and are limited to lower temperatures for accuracy.

National Aeronautical Establishment Facilities

Reference 54 contains a discussion of icing experiments in flight compared with icing wind tunnel testing at the National Aeronautical Establishment Facilities in Canada. This reference concluded that natural icing conditions are used with little or no choice of the conditions of the test. In simulated icing, LWC, droplet size, etc., can be changed or controlled as can the temperature and air velocity. In both cases measurement of the icing parameters is difficult and inconvenient and are more expensive when done in an aircraft. Tests in tunnels have not as yet been able to reproduce the higher speed, low turbulence levels, and natural humidity conditions. In the wind tunnel, due to turbulence or a degree of supersaturation (either true supersaturation or semisaturation caused by presence of large numbers of very minute droplets), frost is usually deposited aft of the true ice formation. The tunnel tests give the impression that the ice formation is of greater extent than would be observed in flight. Intermittent icing from broken clouds cannot be satisfactorily reproduced in a wind tunnel as it involves transitions from saturated to drier air. This is why a pressure type ice detector may function in a wind tunnel and give no signal in natural icing, since the holes may not plug in intermittent (broken cloud) icing. Total aero drag effects cannot be satisfactorily measured in icing tunnels, due to disturbances of spray rigs and interferences of full scale models, etc., plus major drag effects are often on unprotected parts of the fuselage, wing tips, antennas, etc. Good practice dictates prudent use of both wind tunnel and natural ice flight tests and good engineering judgement.

Naval Air Propulsion Test Center (NAPTC) Facilities

Reference 43 discusses the facilities, instrumentation, and ice tunnel testing at NAPTC, Trenton, New Jersey. The facility at Trenton is capable of supplying complete environmental simulation for experimental and production turbojet and turbofan engines. The test wing houses six major test areas. There are three altitude chambers, two sea level cells, and a ten foot diameter subsonic induction wind tunnel.

Control of water droplet size in the icing system is considered to be probably the most critical factor required. The icing systems are calibrated in the test cells prior to each engine evaluation. It has been found that droplet sizes vary due to variations in the cell geometry. Consequently, parameters such as nozzle water/air pressure ratio for various droplet sizes are determined for each new installation.

The following icing parameter instrumentation is provided at the NAPTC facility:

1. Rotating Cylinders (5 cylinder)

2. Oil Slides with Silicon Grease

3. Bausch & Lomb Photomicrograph Camera

4. J-W LWC Meter

5. Closed Circuit TV upstream of spray rig

6. 16 mm High Speed Camera

7. 35 mm Robot Camera

The most effective way of determining LWC was by calculation, knowing the total water and air mass flow in the spray rig. This was because the attempts made to use the Johnson-Williams LWC meter in the cells resulted in inaccurate data.

Duct airflow is measured utilizing a steam heated total pressure probe and four heated wall statics. Duct air temperature is read on an electrically heated Rosemount probe.

Aircraft Tanker Facilities

Reference 121 contains discussions of the advantages and disadvantages (shortcomings) of aircraft tanker testing. It is the opinion of some Air Force experts that (after observing numerous evaluations of ice sensitive component ice protection subsystems) tanker, natural, and wind tunnel tests conducted on similar planforms do correlate where similarity in temperature, airflow, average LWC and drop sizes exist. However, with tanker tests the models are always full scale, and the aircraft, in combination with the spray tanker, has the capability to move different sections of the aircraft in and out of the spray cone, providing a degree of safety not found under natural icing conditions.

Tanker tests are reliable but meteorological conditions day-to-day cannot be controlled. Variations in humidity and ambient temperature, effects of cloud cover, and freezing level altitude are a few factors which have to be reckoned with when conducting tests with a tanker. With present systems, adequate control is maintained over the flow, both in rate and volume, of air and water to produce consistent clouds having an average LWC of any chosen value from 0 to 1.75 grams/cubic meter of air. However, only very limited control over droplet size distribution is attained. This is due to the fact that the spray nozzles are usually designed to operate most effectively over a fixed distribution having a mean droplet size or a fixed flow rate. Also, the cloud behind any tanker is turbulent, as opposed to the stable conditions in natural weather. There is a definite distance from the tanker in which to properly conduct in-flight icing tests. Flying too close to the nozzles produces liquid water instead of ice, and too far from the nozzles produces equally unusable ice crystals. Rime ice through clear ice formations may easily be found in that part of the cloud between the two extremes.

In recent years, the Air Force has attempted to improve the spray system (reference 61). Limited calibration of a modified icing nozzle configuration was jointly performed by the AFGL and the 4950 test wing, WPAFB, Ohio. The basic modification consisted of blocking 50 of the 100 nozzle elements in the icing manifold. The resulting calibration of the nozzle configuration showed that the system provided droplet diameters in the range of 26 to 212 microns; an improvement in the 18 to 944 micron range of the unmodified manifold configuration. Since natural environment droplets are from 20 to 50 microns, the problem remains.

Facilities Rankings

Table XX is an assessment of the icing facilities by relative ranking. The "Facilities" column also contains some subdivision by including methods with the facilities. The various factors are ranked with each facility in an order from 1 to 6 beginning with the top "Undisputed Best" rank of 1 to a "Fair" ranking, number 6. In the places where no rankings are given, the assessment factor is not applicable to that particular method or facility. Therefore, no overall ranking of one facility against another is given or is it thought to be necessarily appropriate.

ASSESSMENT OF NEW ICE PROTECTION METHODS (TASK 6)

The majority of modern light transport aircraft and some general aviation aircraft will fly in icing conditions, either in the course of regular routes or during inadvertent/unavoidable encounters. Conventional ice protection systems (electrical, hot air, chemical, and pneumatic) have been developed to the extent that technical improvements seem to come only in small expensive steps. Consequently, there exists a requirement for new innovative, low power, and inexpensive ice protection systems. The major technical need (reference 29) is a system characterized by a small required specific power. By this, is meant the smallest amount of power per square inch of the projected surface. Such systems are discussed in detail in the succeeding paragraphs.

ELECTROIMPULSE ICE PROTECTION SYSTEM

Electroimpulse deicing is based upon the technology of exerting an impactless mechanical shock to the aircraft skin in such a way that the elastic deformations of the skin result in a mechanical shedding of the ice. According to reference 102 in a more discrete definition, it is said that a high acceleration is imparted to the skin by a high pulse of energy in such a way that the ice is shed or precipitated in an inertial fashion.

The electroimpulse ice protection system is a mechanical system characterized by low power requirements as compared with thermal-electric systems, worth consideration as a new concept for ice protection. The

TABLE XX

ASSESSMENT OF THE ICING FACILITIES BY RELATIVE RANKING

RANKING LEGEND

1. Undisputed Best
2. Excellent
3. Very Good
4. Good
5. Medium
6. Fair (Rarely Useful)

METHOD OR FACILITY	RELATIVE COST	CONTROL OF ICING PARAMETERS	CONTROL OF FLIGHT PARAMETERS	EASE OF MODEL MOD., CHANGE, OR REPAIR	TURNAROUND TIME	VISIBILITY/OBSERVATION OF ICE ACCRETION	SIMULATION OF NATURAL ICE CONDITIONS	SIMULATION OF NATURAL ICE ACCRETION	INSTRUMENT INSTALLATION & ACCESSIBILITY	DATA AQUISITION & ACCESSIBILITY	OVERALL AIRCRAFT PERFORMANCE EFFECTS	SPECIFIC COMBINED ICE EFFECTS	FLIGHT AERODYNAMIC CHARACTERISTICS - STALL	FLT AERO CHARACTERISTICS - DRAG AND LIFT	ICE SHEDDING EFFECTS	SAFETY CONSIDERATIONS	OVERALL ACCURACY
Analytical Methods	1	1	1		1	-	2	4	-	-	3	5	4	3	4	1	3
Full Scale Icing Wind Tunnel	3	2	3	2	3	2	3	2	2	2	2	2	2	1	3	2	2
Subscale Icing Wind Tunnel	2	3	3	1	2	2	3	4	2	2	3	4	3	4	3	2	5
Engine Direct Connect Icing Wind Tunnel	3	2	2	2	3	3	3	2	2	2	5	4	-	-	4	2	3
Engine Free Jet Icing Wind Tunnel	3	2	2	2	3	3	3	2	2	2	5	4	-	-	4	2	3
Flight Test Tanker Icing Test	3	3	2	5	3	4	4	2	4	3	2	2	2	3	2	3	3
Flight Test Natural Icing	5	6	2	5	5	4	1	1	4	3	1	1	2	2	1	4	2
Flight Test Ice Shapes	2	2	2	4	4	1	4	4	-	-	2	2	1	2	-	5	4
Spray Rig Icing, Fan Blown	3	3	3	5	3	4	4	3	3	3	2	3	3	3	6	4	3
Spray Rig Icing, Wind Blown	3	3	3	5	3	4	4	3	3	3	2	3	3	3	6	4	3
Icing Test Cell	2	2	-	2	2	3	3	4	2	2	6	6	6	6	5	2	4

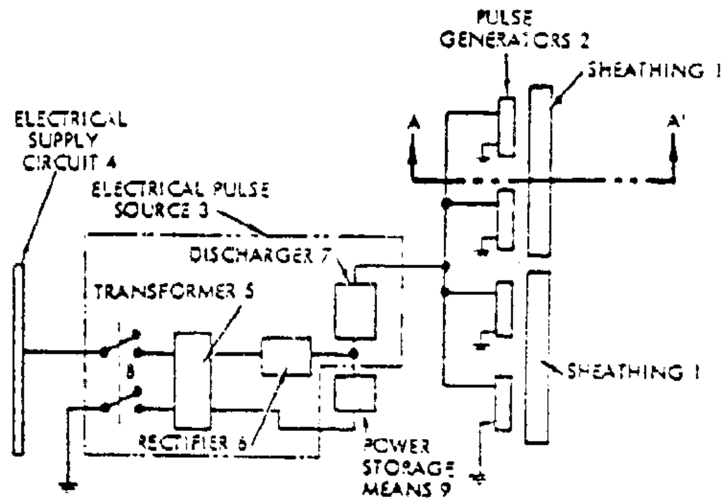
electroimpulse system is based on the principle that an impulse, coming in a precise time sequence, causes deformation in the skin and ice layer. The resultant mechanical stresses in the skin are of smaller values than the fatigue limit or the limit of cyclic strength, while those stresses arising in the ice layer are sufficient to effectively destroy the bond, resulting in ice shedding.

In order to avoid large deformations, the electroimpulse method uses a noncontact remote action such as electronic induction. To decrease power required, the system uses short power impulses followed by prolonged time intervals to recharge electric capacitors. Optimizing the shape of the impulse also decreases the power consumption. For optimum efficiency the capacitor discharge time is controlled as a function of the natural frequency of the skin and is usually set to be less than one-fourth of the natural time period. By establishing a sharp wave-front pulse of energy in the electromagnetic (inductor) coil, the skin is rapidly displaced and caused to vibrate at its own frequency. Maximum displacement occurs at one-fourth of the period; also, the ice must be shed while the skin is accelerating to its maximum rate during this period. The power requirement for the electroimpulse system is about 1/10 of that required for conventional ice protection systems, and is discussed in this section under "Ice Protection System Penalties."

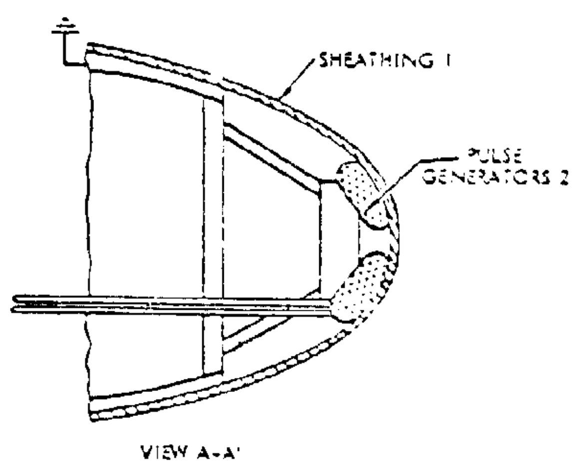
The electroimpulse deicing system in an aircraft consists of one or several standard sets of units; the actual number depending on the size of the aircraft area to be protected against icing. A standard set comprises an electric unit, a programming switch, several dozen inductors, and the corresponding number of semiconductor switches - thyristors. The electric unit consists of a voltage transformer, a rectifier, and capacitors. The electric units may be standardized, and therefore used on practically any type of aircraft. Figure 14 shows a typical electrical schematic and leading edge arrangement.

The design and location of the inductors is extremely important. The number of inductors should be kept to a minimum and they should be used with maximum efficiency. Efficiency is governed by the gap between the skin and wire turns in the inductor. The inductor itself is mounted to a nonmetallic (or insulated) rigid bracket such that the bracket deformation is much much smaller than the skin deformation. The area of skin protected (vibrated) by the inductor must be carefully determined and there should be some overlap of the areas.

Inductors can be made in various shapes and sizes, although most are round for design convenience. The number of wire turns is a function of the skin rigidity and rigidity of the structure, so several types of inductors may be required on one aircraft or component thereof. Sometimes two inductors in series connected to one thyristor unit will prove to be more effective and will allow an increase in the number of inductors in a standard set.



Electroimpulse Deicing-Electrical Schematic



Electroimpulse Deicing-Leading-Edge Arrangement

Figure 14. Electroimpulse System Details, Ref 1[illegible]

The chordwise and spanwise spacing location of the inductors is extremely important. The inductors should be mounted along the span of wing or stabilizer at intervals of 20 to 40 inches (500 to 1000 mm). If the ribs are closer together than this interval range, then an inductor should be mounted at every rib spacing. The shorter the span or the closer the ribs the more sharply the rigidity of the structure increases. As a result, the requirements for effectiveness of the inductor increase; also, a thicker skin is required because the stresses increase accordingly. The inductors should preferably be mounted between the ribs. However, it is convenient to use the ribs for mounting the inductor bracket. A loss in efficiency occurs when the ribs absorb a portion of the induced vibration amplitude which is measured in fractions of a millimeter.

The electroimpulse deicing system concept is still in the research and development stages in this country with very little information to form a data base.

Laboratory tests have been conducted (see reference 55) to check the efficiency, versatility, and possibility of future application of the electro-impulse deicing system. In this test program, a cantilever (horizontal) beam was set up, part of which was covered by ice or a specific mixture of mortar whose properties simulated those of ice. Subsequently dynamic loadings were applied at various distances from the beam end and the pattern in which the ice or mortar failed was observed. Parameters affecting the ice or mortar failure, such as beam length, distance from impact (inductor), layer thickness, and temperature of ice were measured and recorded. A simple theory for static beam loading was developed.

The tests performed were principally concerned with the mechanics of crack formation and failure of ice or mortar deposit. Since the principal concern was not the operation of the impulsive deicing system, impact (dynamic) loading was employed for deicing instead of inductor devices. A mixture of mortar was used rather than ice in most cases, because it was a more convenient material to use during the tests, not requiring refrigeration with properties which do not depend upon ambient temperature.

The main purpose of the impulsive loading of the beam (or on an aircraft outer skin) is to induce a flexural wave which will transmit some sort of energy capable of removing or breaking the ice on the surface. The flexural wave is believed to be made up of two other wave types: (1) a shear wave transmitted by shear deformations, and (2) a dilatation wave propogated by means of rotation of cross-section about the beam' neutral axis. The shear and dilatation waves are purely transient phenomena and at least 10 reflections of the two propagated waves occur before the first mode of vibration is established. Ice will usually break during the transient period and is off when vibrations on the beam are set up, so that the vibrations are not involved in the initial failure of the ice, although the inertial effects can hasten the ultimate removal of the ice.

The tests indicated that where there were cracks in the mortar caused by static loading, significantly higher impulses were required for initial removal of the mortar (ice). The mortar would absorb some of the wave energy by not letting it fully transmit through the empty spaces of the cracks. It must be remembered, then, that the type of ice accumulated on a wing at higher speed, particularly a highly swept wing, also has highly irregular shapes (lobster tail effect) with gaps which can absorb a significant proportion of the wave propogated through the skins.

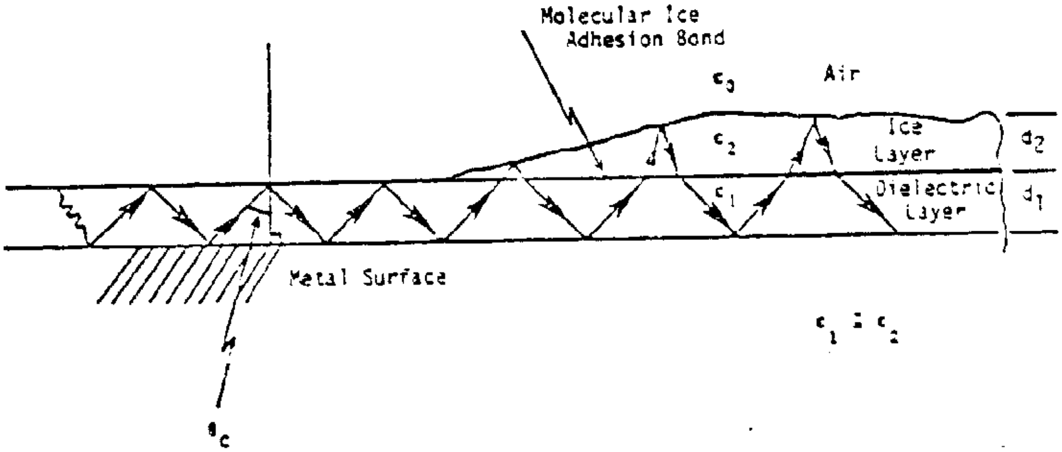
The principles of the electroimpulse system are basically sound, and they are not new since some sheet-metal-forming processes have used the same principles for many years (reference 102). However, the main attraction is that the electroimpulse system affords an electromechanical method of shedding ice, which means the skin surface does not have to be heated above freezing - as is the case for electrical or bleed air systems. As a result, the electroimpulse system operates almost independently of outside air temperature (OAT) and LWC. However, there is some purpose (in different LWC conditions) in changing the cycle time so as to allow some ice mass to form on the surface before it is shed. It is implicit in this type of system that they do not have the runback or insufficient heat problems which plague many present deicing systems.

Because of the potential merit of the electroimpulse type system and the interest shown by various organizations, it is recommended that further research and development activity be conducted to explore, in more detail, the technology of this system. Practical test models representing current and planned airfoil configurations and fabricated with the proper materials and design techniques should be tested in an icing tunnel to validate the performance of the system. These research and development tests should be designed to concurrently provide parametric data as a foundation for an organized data base which will support the requirements of the general aviation industry in the design of such an ice protection system for existing and future aircraft.

MICROWAVE ICE PROTECTION CONCEPT

The basic concept studied in the feasibility analysis of reference 115 is the use of a surface waveguide, composed of a thin layer of a stable dielectric material that has approximately the same dielectric constant as ice, for deicing the surface to which it is applied (figure 15).

In the ice-free condition, microwave power injected into the surface waveguide will propagate down the dielectric slab, with relatively little loss of power, by successive reflections off its boundaries in what has been termed a "trapped mode." This requires that the angle of incidence of the microwaves on the air-dielectric interface exceed the critical angle, θ_c, for total reflection. As layers of ice begin to form on the dielectric surface, they will have the effect of thickening the surface waveguide so that



ϵ_0 = dielectric constant of air
ϵ_2 = dielectric constant of ice
ϵ_1 = dielectric constant of dielectric layer
d_1 = thickness of dielectric layer
d_2 = thickness of ice layer

Figure 15. Guidance of Microwave Energy by Composite Ice-Dielectric Surface Waveguide. Ref 115

microwave energy will be able to penetrate the ice layer and be totally reflected at the ice-air interface (figure 15). The ice layers containing the microwave energy will be subject to dielectric heating by dissipation of the microwave energy and will experience a temperature rise. Only the ice will experience appreciable heating, the ice itself providing the mechanism for converting microwave energy to heat. In the conventional thermal deicing system, electrical energy is converted to heat in resistive heater pads that line the entire leading edge of the airfoil; sometimes the entire leading edge of the airfoil is heated, including portions where there may not be any ice.

The high efficiency of the microwave deicer depends upon the following considerations:

1. The microwave technique provides a means of efficiently directing energy only to the existing ice. The airfoil itself is not heated. If there is no ice, there will be only minor heating of the airfoil leading edge.

2. The use of hard, smooth, erosion-resistant dielectric coatings, such as alumina, significantly reduces the strength of the ice adhesion bond, resulting in lower microwave power requirements.

3. Microwave heating is very rapid and is localized to the vicinity of the adhesion layer. The rate at which the ice is heated can be controlled by pulsing. The loss of heat conduction is a relatively slow process so that there is a very rapid net gain in heat.

The major benefits required of a microwave deicing system that are believed to be feasible are as follows:

1. Low Power Consumption

2. Low Weight

3. Low Cost

4. High Reliability

5. High Maintainability

As shown in figure 16, a typical microwave deicing system preliminary design configuration may consist of the following components:

1. Microwave Deicer Boot(s)

2. Coupler

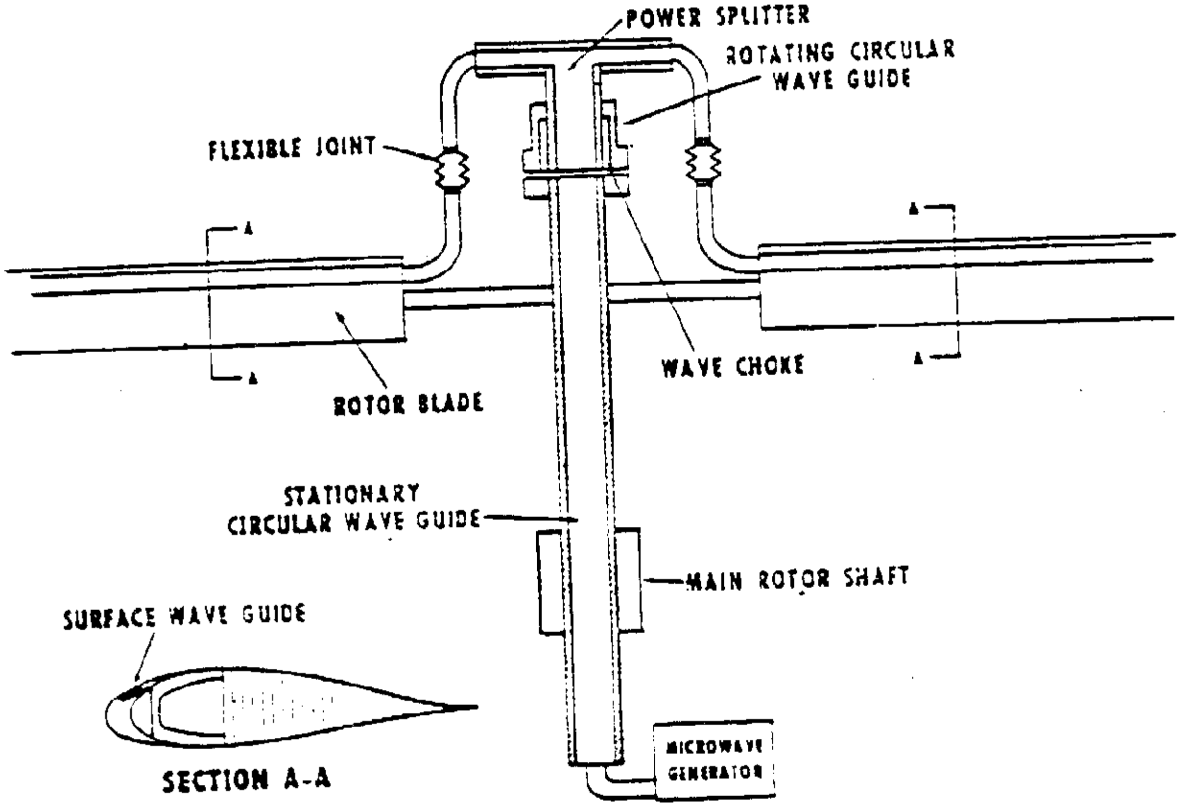


Figure 16. Microwave Deicer Rotor Blade Concept

3. Distributor/Power Divider

4. Feeder

5. Microwave Tube

6. Power Supply

7. Pilot's Control Panel

8. Ice Detectors

9. Temperature Probe (OAT)

The estimate of prime power requirements to shed ice on an airfoil leading edge is an order of magnitude less than that required by an equivalent electrothermal deicing system.

The microwave deicer system requires that the deicer boot be fabricated from highly erosion resistant dielectric materials to protect the surface from sand, dust, and rain. Some of the materials which have received the greatest attention so far are alumina, lennite, polyurethane, and nickel. The most popular combination of materials is alumina and polyurethane, which provides erosion shields equivalent to or better than nickel at considerably lower weight penalty.

The feasibility of a microwave deicer depends upon the dielectric constant and the loss tangent of the ice appearing on the airfoil (or ice sensitive component). A literature search made during the feasibility studies of reference 115 revealed that this specific information was not presently directly available.

The loss tangent of the ice which accumulates on the leading edges of an airfoil is different than that of statically grown, pure, single crystal ice used for scientific purposes. Some of the significant differences are the following:

1. Unfrozen Water Content (Super-cooled Water Content)

2. Air Content

3. Impurities

4. Rate of Growth

5. Crystal Structure

The most significant parameter affecting the loss tangent of the ice is the percent of unfrozen water content. The loss tangent is defined as follows for any dielectric material:

$$\tan \delta = \frac{\varepsilon''}{\varepsilon'} = \text{Loss Tangent of Material Heated}$$

ε'' = Imaginary part of dielectric constant

ε' = Real part of dielectric constant

The dielectric constant is made up of the imaginary and real parts. Depending upon the type of ice and the frequency considered, the loss tangent can vary several orders of magnitude. Since the power required to heat any dielectric material (usually expressed in watts per unit volume) is directly proportional to the loss tangent, it is extremely important to know the loss tangent associated with the characteristics of ice accumulated on a protected component.

Loss tangent tests have been conducted in the laboratory (reference 87) with various types of composition of ice which were supposed to represent natural icing and cover the full range of tan δ expected. Although these ice compositions may represent some of the expected types for helicopter blade icing, they are probably not the types best suited to represent the type(s) of ice collected by ice sensitive components on light transport and general aviation aircraft, particularly those not in close proximity to large bodies of salt water. Salt was used in the high-loss ice samples of the tests cited in reference 87. The ice collected on fixed wing G/A type aircraft would be more typified by the so called low-loss samples which take longer and require more power to shed. One possibility of improving the shed time and power requirements for low-loss ice, is through the use of a third layer in the dielectric composite which is called a "lossier" layer. The third layer is a thin, low loss erosion strip used for controlling the surface wave guide attenuation constant.

A comprehensive ongoing program should be conducted to explore microwave deicing technology for use with general aviation and light transport type aircraft. Much promise has already been shown for its possible use in deicing systems for helicopter blades. The systems research programs may make use of the research work done for helicopters. The research which should include high power, high efficiency, low weight microwave tubes, low-loss high dielectric constant materials, and optimized wave launchers would be applicable to all potential users of microwave deicing systems. Feasibility studies are required to determine the possible use of microwave technology for deicing wing and stabilizer leading edges. The power, weight, and cost studies accomplished for helicopter rotor protection by microwave deicing systems should be repeated as the initial effort for fixed wing aircraft.

ICEPHOBIC MATERIALS

Icephobic coatings have been a subject of investigation for the past 20 years. Many attempts have been made to find a lightweight, inexpensive substance that can easily be applied to aerodynamic surfaces which would either prevent the formation of ice or reduce the surface adhesion force to the extent that aerodynamic and/or dynamic forces would remove the ice (reference 60). A fundamental requirement in any research program to find an optimum icephobic coating material, is the knowledge of what causes ice adhesion and how to minimize it. Factors that play a part in the adhesion of ice to a surface are as follows:

1. Van Der Waals Forces
2. Hydrogen Bonding
3. Wetting
4. Roughness
5. Contaminants (Including Air)
6. Interface Chemistry
7. Contact Angle

Reducing the adhesion of ice requires reducing substrate wettability making it more hydrophobic. This is accomplished by reducing its reactivity and surface forces, making it more inert and more incompatible with water. Also, the resulting higher contact angle makes it more likely to occlude air at the interface. Air at the interface reduces the bonding and produces stress concentrations which reduce adhesion.

Water is prone to hydrogen bonding, which is the basis of the ice structure, and thus, water and ice are attracted to a substrate (surface) having H-bondable components, i.e., oxygen atoms. A low ice adhesion surface should then be free of oxygen atoms.

Chemical bonding strength or energy varies with different atom pairs and contributes to the relative activity or inertness of a substrate. A high energy surface, exhibiting high interfacial energy, has high attraction for a contacting fluid and a low energy surface the opposite. A low energy surface then is desirable. Polymeric fluorocarbons and hydrocarbons have low energy surfaces. They have low attraction for water and low ice adhesion.

Although fluorocarbons have low ice adhesion (much lower than metals), teflon (PTFE) for example, under repeated freezing cycles or high droplet impact velocities, produces stronger ice adhesion than expected. This occurs because: (1) high impact of droplet penetrates into the material pores to anchor ice, (2) the soaking changes the contact angle, and (3) during repeated freezings, the micro air bubbles are removed, thus adding bonding strength.

Another difficulty with low ice adhesion materials like polyethylene, teflon, or silicones is their softness or creep. Poor abrasion resistance may preclude their use on aircraft where there is high impact and wear exposure.

In order to obtain low ice adhesion and induce ice release, certain conditions must exist which include the following:

1. Low energy surfaces of solid substrate (or applied coatings).

2. Absence of high energy contamination of the surface.

3. Presence of low energy contamination to impair bonding.

4. Occlusion of air to impair bonding and promote stress concentrations.

5. Optimum degree of surface roughness to encourage air entrapment.

6. Substrate construction or properties that promote generation of stress and subsequent adhesive failure of the ice.

7. Appropriate stresses.

The appropriate stresses for initiating and propagating adhesive failure (as given in reference 60) include the following:

1. Single shocks from direct mechanical impact.

2. Flexing of the member/component in normal use.

3. Sonic or ultrasonic vibration at optimum frequency imposed electromechanically.

4. Heating (or cooling) intermittently to create temperature gradients and differential thermal expansion to stress interface.

5. Provide alternating strips of high and low coefficient-of-expansion materials in or beneath surface to develop stress upon temperature change.

6. Utilize bimetallic elements to magnify displacement upon thermal change. When heated by radiation, electrical resistance, or hot fluid, these bimetallic elements would induce local stresses in a flexible skin.

The implication is that some external stress is needed to initiate cracking, etc., for ice shedding to occur. This requires that the ice sensitive member or component be designed for natural flexing or be provided with an ice protection system which is a combination of an icephobic material and a mechanical, electrical, or thermal system. The best use of icephobic materials in combination with other ice protection systems is a subject for an icing research program.

Icephobic materials should be investigated to determine which candidate materials exhibit the characteristics most desirable for application to fixed wing light transport and general aviation aircraft, such as:

1. Low cost.
2. Ease of installation in new aircraft or retrofit in older aircraft.
3. Permanent or semipermanent coatings.
4. Compatibility with other aircraft materials.
5. Ease of maintenance.
6. Reliability.
7. Combined use with other ice protection/stress inducing systems.

Icephobic materials possess the potential advantages of low cost and light weight. According to reference 98, a savings of over 200 pounds may be realized in the use of icephobics over an electrothermal equivalent system for large aircraft. The use of icephobics, as with the microwave and electroimpulse systems, does not involve the problem of runback ice which is often a characteristic of the thermal systems.

The majority of the documents obtained during the literature search and listed in the computer file on icephobics concern research and development testing of icephobic materials for ice protection of helicopter rotor blades. The obvious advantage of the helicopter rotor blade over the fixed airfoil is the dynamic force of the rotating blade for shedding the ice, even through this force is variable over the length of the blade. The fixed wing aircraft must attain considerable velocity or flight speed to approach the aerodynamic forces available to the rotor in order to induce shedding.

Figures 17 and 18 show the results of some tests conducted by the U. S. Army Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire. In figure 17, the average shear force required to dislodge the ice from the test sample is plotted against successive or repeated ablative tests. The results are very erratic. Two coatings showed very low adhesion force repeatedly until the test samples were subjected to simulated rain tests, after which the adhesion forces increased to the baseline value. Figure 18 shows the life of a Dow Chemical Company substance under the flight test conditions.

The NASA research program must investigate the following factors considered in the use of icephobics for ice protection systems for fixed wing aircraft:

1. The candidate materials which must exhibit the optimum low energy characteristics, utilized with or without a soft (i.e., sponge) substrate.

2. The aerodynamic forces required to remove fractured ice - minimum required with the candidate materials for various sizes and shapes of ice accretions.

3. The methods by which the required initiating cracks or fractures will be made in the ice accumulation.

4. All of the first three considerations above for both straight and swept airfoils.

REDUCED ICE PROTECTION REQUIREMENT AND ICING INSTRUMENTATION ASSESSMENT (TASK 7)

GENERAL

A comparison of a typical general aviation aircraft flight profile to a modern jet transport profile shows that in many ways the light aircraft is faced with a more difficult ice protection design problem (reference 1).

Statistical data compiled by the FAA over an eleven year period (figures 19 through 21) show that the most commonly assigned cruising altitude for general aviation is around 5,000 feet where the largest number of icing encounters occur. Therefore, general aviation and light transport aircraft (operating up to 10,000 feet) have a more demanding enroute ice protection requirement than jet transports flying at typical altitudes of 30,000-40,000 feet, well above most of the icing conditions. Also, the jet transports climb to altitude very quickly, thus minimizing their exposure.

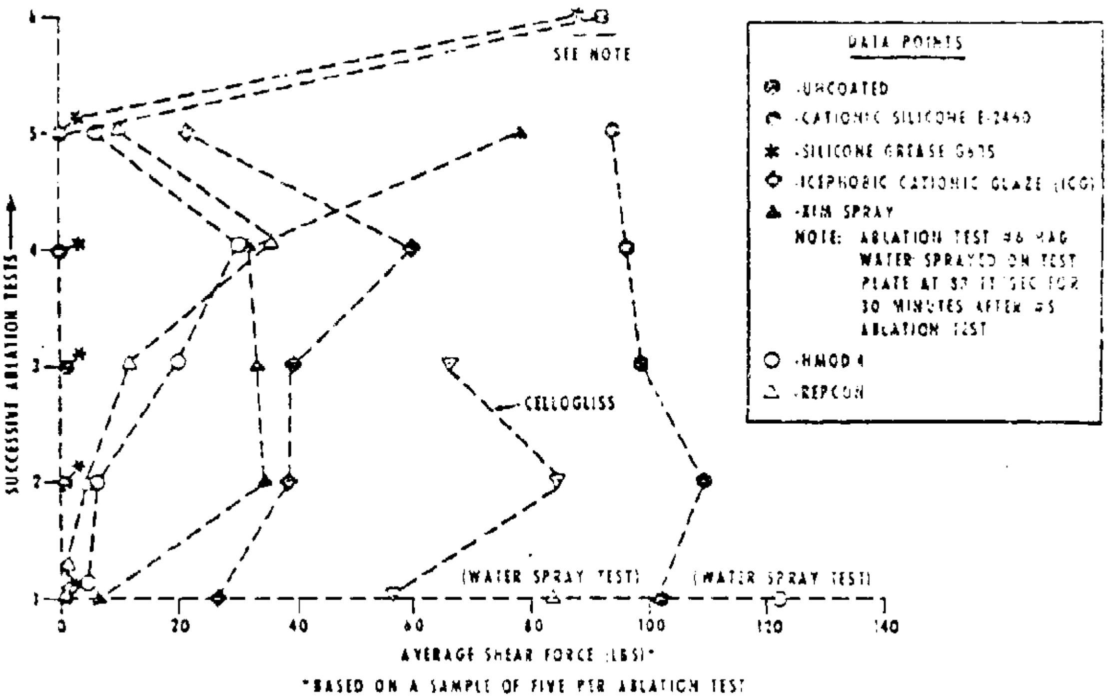


Figure 17. Average Shear Force per Ablation Test, Ref 107

AVRADCOM

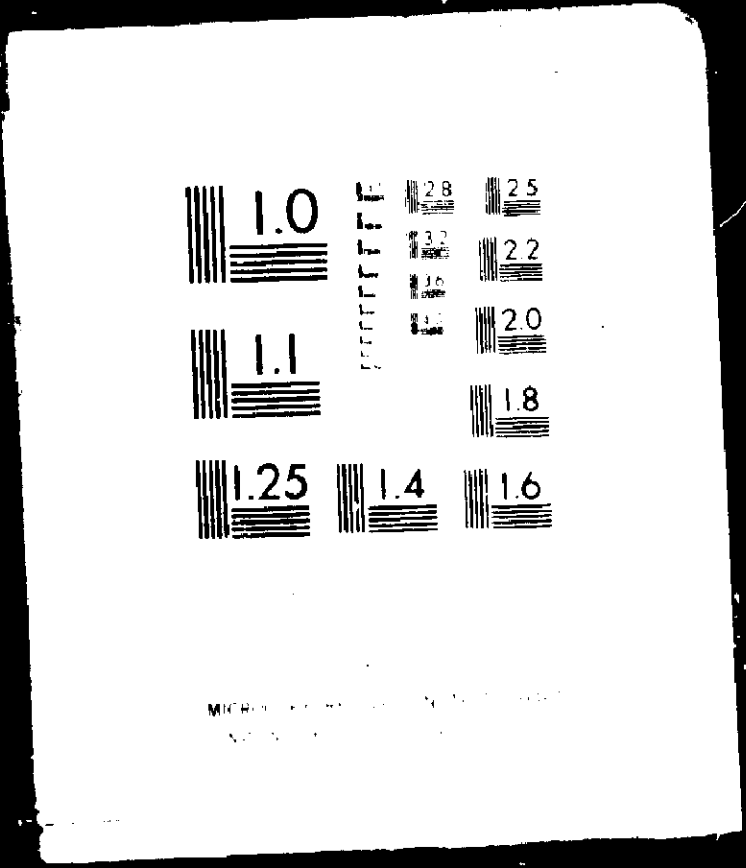
ICE PHOBIC COATING FLIGHT TESTS

- Two Materials Tested (Jan-Feb '78)
- HISS/UH-1H Tests
- DOW E-2460 Most Effective
  - -5°C ; 0.25 g/m³ >79 minutes
  - -5°C ; 0.50 g/m³ >60 minutes
  - -10°C ; 0.25 g/m³ >77 minutes
  - -10°C ; 0.50 g/m³ 40 minutes (mild shed)
  - -15°C ; 0.25 g/m³ 13 minutes (torque limit)
- Effects of Rain, Snow, and Dust, etc. Unknown

Figure 18.

2 OF 4

81-19079 UN



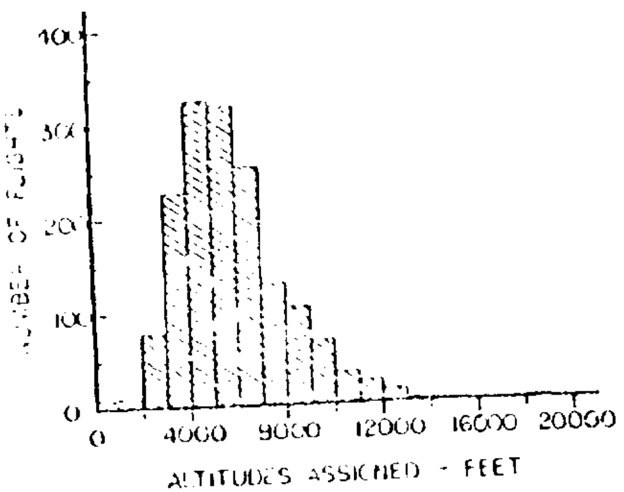


Fig 19. IFR Departures of Single Engine Aircraft, Ref 1

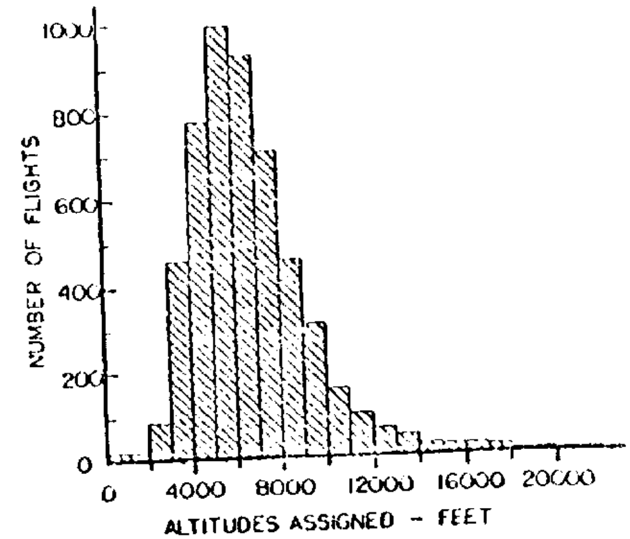


Fig 20. IFR Departures of Multi-engine Aircraft, Ref 1

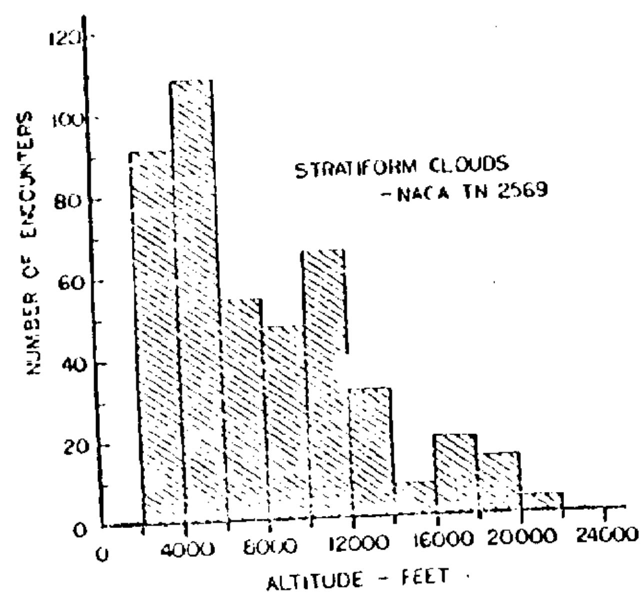


Fig 21. Icing Encounter Frequency Vs Altitude, Ref 1

Data on the characteristics of icing clouds with regard to icing severity have been obtained from a variety of locations around the world, mostly in the northern hemisphere. They cover diverse time periods, flight conditions, and sensing equipment. A very excellent summary of the icing severity data from various sources including the NASA Perkins Report, the 1972 Briggs and Crawford British Data, and the V. S. Savin, et al Russian data, is contained in reference 102, a study of ice protection for advanced helicopter designs.

No new icing severity measurements have been reported in the United States since 1952 (reference 102). However, foreign icing severity data collected more recently (1972) confirmed the validity of the older U. S. data, as shown in figure 22. The figure is an overlay of a liquid water content probability curve derived by Lewis in 1952 from 1940's data superimposed on the probability curves from V. S. Savin's data, which was based on five times more data gathered over a twenty year period.

REDUCED ICE PROTECTION REQUIREMENT

In setting up a hypothetical ice protection system requirement that is less than the severest icing condition required by FAR 25 (Appendix C), one must consider the following:

1. What are the actual cloud icing severity data measured worldwide from all sources?

2. What is the accuracy of the measured data (i.e., do the data from various sources verify each other)?

3. What are the present design requirements for full ice protection as established by the FAA?

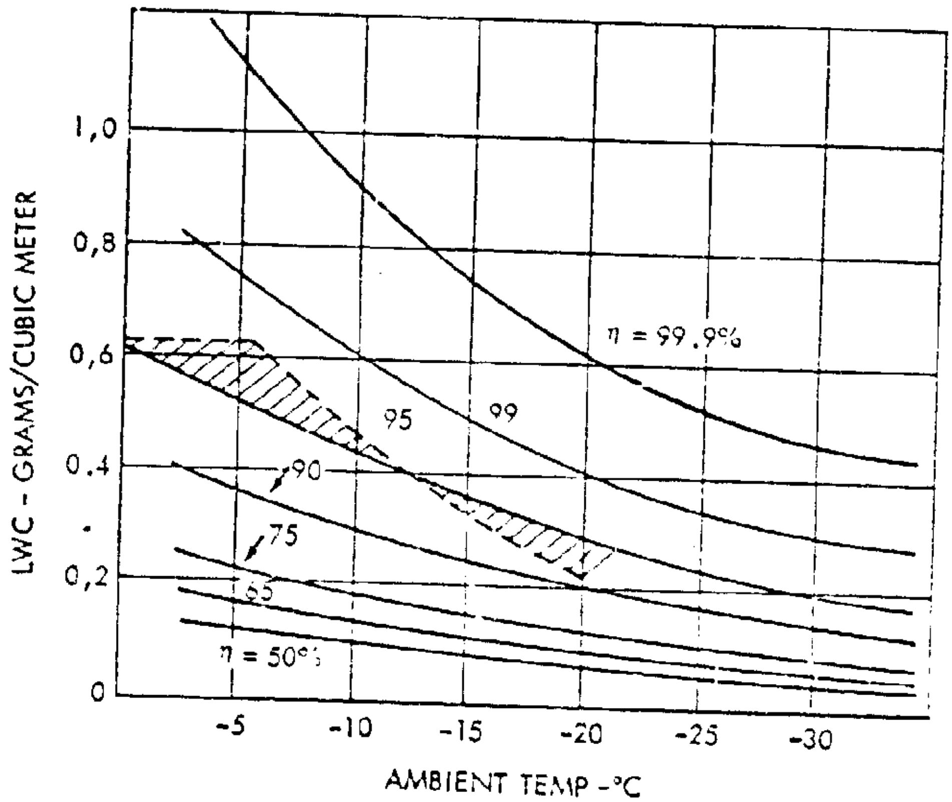
4. Considering the given flight envelope or profile for light transport and general aviation aircraft, how can the design requirements (FAA FAR 25 icing envelopes) be logically or plausibly reduced without compromising physical realities in a hazardous manner?

5. What other factors may be addressed to reduce the ice protection requirement from the severest icing condition?

The operational implications of limited, i.e., less than full FAA FAR 25 ice protection certification, requires that the following areas be studied for possible improvements:

1. Dispatch Rules

2. Crew Options



LEGEND: - - - 95% PROBABILITY LINE FROM NACA TN 2738

Figure 22. Water Content as a Function of Ambient Temperature at Different Water Content Quantities (Stratus Clouds)

3. Airborne Instrumentation Requirements

4. Forecasting Improvements

5. Air Traffic Control Restraints

6. Icing Intensity Definitions

7. Levels of Icing Severity
   Appropriate for the various G/A aircraft in terms of: (a) altitude, (b) temperature limits, (c) icing intensity, and (d) geographical limits.

Also to be considered for less than the full FAR 25 certification requirements, would be the consideration of matching limited protection systems to limited icing conditions. This would require definition of allowable ice accretion rates and knowledge of the penalties associated with the ice accretions for each individual aircraft. The decision as to what components should be protected in the designated limited icing condition, would necessarily be based on as much analysis and testing of the aircraft and its protective systems as presently required for the full FAR 25 certification.

An alternate way of showing icing severity probability is shown in figures 23 and 24 as calculated during the study for reference 102. These curves show independent probability of icing temperature and liquid water content below 10,000 feet.

The present standard icing conditions used for the design of all ice protection systems are the icing envelopes of FAA FAR Part 25, Appendix C. These envelopes of conditions are shown in figures 25 and 26 and are the basis for certification for all aircraft ice protection systems if the airplane is to fly in known icing conditions. These envelopes do not represent physical relationships between the variables, but represent combinations of the parameters considered to have sufficient probability of occurrence to make it appropriate that transport category aircraft be designed to cope with them (reference 17).

Since the probability of encountering natural icing conditions below -17.8°C (0°F) has been shown to be extremely remote (reference 102 indicated that Canadian experimenters did not find one encounter below -11°C (12.2°F) in three years of natural ice testing), the first estimate for reduced icing conditions for light transport and general aviation aircraft operating below 10,000 feet altitude would be the same as the conditions proposed for helicopters (figures 27 and 28). The curves are the same as the existing FAR 25 curves except that the low temperature limit is -17.8°C (0°F). Some researchers have considered -20°C (-4°F) as the lower limit because of the AVSCOM specification lower limit for engines (reference 102). These

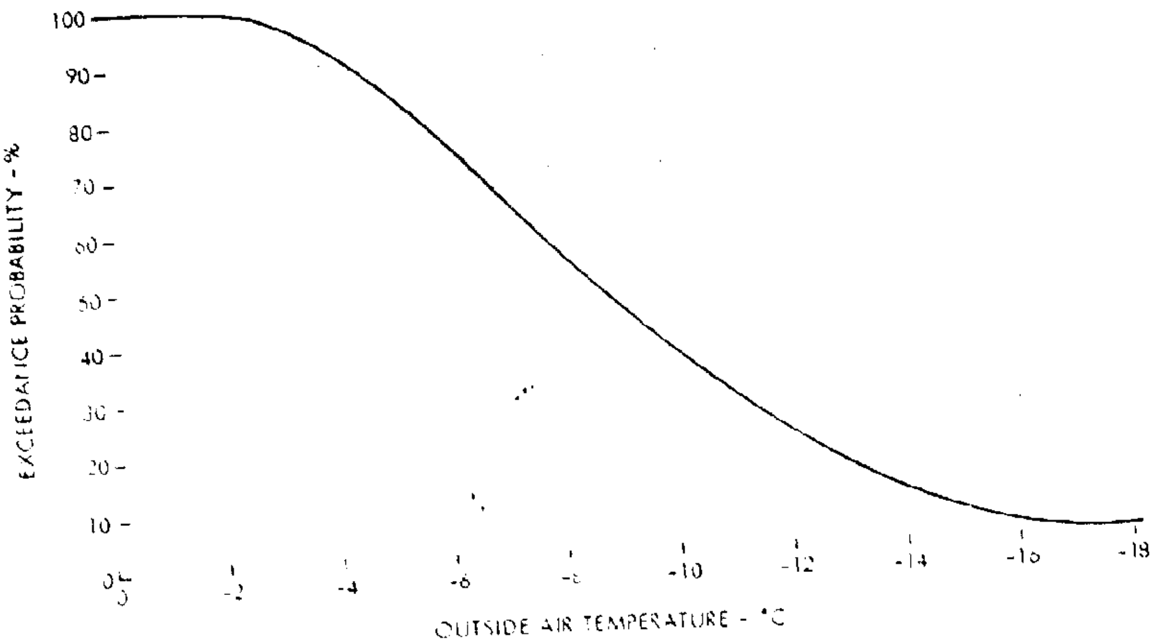


Figure 23. Outside Air Temperature Exceedance Probability Below 10,000 Ft, Ref 102

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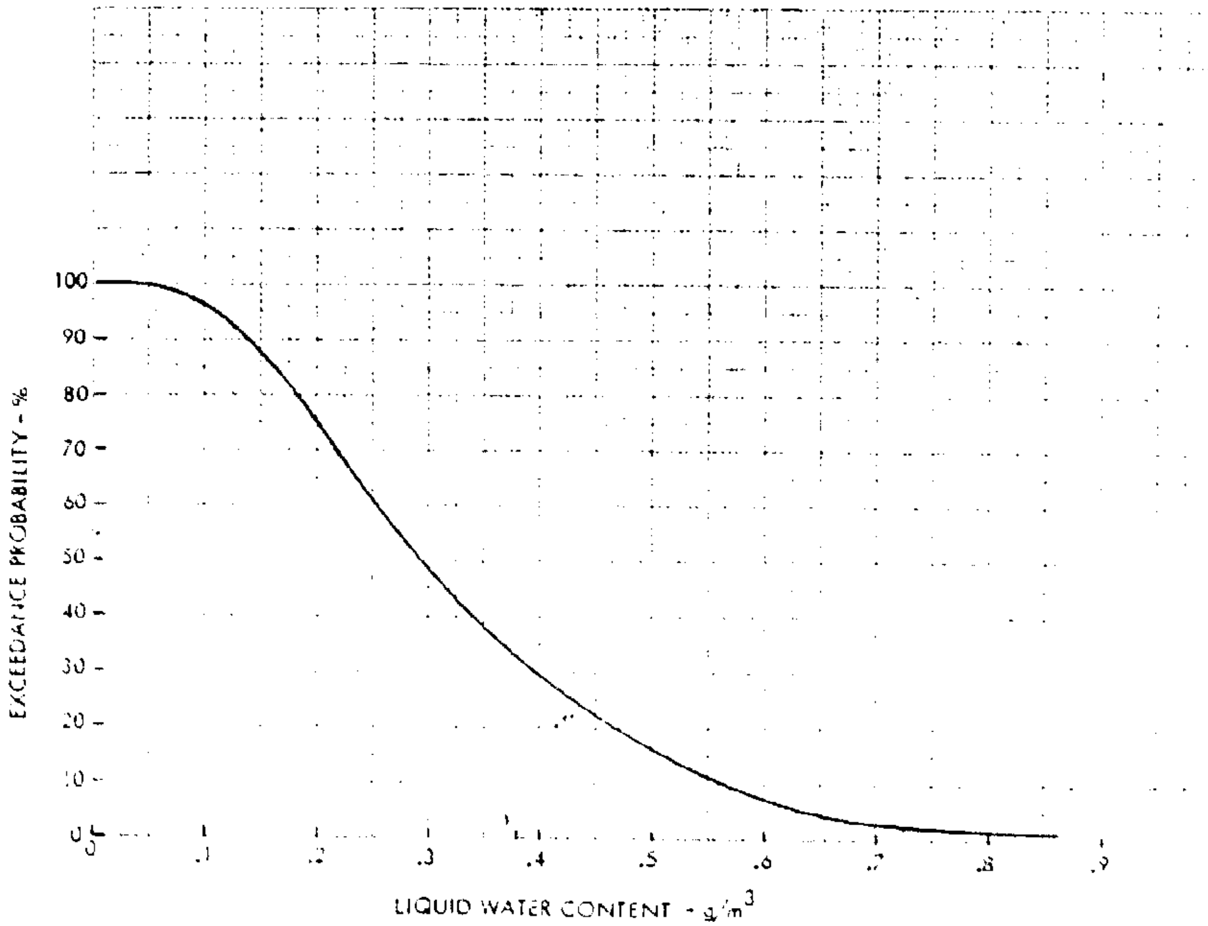

Figure 24. Liquid Water Content Exceedance Probability Below 10,000 Ft, Ref 102

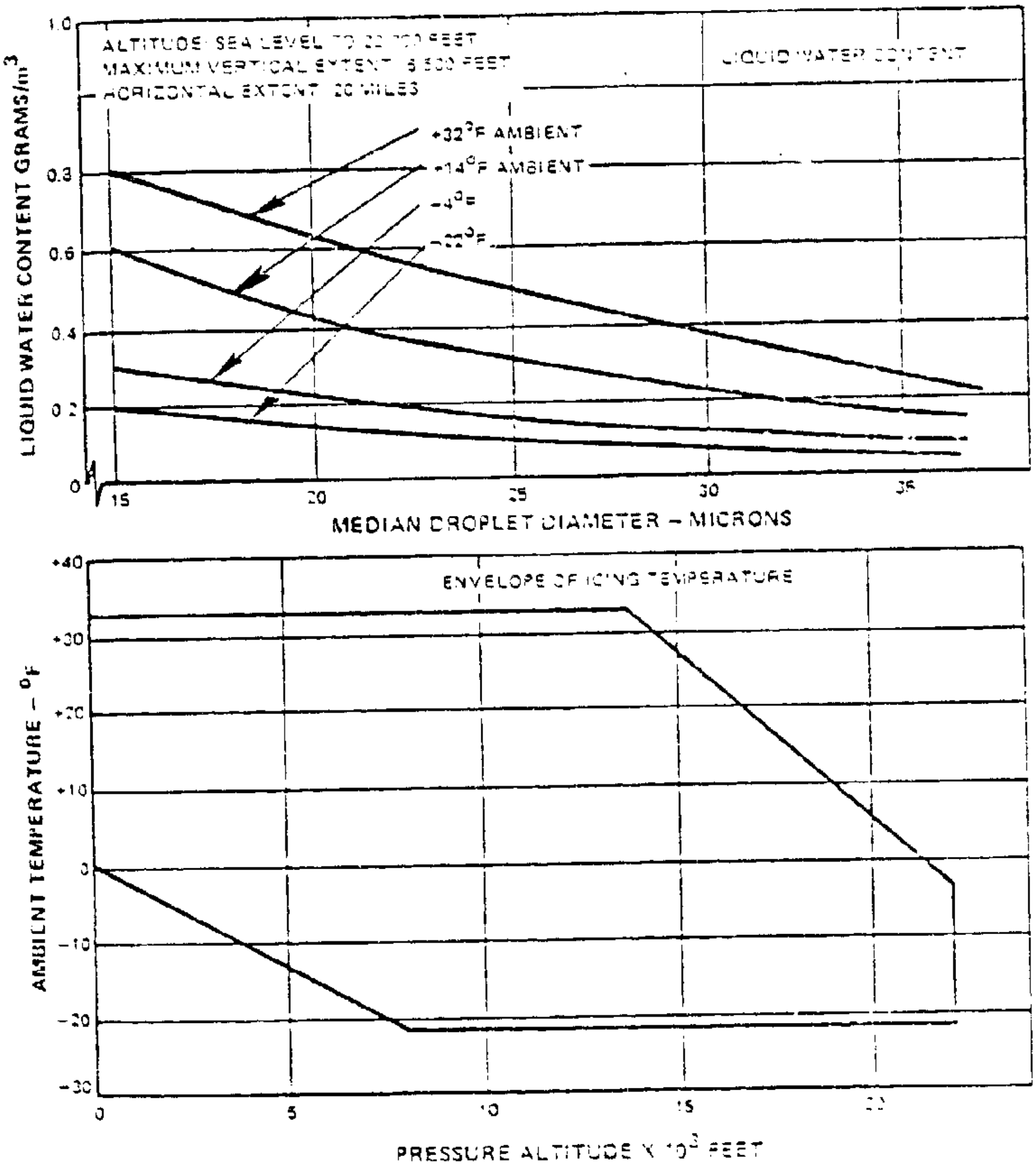

Figure 25. Continuous Maximum (Stratiform Clouds)
Atmospheric Icing Conditions
FAA FAR Part 25
(Source of Data: NACA TN No. 1855 and No. 2569)

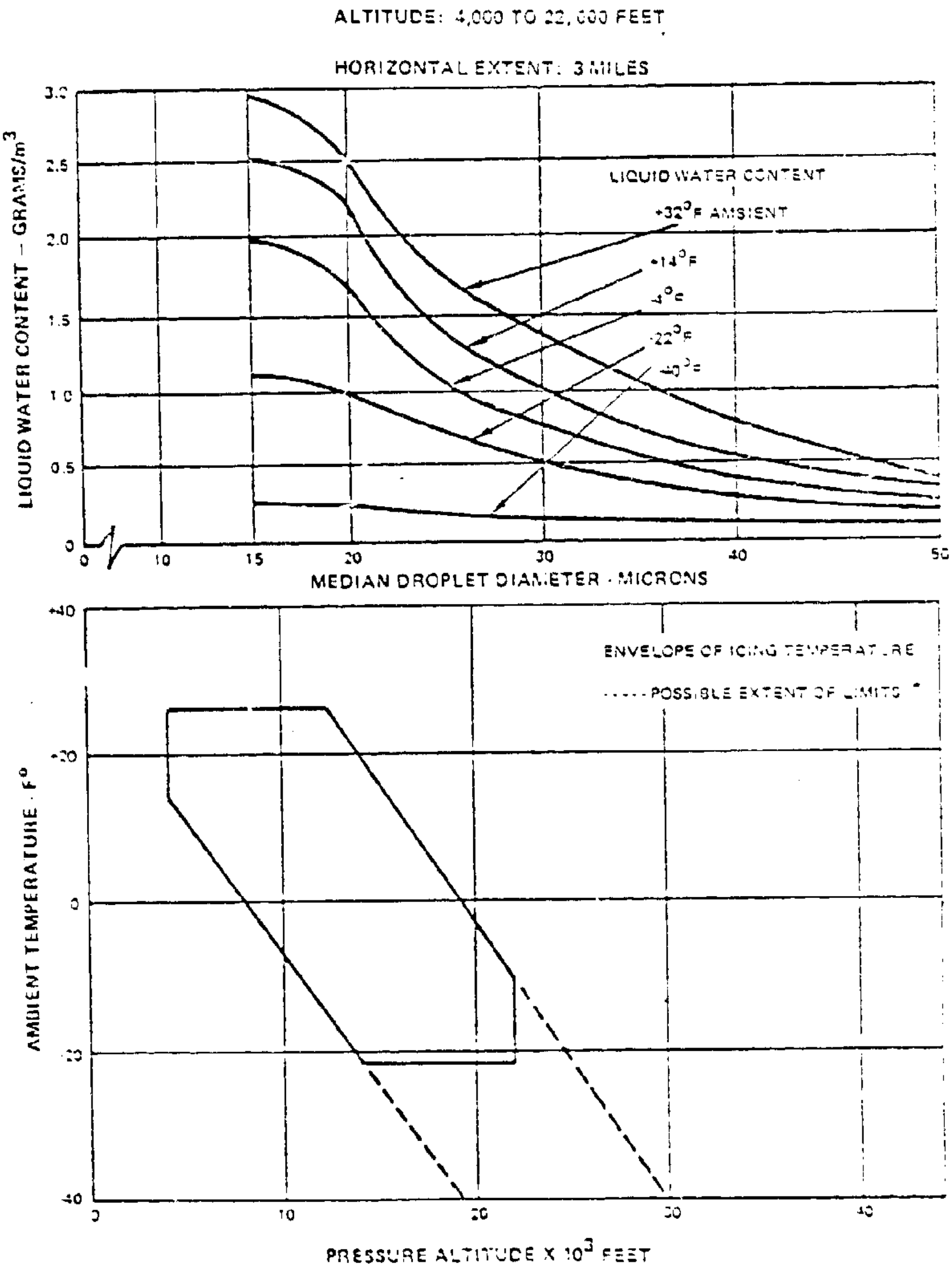

Figure 26. Intermittent Maximum (Cumuliform Clouds)
Atmospheric Icing Conditions
FAA FAR Part 25
(Source of Data: NACA TN No. 1855 and No. 2569)

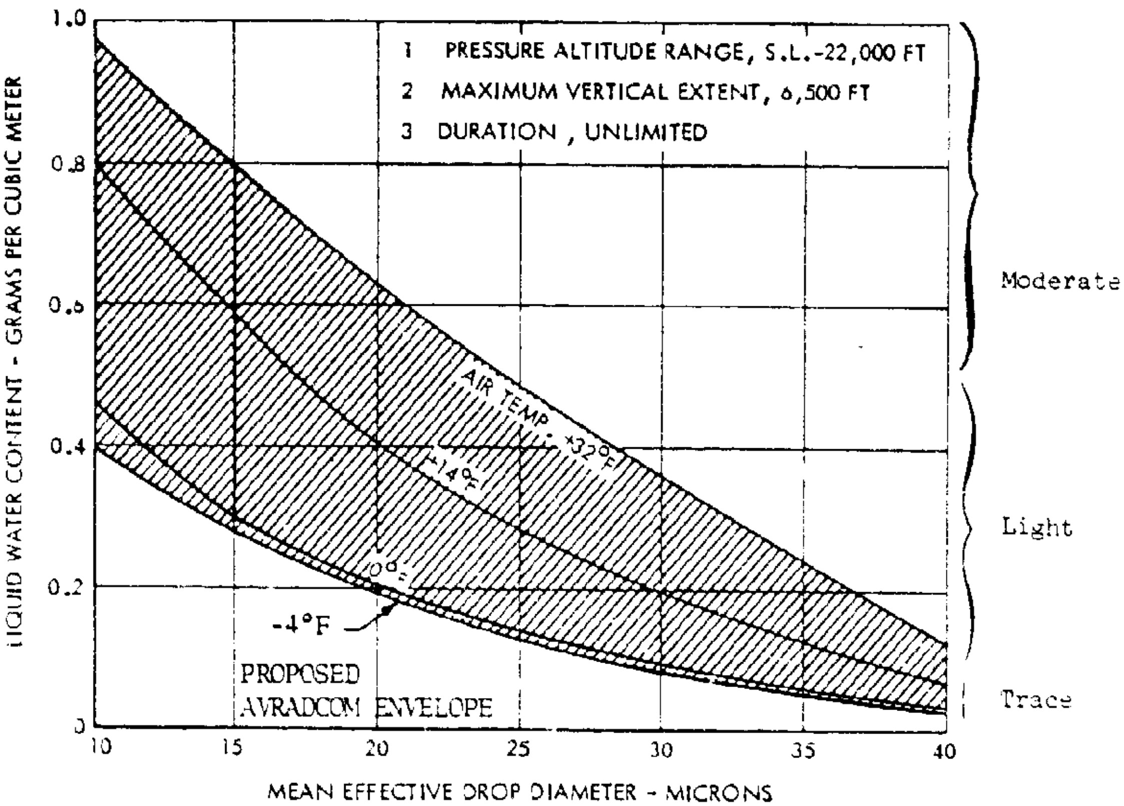

Figure 27. Recommended Continuous Maximum (Stratiform Clouds) Atmospheric Icing Conditions, Liquid Water Content Vs Mean Effective Drop Diameter, Ref 102 for Helicopters, With Ref 134 Overlay

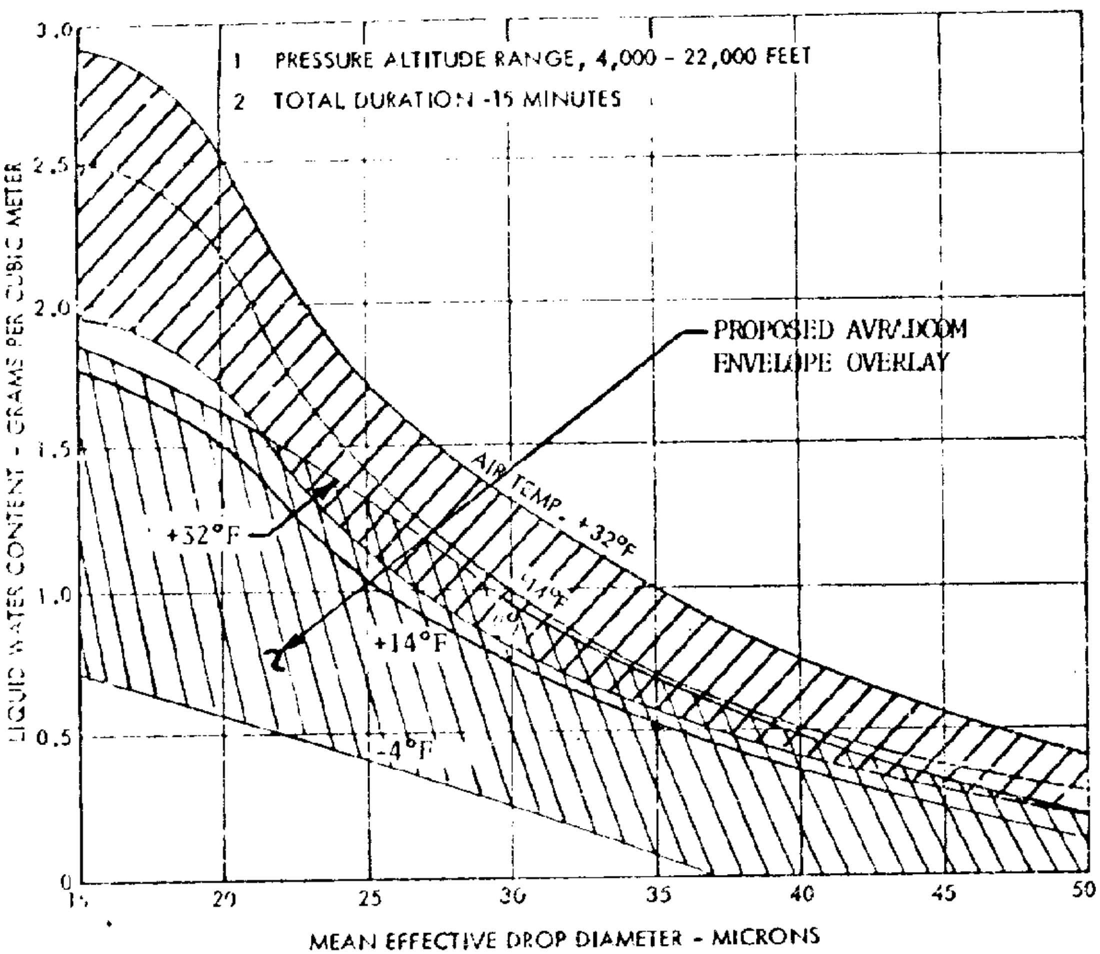

Figure 28. Intermittent Maximum (Cumuliform Clouds) Atmospheric Icing Conditions, Liquid Water Content Vs Mean Effective Drop Diameter, Ref 102 for Helicopters, with Ref 134 Overlay

criteria represent the 99th percentile of exceedance probability for altitudes up to 10,000 feet, the normal altitude range of light transport and general aviation aircraft of this study program.

ASSESSMENT OF AIRCRAFT ICING INSTRUMENTATION - EXISTING AND UNDER DEVELOPMENT

Aircraft structural icing is one of the major weather related hazards to general aviation. This hazard can be greatly reduced if the aircraft are provided with devices that will do the following:

1. Warn the pilot of icing conditions or give an indication of initial icing before the pilot would otherwise be able to detect it.

2. Give the pilot an accurate indication of the icing rate or intensity, if he chooses to remain in the icing conditions.

Another requirement is for the quantitative measurement of the various icing parameters which stems from the FAA certification requirement for demonstration of the aircraft to operate safely in icing conditions. To fulfill this requirement, it is necessary to obtain quantitative data on flight parameters such as airspeed, altitude, OAT, etc., and on icing conditions such as liquid water content, droplet size and distribution, and ice accumulation (size and shape). Also, qualitative data on aircraft handling, such as stability and control are required.

An assessment of the icing instrumentation presently used or under development by various industries and Government agencies, both at home and abroad, has been accomplished through a review of the literature. The documents containing icing instrumentation information were selected by interrogation of the computer file for such data (see Appendix C - Comments Table on Instruments). The extracted information has been summarized in table XXI. The table contains a list of icing instrumentation by name, agency source, and/or inventor. The type of principle of operation is shown for each instrument as data have been found in the literature. The instrument utilization, the measured icing parameter(s), and the problem areas associated with the instrument which may limit its accuracy or its utilization are given where known. The lack of a check mark in the problem area column does not necessarily mean there are no problems with an instrument, it can mean no data were available.

There are two basic methods of detecting and assessing icing in flight and all icing instruments fall into these two categories (reference 35). The first method is to allow ice to accumulate on a suitable probe and then detect its presence (ice accretion instruments). The second method is to sense the atmospheric conditions conducive to icing and then to continuously evaluate its likely severity (inferential or thermal detectors).

TABLE XXI

ASSESSMENT OF ICING INSTRUMENTATION

INSTRUMENT NAME AND AGENCY SOURCE OR INVENTOR	TYPE OR PRINCIPLE OF OPERATION																	UTILIZATION						ICING PARAMETERS									PROBLEM AREA				
	Differential Pressure	Electrical Resistance Conductivity	Beta Radiation Meter	Rotating Cylinders (Multiple)	Mass Balance	Electro Thermal	Heated Rod(s)	Single Cylinder (Rotating)	Vibrating Rod	Electro Chemical	Microwave	Acoustic	Mechanical/Biochemical Chemical	Optical	Infrared	Nuclear	Induced Airflow & Optical Sensor	Wind Tunnel (Icing)	Aircraft - Natural Icing	Aircraft - Tanker Icing	Statistical Research (Meteo)	Weather Balloon	Weather Station	Ice Detection	Droplet Size	Liquid Water Content	Droplet Distribution	Icing Rate	Temperature	Pressure	Humidity	Particle Counting	Limited Time (Temp. limited)	LWC or Drop Size (Range)	Electronics	Mechanics	False Signals or Delay
Kelly Probe																											X										
CSTC Laser Nephelometer														X												X						X					
Rotating Multicylinders				X														X	X	X	X				X	X							X				
NASA Icing Meter	X																	X						X		X							X				X
Fixed Large Diameter Cylinder													X						X		X				X								X	X			
Johnson-Williams Heated Wire		X																X	X	X						X								X			
Drop Snatcher - Oil Slide													X					X	X	X	X				X									X		X	
Laser Beam (ASSP) - PMS														X				X	X	X					X	X								X			
Knollenberg - PMS														X											X	X								X			
NCL Hot Rod							X												X	X						X											
Vernier Accretion Meter (VAM)							X																					X									
Evaporative Total Water - Ruskin						X																				X								X			
Dynamic Ice Detector - Stallabrass (also Leith Probe)																	X		X					X				X									
Icing Onset Detector - Rosemount									X										X	X				X												X	
Soviet IO-4A	X																		X					X													X
Differential Meter - Teddington						X													X	X				X				X						X			
PMS Raster Accretion Meter							X							X				X						X				X									
Rosemount Ice Rate Meter									X										X	X				X				X								X	
Nuclear Ice Accretion Meter																X												X									
Microwave Ice Detector											X													X				X							X		
Beta Radiation Meter			X																					X				X									
Vornvar Applicator													X											X								X				X	
Ice Particle Counter - Mee Industries														X																		X					
Univ. of Washington Ice Particle Counter														X				X														X					
Fiber Optics PMS (FWPSS)														X				X														X			X		
PMS Interferometer (PSI)														X				X														X			X		
Backscattering PMS (BSPSS)														X				X														X			X		
Pitot Static Probe																			X	X										X							
Standard Total Pressure Probe																			X	X										X							
Laser Hologram System														X				X														X		X	X		
Mechanical Scraper													X											X													X
Rosemount Type (2230) TAT		X																											X								
Normalair Garrett TAT Indicator		X																											X								
Holley Ice Condition Detector																													X		X						X
Radiosonde Instruments																						X	X						X	X	X						

For further details and discussion on these instruments, see references 36 and 37

Ice accretion instruments include rotating cylinders and discs, stationary and vibrating rods, pressure orifices, beta radiation probes, etc. The accretion method is the simplest but it does have the limitation that at high LWC and high subzero temperatures the latent heat that is released as the water freezes raises the temperature sufficiently to prevent all the water from freezing. If the instrument operates above this "Ludlam Limit" (freezing fraction less than one), it will underestimate the LWC. The accretion probe must be deiced, usually thermally when a predetermined amount of ice has formed. This is followed by a "dead time" for the deice and subsequent cooldown periods before the next reading can be taken.

At first glance, it would appear that the accretion meter is the most direct detection and warning device, but there is a wide range of icing conditions where there is no simple correlation between the impingement rate and the potential accretion rate and the form of the ice. Considering all of the variables of catch efficiency, ambient temperature, LWC, and airspeed, etc., the accretion type instrument will give fairly accurate readings in low water content air at temperatures below -10°C (14°F).

The thermal or inferential ice detection and LWC instruments utilize a heated probe or wire, exposed to the airflow, that is either maintained at constant temperature or has a constant heating power applied. The power required or the temperature attained can be used to determine the LWC, when the convection cooling is accounted for. Inferential instruments have the advantage, in that they depend solely on the evaporation of water and temperature measurement and do not suffer from the limitations imposed on accretion instruments due to accumulation of stray deposits. However, instruments such as the Johnson-Williams instrument, used widely over the years, underestimate LWC when droplets much larger than 100 microns are present. Inaccuracies occur in turbulent flow in ascertaining the amount of convective cooling.

A third method of detecting and assessing icing in flight and in icing wind tunnels for airframe structure or engine tests, uses cloud particle sizing instruments such as the Knollenberg system. These instruments measure the light scattered by a particle as it passes through a laser beam. The resultant signal is a function of the particle diameter and is used to generate a count in one of the fifteen 3 micron-wide size channels in the axially scattering spectrometer probe. This instrument measures droplets in the 3 to 45 micron range. Particles in the 20 to 300 micron diameter range are measured by one of the Particle Measuring Systems, Inc. optical array probes (reference 36). This instrument uses fifteen 20 micron-wide size channels for counting the particles. By electronically integrating the number of particles and the sizes of particles, an estimate of the LWC can be made with the Knollenberg type of instrumentation.

The majority of the ice detector and particle measuring/counting instruments that fall into this third category are used in icing wind tunnels or engine icing test cells. However, some of the laser (ASP) systems such as used by Meterorology Research, Inc. (MRI) are small enough to be adapted to aircraft for use in certification or in meteorology research data gathering. These systems are connected to a complete system which may include altitude and temperature measuring instrumentation as well as the data recording system. While this kind of instrumentation is excellent for aircraft certification programs to qualify them for flight into known icing conditions, it is much too large and expensive for standard aircraft equipment for ice detection and intensity determination for pilot warning purposes.

Assessment of icing instrumentation is complicated by the fact that different groups or different researchers cite such different opinions on effectively the same kind of instrumentation. In reference 137, experience with oil slide data for measuring droplet sizes in the 10-50 micron range resulted in data too large by a factor of 1.8. Errors were due to evaporation of small drops, coalescence of drops (small ones into big ones), and impact or flattening errors. In reference 33, oil slide droplet sampling gave repeatable, stable samples such that there was no reason to doubt the accuracy of the oil slide system. It was stated that the reason that none of the normal problems attached to oil slide measurements were encountered, was due to the choice of oil and the method of operation. The oil used was a Shell Dentax 250 or a straight mineral oil SAE 250. The procedure was to extend the slide for only 20 seconds, expose it for 1/10 to 1/20 of a second and then retain the slide in the conditioned cabin of the airplane.

Considerable research remains to be done with respect to icing instrumentation technology. This research includes the following:

1. For existing instrumentation, determine the practical or optimum range of conditions for the instrument, its percentage of uncertainity, and the proper operational procedures.

2. Develop new icing parameter instrumentation such as the laser hologram two and three-dimensional systems with the associated electronics that may be used in icing wind tunnels. For this use, size and complexity are not limiting factors and the intent is the development of equipment that can be used as a standard for calibration of smaller and less expensive instrumentation. There is no standard at present.

3. Develop small accretion and inferential icing instruments that can be calibrated in icing tunnels against the standard equipment with the desired high level of confidence. The inexpensive small instruments can be the suitable instruments needed by general aviation aircraft.

4. The instrumentation required for airborne utilization should include instruments for measuring liquid water content, outside air temperature and possibly mean water droplet size. However, in the case of the latter parameter, it is not necessary to know the droplet distribution for aircraft icing effects evaluation. Also required for the airborne instrumentation which will be used for supplying data for forecasting, is the recording and transmitting equipment. Development of this equipment is required right along with the sensing equipment if weather stations are to be provided with the required data base for current up-to-the-minute quantitative forecasts.

ASSESSMENT AND RECOMMENDATIONS FOR ICING FACILITIES (TASK 8)

NASA recently completed a survey of aircraft icing simulation facilities in North America, providing for each facility its operational parameter ranges and size restrictions. (The results of this survey and a similar summary from reference 130 for the European facilities are provided in Appendix E.) Each North American facility was classified by NASA as one of four possible types: (a) wind tunnel, (b) engine test facility, (c) low velocity facility, or (d) tanker facility. The advantages and disadvantages of each of these categories were previously discussed in the section on "Experimental Prediction Methods."

The wind tunnel capabilities presented in the above survey indicate that test chamber sizes vary from 6 inches to only 4.5 feet, when NASA facilities are excluded. These size restrictions limit testing in these tunnels to instruments, small components, or scale models of larger aircraft components. Larger components and full scale aircraft will have to be tested in the NASA Icing Research Tunnel (IRT) or the rehabilitated Altitude Wind Tunnel (AWT). Only six wind tunnels other than the IRT and AWT are listed. and of these, only three (Lockheed, Boeing, and NRC-Canada) appear appropriate for testing of small components or scale models of aircraft. As a result, in addition to size restrictions, availability of these tunnels to industry becomes a problem.

It becomes increasingly apparent that in order to obtain the wind tunnel data base required to solve general aviation aircraft problems, the NASA icing wind tunnels will have to be utilized to a greater degree, and improvements will have to be made to expand the applicability of these tunnels, increase the accuracy of test measurements, and reduce the turnaround time between tests. These facilities are discussed in more detail below, including needed instrumentation, and recommendations for usage.

NASA ALTITUDE WIND TUNNEL (AWT)

Details of the existing NASA Lewis Altitude Wind Tunnel are shown in figure 29. Proposed rehabilitation modifications indicate that the AWT will have two large chambers for testing complete or large sections of

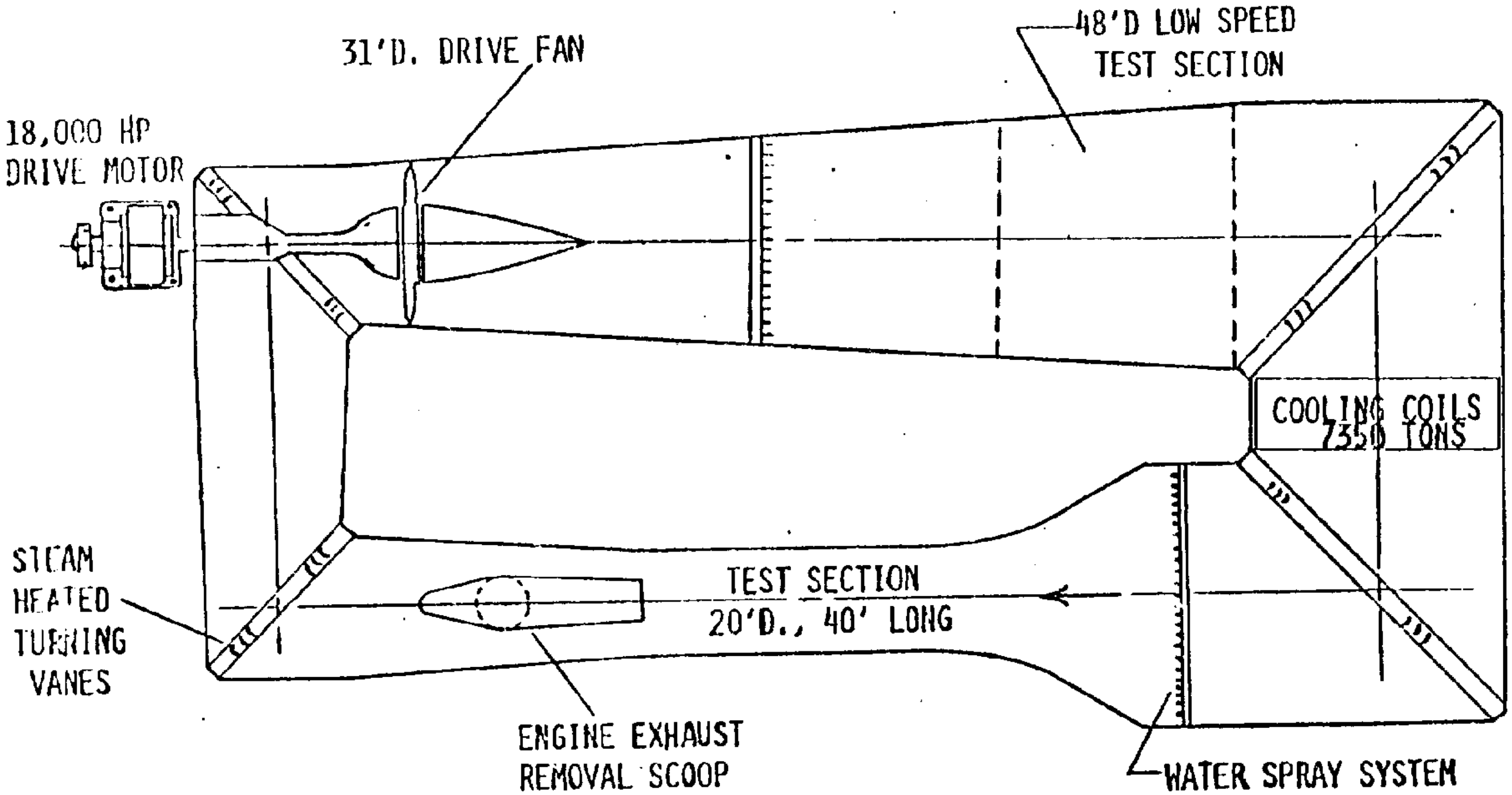

Figure 29. AWT Flow Circuit

aircraft. One test chamber is 45 feet in diameter and the other is 20 feet in diameter. The altitude versus velocity envelopes of the two different test sections are shown in figure 30. The altitude capabilities of the facility are sea level to 55,000 feet. This capability is applicable to both test sections since they are in the same loop. The velocity of the 20 ft diameter section is mach 0.8 maximum and the velocity of the 45 ft diameter section approaches 60 knots maximum. An overlay of the general aviation operational envelope on the AWT characteristics envelope is shown in figure 31. The characteristics of the 20 ft diameter section completely contain the general aviation envelope. The 45 ft diameter section characteristics are shown to be outside of the flight envelope of general aviation, but are applicable to ground operation and certain aspects of landing and takeoff operations.

A future option to the rehabilitation design of the AWT is to provide a 90,000 horsepower drive motor unit for the 26 ft diameter fan which in effect triples the power of the smaller drive motor. The "back leg" of the tunnel will have a simple rotor whirl rig for testing large scale rotors at speeds of approximately 60 knots. An overlay of these characteristics on the general aviation envelope (figure 33) shows that most of the envelope below 10,000 feet is included in the envelope if the provisions of this option are added.

It is understood from a recent conversation with NASA Lewis Icing Research Center staff members, that the 90,000 horsepower drive motor unit will be a future proposed modification to the facility. The velocity in the 20 ft diameter section will be sonic for the maximum power condition.

In an effort to realize maximum efficiency with regard to the energy requirements of the AWT operation, it is recommended that simultaneous testing in the 45 ft section and in the 20 ft test section be considered whenever it is possible and practical to schedule them in that way. This will require considerable planning and coordination under the direction of NASA personnel, so that tunnel conditions will be suitable to the requirements of both icing test programs.

The AWT 20 ft diameter test section with it broad range of altitude and velocity conditions will have the capabilities required for icing tests of a variety of general aviation aircraft ice sensitive structure and components and associated general research. The following are representative of the types of tests envisioned for the two test sections.

1. Wing ice and tail ice interactions.

2. Wing and fuselage junctures.

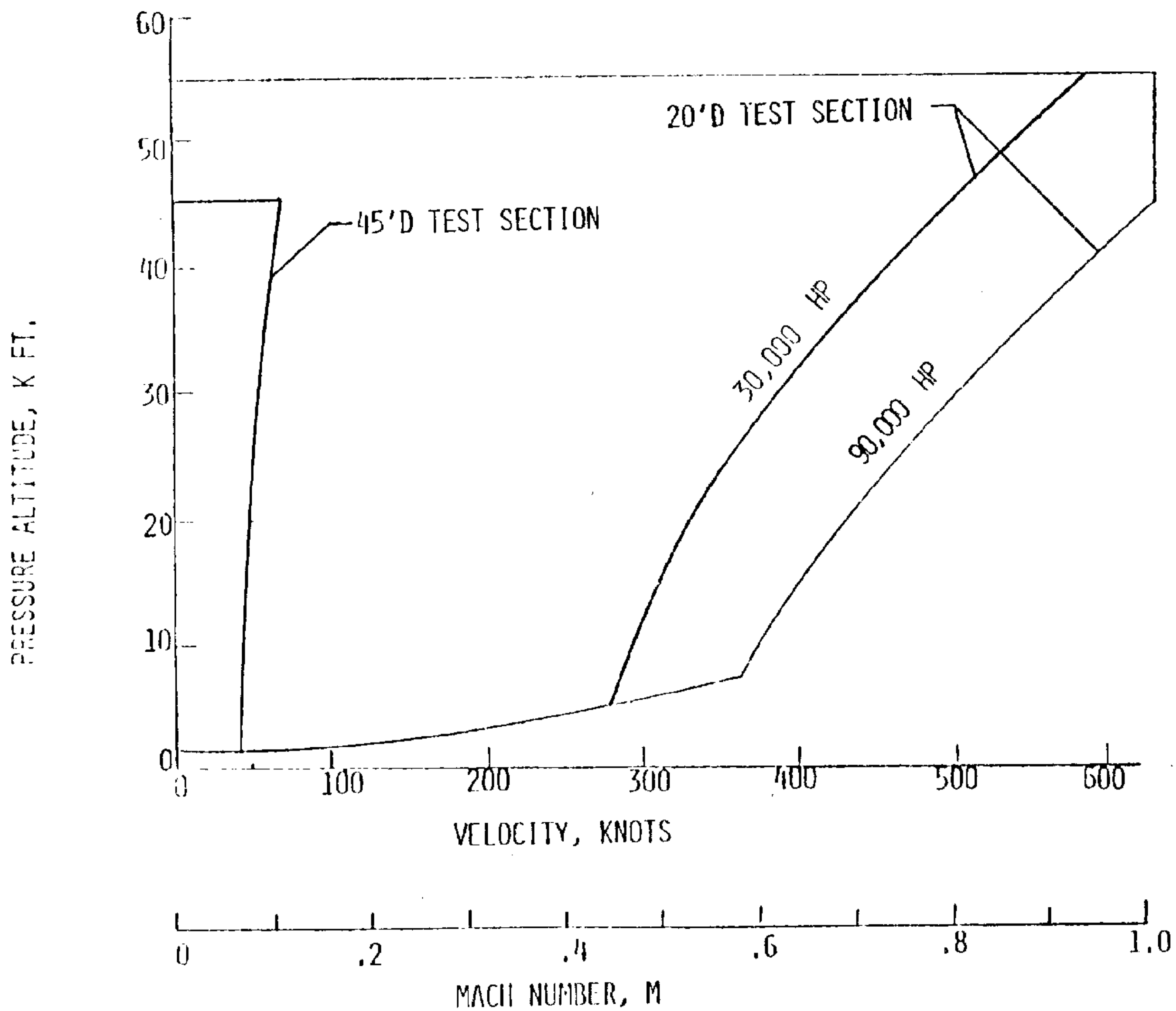

Figure 30. AWT Characteristics

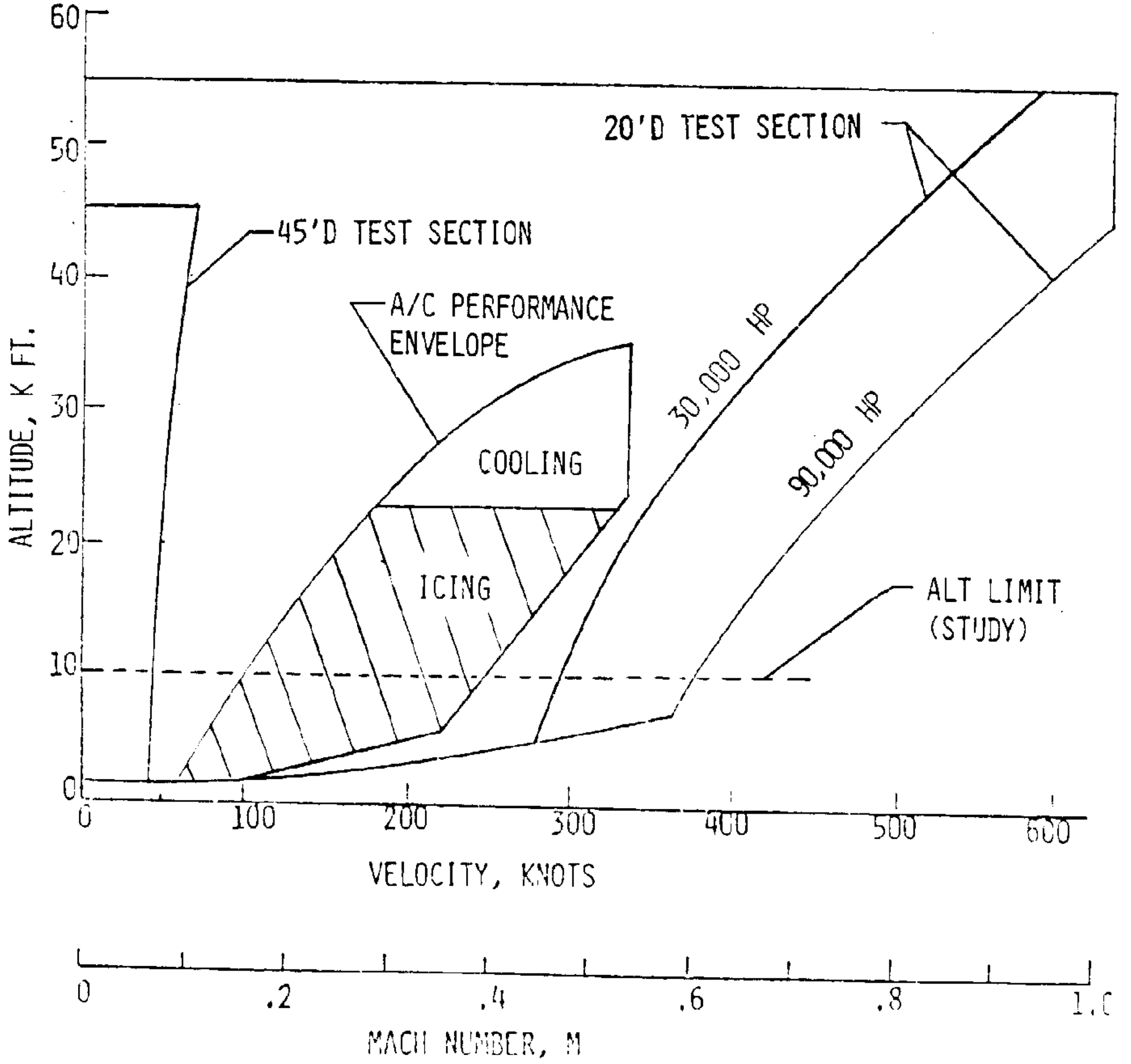

Figure 51. Comparison of a Typical General Aviation Aircraft Operational Envelope With the AWT Capabilities

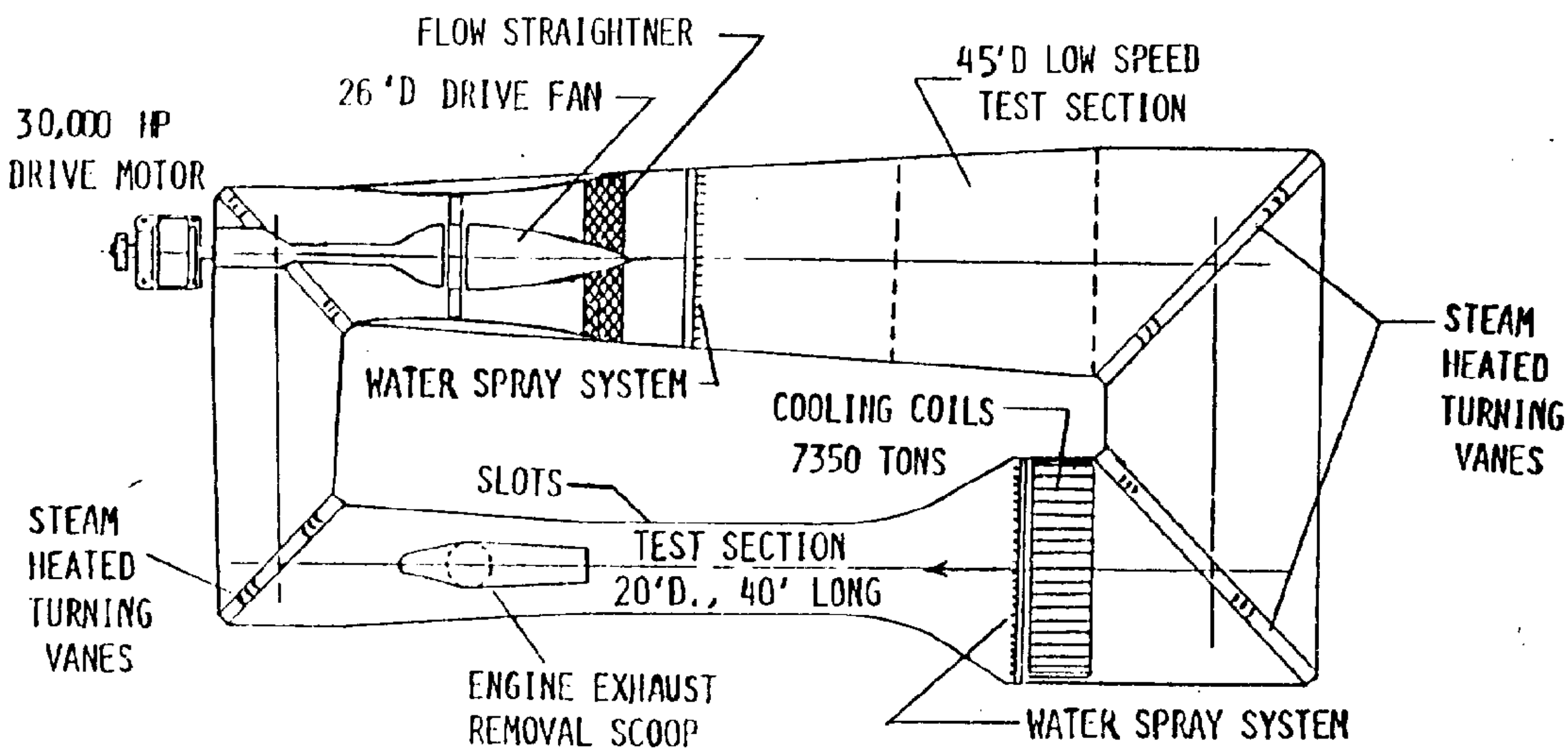

Figure 32. AWT Flow Circuit

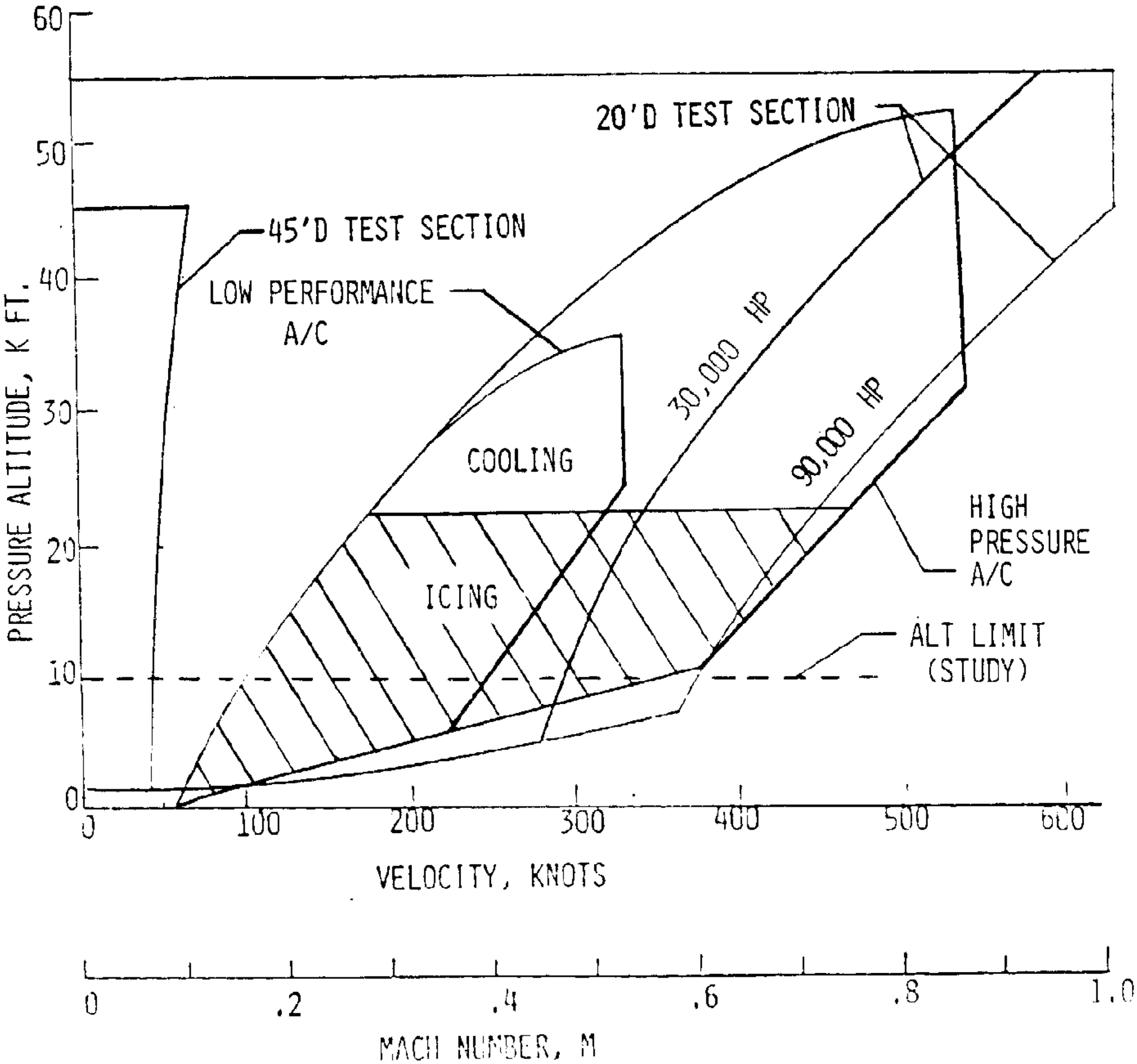

Figure 33. Overlay of General Aviation Operation Envelope

3. Wing and engine combinations.

4. Propeller, engine, fuselage combinations.

5. Empennage pod-mounted engines and fuselage (ice shedding problem).

6. Large wing sections.

7. Empennage sections (complete vertical and horizontal stabilizers; T-tails or V-tails; fuselage interaction).

8. Nacelle inlets.

9. Full scale verification tests of scale model test techniques used in small icing wind tunnels such as the IRT or smaller industry/university icing tunnels, to verify accuracy of mathematical scaling factors used for scale model testing.

10. Research and initial calibration of water spray systems designed for use on icing tanker aircraft.

NASA ICING RESEARCH TUNNEL (IRT)

The NASA Lewis Icing Research Tunnel, which is the largest icing tunnel (6 feet by 9 feet) in the United States, has been used for testing sections of full scale aircraft structure, full scale small components, and scale models of many ice sensitive components such as the following:

1. Straight and Swept Wing Sections

2. Engine Inlets

3. Radomes

4. Missile Components

5. Tail Surfaces, Horizontal and Vertical

6. Fuel Vents

7. Helicopter Rotor Blades

8. Elevator Horns

9. Engine Bullet Noses

10. Helicopter EAPS (Particle Separator)

11. Pneumatic Boots

12. Engine Cowlings

13. Inlet Screens

14. Antennas

15. Slatted Wing Sections

16. Slotted Wing Sections

In addition to the ice sensitive components that have been tested by various aircraft companies in conjuction with NASA, many other basic research programs on icephobics, icing instrumentation, ice protection systems, and other aspects of general icing technology have been conducted by NASA over the past years in the IRT.

The IRT is a closed-return atmospheric type tunnel with rectangular cross-sections except at the 20 ft diameter drive fan in the return leg. The four corners have turning vanes and the contraction section has a 14 to 1 area ratio. The test section is 6 feet high, 9 feet wide, and 20 feet long. Maximum speed for the empty test section is 300 miles per hour, creating a test section pressure equivalent to about 3,000 feet altitude. The floor of the tunnel contains a mounting plate located on a turn-table which is nearly 9 feet in diameter. The tunnel airflow may be refrigerated to -15°F or lower, if necessary. Calibrated icing clouds may be generated with liquid water contents from about 1/2 to 2 grams/cubic meter with volume mean droplet diameters from roughly 10 to 20 microns. The drop size distribution is approximately a Langmuir "D" type. The icing cloud is uniform in intensity in the center of the test section over a region about 3 feet high by 5 feet wide.

The IRT is operated by NASA personnel, but the company testing in the facility must build the model and supply a test crew to install it, run the tests, record the data, and remove the test equipment at the conclusion of the tests. The company must provide its own data recording and data processing systems.

An improvement in these conditions would be to have NASA provide the data recording and processing equipment. This would include standardized temperature recording equipment for the standard thermocouple materials normally used in the temperature range of icing and ice protection systems. Pressure measuring equipment and the data recording equipment for reasonable ranges and numbers of parameters could be provided which would simplify the logistics problems and help the preplanning of many of the test programs. Any specialized instrumentation should still be supplied by the company doing the test, the same as before. By providing data recording and automated data reduction systems, test efficiency would be greatly improved. The result would be to simplify test planning, reduce setup time, and increase convenience in operation during the actual testing periods.

The liquid water content and droplet size of the atmospheric icing clouds provided in the IRT are controlled by the water and air pressures in the spray nozzles and the air velocity in the wind tunnel. The tunnel and spray rig have been calibrated for combinations of LWC, mean droplet diameter, and airspeed, and graphs have been drawn so that other conditions can be determined. Whenever a test is conducted, the required pressures and water flow rates of the spray system are calculated from equations and graphs based on the desired icing parameters and the calibration of the tunnel. Individual measurement of the icing parameters using any of the commonly accepted instrumentation, for every test run, is generally considered unnecessary for these facilities.

Improvements to the NASA IRT was one of the subjects addressed by the industry/Government questionnaire. An evaluation of the suggested modifications and needs of the IRT to improve its utilization and efficiency are specifically as follows:

1. A large test section approximately 15 ft x 15 ft is required. (This could be the 20 ft diameter AWT section.)

2. Increased range of liquid water content (at least the complete range of continuous icing as defined in FAR 25, Appendix C).

3. Improved instrumentation (see Discussions).

4. Higher speed capability (400 knots has been suggested).

5. Altitudes up to 20,000 feet.

6. Improved accuracy in method of setting air and water pressure in spray system.

7. A uniform cloud at the test section.

8. Lower temperature range (-22°F).

9. An automated control system which would assist in faster stabilization of tunnel condition to save time and energy.

10. Complete recalibration of liquid water content and droplet size versus rotometer, air and water pressure (after other improvements in spray system, etc. are made).

11. Refurbish vanes, blades, etc.

12. Improved wake drag system.

13. Blowing/falling snow and ground fog capability.

14. More tunnels (facilities) to reduce lead times (improve availability).

15. Provide IRT force balance system.

INSTRUMENTATION REQUIREMENTS FOR ICING RESEARCH

The kinds of test techniques and instrumentation that should be available for icing research are the kinds that are oriented towards gathering the information necessary to resolve problems. The icing tunnels should have the condition control, instrumentation, test sample capacity, and other sophistication to meet this purpose. Sufficient variation in instrumentation should be utilized such that the complete required range of parameter values will be covered. Since no instrumentation exists today which can be considered as an industry standard to measure all ranges of liquid water content and droplet size/distribution more than one type of instrument for measuring these parameters will be required in an icing tunnel to increase its efficiency and flexibility.

Conventional instrumentation is required to measure temperatures, pressures, and drag and lift forces. Specialized instrumentation is required to measure total pressure and temperature in the icing environment. Heated calibrated probes are required for measuring total temperature and pressure.

Different methods of photography should be provided for good visual coverage of the test model in the icing tunnel test section. Motion pictures, television, and still photography provisions are required to record all ice deposits of interest on model mounted in position in the tunnel. Special portholes should be provided for photographic coverage of inaccessible areas. Telephoto lens and wide angle lens should be available for those photos and situations requiring such equipment.

Along with conventional equipment such as multiple cylinders and droplet oil slides, an inline laser holography system should be available for measuring liquid water content and droplet size for both calibration purposes and actual icing tests.

A large amount of test data will result from all the measurements discussed above. In order to assimilate the data successfully, it is important that data reduction be accomplished quickly and efficiently, to serve as a tool for test direction during the course of any given test series. An automated data reduction system should be considered for this purpose.

TESTING TECHNIQUES

Testing techniques in an icing wind tunnel should ensure that the air and water supplies be automatically controlled so as to provide the desired icing conditions (i.e., maximum continuous or maximum intermittent) while keeping the droplet diameters nearly constant (droplet size distribution) for varying periods of time. Techniques should also ensure that the main flow of the tunnel is saturated so that evaporation will not modify the droplet diameters which could in turn cause ice accumulations not representative of the set conditions. Continuous monitoring of the tunnel air humidity during icing tests may be accomplished through the use of automatic dew point hygrometers in the test section. This has been accomplished in the SI-MA Modane Wind Tunnel (reference 23). Humidity affects the heat and mass transfer from droplets in the spray as well as the heat and mass transfer from the surfaces subjected to ice accumulation.

RECOMMENDED USAGE OF NASA ICING WIND TUNNEL FACILITIES

The NASA icing research tunnels should be used to provide whatever test data are needed to solve the problems of general aviation and light transport aircraft. High priority problems should be attacked first, but may have to be postponed until the AWT is rehabilitated (about 1987) if large scale testing is required.

The literature search and review, and the Government/industry survey identified about eleven areas of needed research which directly require testing in the icing wind tunnels. Additional testing would also be required to support other research areas for verification of newly developed ice protection systems and analytical prediction methods. Powerplant icing tests could be pursued at the engine test facilities.

Some of the high priority items identified include generation of icing data for the newer airfoils in existence today, and the aircraft penalties which accrue from this ice buildup. The NASA LeRC facilities can be used to provide such measured ice buildup and the resulting performance degradations. Alternatively, testing at NASA LeRC could be used to define the ice accretion and shape. Then simulated ice, based on the icing tunnel results, could be used to test airfoil performance effects in any one of a variety of the dry air wind tunnels throughout the country. This might be a preferable approach, since the instruments for measurement of aerodynamic drag, lift, pitching moments, etc., are readily available at the latter facilities.

Another approach would be to use the NASA LeRC facilities to obtain measured performance data on airfoils with real or simulated ice accretions. Flight tests of aircraft utilizing the same airfoil and simulated ice accretion will provide qualitative performance data from pilot results for comparison and verification of overall effects of ice accretion. These comparisons will provide the desirable levels of confidence for aircraft performance characteristics and certification purposes.

To study the effects of airframe and nacelle ice shedding on engine performance, a combined use of NASA LeRC and existing large engine test facilities might be appropriate. The large engine test facilities in the U. S. (mainly the AEDC test facilities in Tennessee) have not only increased in size but have modernized their state of operation, including instrumentation for measuring LWC and droplet size/distribution. These facilities are used primarily for engine icing tests for full scale engines. NASA LeRC's AWT facilities would be used to define the nacelle inlet ice accretion characteristics and the amount of ice shed from the airframe which would be ingested by the engines. The AEDC test cells would be used to define engine ingestion characteristics, inlet anti-icing/deicing system operation, etc. Integration of icing test programs with more than one facility could ultimately lead to more standardized icing instrumentation for measuring the simulated cloud icing parameters.

As part of any program to develop ice accretion analysis models, it would be necessary to provide actual icing data for support and verification of the models. It would be advantageous to use the NASA icing wind tunnels for this purpose due to the capabilities and controllability of wind tunnel conditions. Controlled testing of subscale and full scale components in conjunction with model development will assure consistency and accuracy of the results.

Scaling effects should also be addressed in the NASA icing tunnels, especially after rehabilitation of the AWT. Scale model testing in the IRT would be verified by full scale tests in the AWT. The data would then be used to determine appropriate scaling parameters to improve icing predictions based on scale-model testing or analytical models.

Horizontal tail stall, wing-tail interaction, and ice shedding from full scale structural components are research areas for which a large, rehabilitated AWT would be ideal. Due to safety considerations, it would be unwise to test for these effects in natural ice. It would also be uneconomical, for reasons previously discussed, and control of the degree of icing would be up to nature.

These and a number of other icing wind tunnel test programs are discussed in more detail in the subsequent section. It is important that NASA utilize its facilities to provide ice accretion data for new airfoils, to verify the development of new or improved prediction models, and to assess the aerodynamic and safety penalties due to icing on wing, empennage, combinations, or due to ice shedding into engine inlets.

Section V

RECOMMENDED NASA ICING RESEARCH PROGRAM (TASK 9)

GENERAL

Discussed in this section of the report are summaries of the payoffs and potential benefits of research into new or advanced ice protection systems, required advancements in icing forecasting and icing definitions, requirements, for improved accurate new instrumentation, and new and/or improved analytical ice prediction methods. This summary is a prelude to the specific research program listed in detail later in this section.

Figure 34 is a flow chart of integrated icing research technical areas. The primary elements of each are listed, and the integration and/or relationship of each area is shown by the connecting lines and arrows to aircraft design and certification. The design and certification tasks are shown with many of the other elements to be directly connected with the main goal of safe operation of general aviation aircraft in the icing environment.

This goal of safe operation and improved utilization of present and future light transport and general aviation aircraft can only be achieved by new and continuing research programs directed towards improvement of the technology data base.

ICE PROTECTION SYSTEMS

In order to summarize the areas of maximum payoff and potential benefits of new research programs on ice protection systems, many factors which have been addressed in the earlier sections must be considered. One of these factors has to do with the desirable goals of any new or improved ice protection system design. Listed in rank order with the most important goal first, are the following:

1. Provide the Required Protection.
2. Low Manufacturing, Installation, and Maintenance Costs
3. Low Weight
4. Low Power Requirement
5. High Reliability
6. Simplicity of Operation
7. Minimum Effect on Aerodynamic Performance

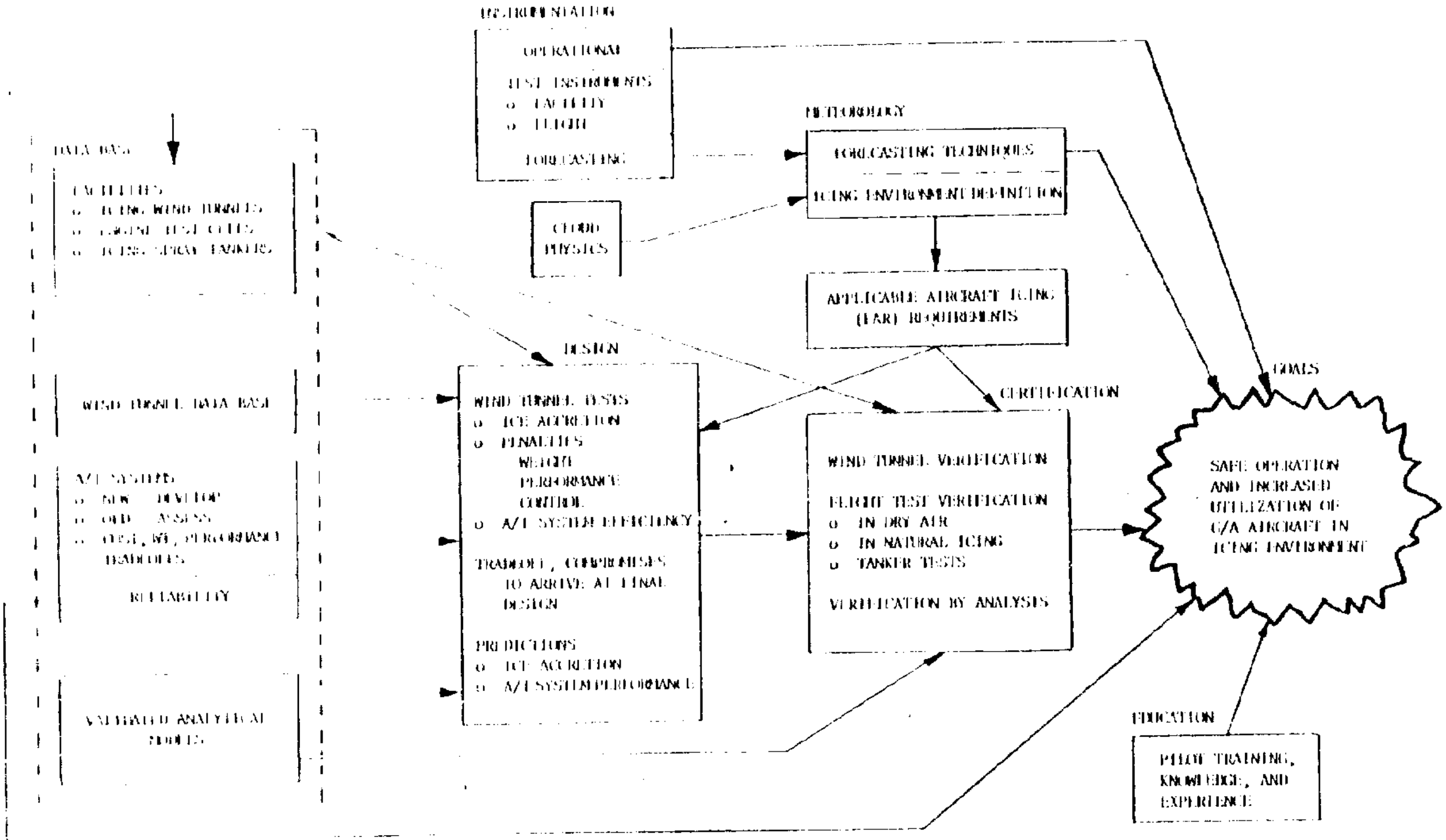

Figure 34. Flow Chart of Integrated Icing Research Technical Areas

8. Goals of equal importance include:

   a. Ease of Maintenance

   b. Quick Response

   c. Minimal Effect on Pilot Work Load

   d. Ease of Mathematical Analysis for Aid in Certification

The results of the literature search and survey questionnaire indicated that the types of ice protection systems considered the most promising for future development are the following:

1. Icephobics

2. Electroimpulse

3. Microwave

4. Acoustic

5. Combination Methods (One is primarily icephobic material.)

6. Engine Waste Heat (Exhaust gases, cooling systems and hot oil systems.)

7. Antifreeze Fluids

8. Lightweight Pneumatic Boots

9. More Efficient Electrical Systems (Heating pads, surface coatings, etc.)

10. More Efficient Application of Hot Bleed Air

The first five systems are new systems which have been investigated to some degree by various organizations in both Government and industry but as yet have not been developed to a prototype level in this country. The last five basic systems have been used with many variations. They have met with considerable success over many years, but it is the considered opinion of many experts in the field that much can still be done to improve the design and application of these types of systems. Therefore, the research requirements plan contains suggested research related to improvements of what would be considered old or proven systems as well as the new concepts.

The promising lower weight and lower power features of new ice protection system concepts (such as the electroimpulse or microwave systems) may be attained only after a considerable dollar investment into the feasibility studies and developmental tests required to produce prototype systems. This investment should be compared with the investment required to reduce weight and power of conventional/proven systems or to reduce their installation, reliability, and maintenance costs. However, this comparison cannot be made with confidence until enough research work has been accomplished on the new concepts, and on old system improvements, to obtain the data necessary to make the required trade studies. To this end, research effort is suggested in the research program plan for conducting tradeoff studies to evaluate the ice protection systems best suited to light transport and general aviation type aircraft.

It should be noted that in some cases, considerable savings could be produced by demonstrating that an ice protection system is not required. For example, if research on the aerodynamic penalties associated with ice accretion on the unprotected leading edges of the wing and empennage of an aircraft, coupled with the operational characteristics of the aircraft, showed that the need for ice protection of these components is not required, then considerable savings could be realized.

ICING FORECASTING AND ICING DEFINITIONS

Research in icing climatology, meteorology, and cloud physics to increase the data base for developing improved statistical design icing envelopes, icing intensity definitions, and timely forecasting, will lead to more accurately defined requirements for ice protection systems. This research will also provide for better utilization of the general aviation aircraft within their defined limits of operation.

ICING INTENSITY DEFINITIONS

Current definitions of icing intensities were established by the National Coordinating Committee for Aviation in February 1964 and adopted by the Subcommittee on Meteorological Services in 1968 for reciprocating engine, straight wing aircraft. These qualitative intensity definitions of "trace, light, moderate, and severe" have been interpreted differently for different aircraft. A quantitative definition of icing intensity is required which would allow the pilot to evaluate the effects of icing with respect to the particular aircraft he is flying.

Past and current efforts have been directed toward such quantitative evaluations. For example, qualitative definitions relating the icing intensity definitions to liquid water content were put in the 1969 Air Weather Service Manual based on the work of Lewis (1947) from NASA. In 1977, Newton (ref. 17) suggested that definitions relating the rate of collection of ice at 200 miles per hour on a cylinder 3 inches in diameter may satisfactorily be used for quantitative measurements. Furthermore, efforts to correlate ice collection rates on a four inch diameter sphere have been used to suggest new ways of estimating ice accretion for forecasting purposes (reference 5). This technique is intended to be an improvement on the Air Force Skew T-Log P Thermodynamic Diagram Method for existence of icing conditions and their intensity.

Both the literature search and the survey questionnaire results indicated that there is much dissatisfaction with the current definitions of icing intensity. It is felt that further efforts such as discussed above are warranted, and a research item has been included in the program plan which addresses the problem. It is the desire of all concerned that new definitions will be useful in transitioning the currently qualitative icing intensity definitions to quantitative values which apply to individual aircraft.

FORECASTING AND ICING ENVIRONMENT MODELS

Icing forecasts have been provided by the National Weather Service (NWS) and the U. S. Air Weather Service (AWS) for about 17 years without significant changes in the basic techniques to provide these forecasts (references 22 and 92).

When the Automation of Field Operations and Services (AFOS) system is installed by the NWS at Weather Service Forecast Offices (WSFO's), weather forecast offices, and air traffic control centers, it will do away with the present system. The AFOS will eliminate all the teletypewriters and facsimile machines and the enormous quantities of paper they generate and substitute an all-electronic system in which weather information will be displayed on TV screens. A weather map will arrive 40 times faster than it would on paper, and messages about 30 times faster.

Currently, forecasts (including those for icing conditions) are issued three times a day. They are updated as new data indicate that changes are warranted. With the advent of AFOS, the NWS will be in a position to provide forecasts every two hours for four-hour periods. Since 95 percent of flights have a duration of four hours or less, forecast of 0-4 hours is an important step to meet pilot demands for improved forecasts (FAA-NASA Aircraft Icing Workshop at LeRC, July 1978).

Although improvements have been made in forecasting, particularly in the area of timing, there is still much to be done. One of the major areas for improvement is in the collection of quantitative icing data for forecasting. These data would also be used to update or validate current definitions of icing intensity conditions. Respondents to the survey questionnaire indicated a need for improvement in forecasting and updated icing envelopes, and so these areas have been considered in the proposed research plan.

At present, one of the major hurdles to overcome in changing to quantitative forecasting will be in convincing the federal agency coordinating and controlling meteorological services that this is the desirable course to take. New programs in icing instrumentation research to obtain instruments for measuring the type of data which aids quantitative forecasting is a step in the right direction.

INSTRUMENTATION

Although significant advances in instrumentation techniques and design have already taken place, accepted methods of measurement still differ by more than plus or minus 25 percent in the determination of basic parameters such as liquid water content and drop size in ground test facilities. The problem is much more difficult in aircraft flight installations due to the limited space available and the usual cost restraints. There is no standard instrumentation of such proven accuracy that it may be used to calibrate other instrumentation in all ranges of parameter values.

From the assessment of the literature concerning both the current instrumentation available and that which is under development, there is still a requirement for much research to be accomplished in this field. There is a need for the development of accurate, continuous operation instrumentation for measuring LWC and droplet size and distribution in icing wind tunnels for all ranges of air velocity, altitude, and temperature conditions. The development of this type of instrumentation will not only allow for the calibration of the icing tunnel spray equipment, but will allow the tunnel to be used for calibration of other types of instrumentation measuring the same parameters, detect subtle changes in spray system conditions not normally found without instrumentation, and provide the capability of testing spray systems for use with tanker aircraft or other icing tunnels, etc. The development of instrumentation with a high confidence level for use in icing wind tunnels will lead to the development of smaller, less expensive instrumentation for airborne use. This will result from the capability to calibrate the less expensive equipment with confidence and increased knowledge.

Development of highly accurate and/or calibrated airborne icing instrumentation will facilitate the establishment of quantitative icing intensity data considered extremely desirable, if not mandatory, for improving icing forecasts, revising regulations for flying in known icing by general aviation aircraft, and improving information for flight decisions by individual pilots.

ANALYTICAL METHODS

Both the literature search and the results of the survey questionnaire indicated that the majority of the general aviation industry utilize the FAA ADS-4 document as one of their most important references with respect to icing technology. Specifically, it is one of their most important references with respect to ice accretion prediction and ice protection system design. However, questionnaire responses indicated that ADS-4 technology needs updating and improvement in many areas including fluid systems, ice shape predictions, new airfoil shapes, etc. Beyond ADS-4, a small number of specific documents were mentioned by number or author in the survey answers. These are listed in the summary of the survey/questionnaires in Appendix D.

The majority of those surveyed possess or desire computer codes for ice accretion and/or ice protection analysis. In general, these codes are considered proprietary by the company who developed them. The indication is that the codes developed for ice accretion prediction and for heat transfer analysis are all very similar in nature and essentially contain the following elements:

1. Two-dimensional potential flow field analysis.

2. Two-dimensional droplet trajectory analysis based on 15-20μ droplet for ice accretion (or Langmuir distribution), 40-50μ droplet for impingement length, etc.

3. Computer code to calculate local and overall catch efficiencies and the modified inertia parameter K_o.

4. Transient and steady-state heat transfer code that calculates heat requirements, with various refinements for convection losses, evaporation rates, runback ice amounts, temperatures, and areas of the heated surface that are dry or running wet.

In reference 121, a computer code is described for calculating ice shedding characteristics of airfoils and other body shapes. This code includes ice shedding times and simplified shed ice trajectories. A few companies have techniques developed for predicting ice shapes. Generally, little or no detail on these techniques have been indicated except that at least one company mentioned that their technique applied only to glaze (mushroom or double horn) type ice. In other areas of concern, industry has developed computer codes for engine nacelle inlets for calculating ice accretion and heating requirements.

All of the analytical techniques currently known that pertain to design and performance of ice protection systems are for conventional systems (i.e., electrothermal, hot-air, mechanical, and freezing temperature depressant fluids). In addition, there are not analytical techniques in the literature yet available for the design or performance analysis of the suggested new systems such as electroimpulse, microwave, icephobics, and acoustical. The only reported work encountered in this study program have been some feasibility studies, mostly related to helicopter rotor blades.

In light of the proprietary nature of the existing codes and the expressed desire of the industry for access to such codes, research efforts should be undertaken by NASA to improve the availability of existing and new codes for industry use. This may be done by NASA acting as a clearing house for currently available codes and/or developing new codes in-house or through contracted efforts.

ICING WIND TUNNEL TESTING

It is the concensus of opinion of many experts in the field that icing wind tunnel testing has been and still is the best method for determining ice accretion rates and ice shapes. The icing parameters can be carefully controlled within the tunnel and testing can generally be conducted conveniently without too many restrictions on weight, power, instrumentation used, etc., except for the size limits of the facility itself. Therefore, much of the research program is directed towards the use of the NASA IRT and a refurbished AWT to obtaining the icing data that meets the needs of the general aviation and light transport industry.

Scale models have always presented a problem with regard to scaling factors to be used for all of the icing parameters. If scale model test results could be effectively applied to full-scale components, large savings in time and cost would result by eliminating the need for expensive full-scale testing or flight testing in natural ice. Tests using new and current airfoils are therefore included in the program plan to research this area.

Tests are also proposed to evaluate the effects of ice accretion on auxiliary inlets and curved engine inlets. Other proposed icing wind tunnel tests include flight control surface flutter, wing tail interaction, horizontal tail stall, and ice shedding characteristics. Associated with the wind tunnel tests, are investigations of the methods for ice simulation to be used in dry air testing.

NASA SHORT AND LONG TERM ICING RESEARCH PLAN

RESEARCH ITEMS

During the course of this study, a comprehensive search was made of the recent literature concerning aircraft icing. In addition, Government agencies and industry were surveyed to obtain current aircraft icing data and viewpoints on icing problems. As the work progressed, many areas where the icing technology was weak or lacking were uncovered. Also, new ice protection systems which promise reductions in weight, cost, or power usage were identified.

These efforts culminated in the formulation of a list of research items that are responsive to the needs of the general aviation and light transport industry. Because of their nature, many of these items are responsive to the needs of large aircraft and helicopter industries as well. In table XXII is the list of the items which resulted, including short descriptions of the type of research program suggested for each one. They are grouped within the table by the general area of study, and together, they form the basis for the short and long term NASA research program suggested herein. The eight general areas of study are listed below.

1. Instrumentation

2. Meteorological Efforts for Determining Icing Criteria

3. Icephobics and Antifreeze Fluids

4. Icing Wind Tunnel Testing

5. Ice Protection Systems Development and Evaluation

6. Analytical Techniques for Prediction/Certification

7. Propulsion

8. Others

RANKING AND SCHEDULING

The list of research items in table XXII reflects the desires expressed by the general aviation and light transport industry in the literature and through the survey. However, there was no clear-cut concensus expressed as to which area should be addressed first, other than the general agreement in the survey that a training film for flight in icing conditions would be beneficial. As a result of these varying opinions and desires, it is difficult to rank and schedule the listed research items in order of importance. In addition, any attempt to do so must include other considerations, such as availability of test facilities, funds, program balance, and the need for complementary or preliminary efforts. For example, the development of standardized, accurate wind tunnel instrumentation is an effort that would affect all subsequent wind tunnel test work. Also, analytical methods for prediction and certification must be verifiable by test results, and so should follow or be concurrent with related test efforts.

A tentative scheduling of the research items described in table XXII is presented in figure 35. A ten year period is shown, with "short term" encompassing the first five years, and "long term" the last five. NASA planned facilities improvements for the Icing Research Tunnel (IRT) and the

TABLE XXII

SUGGESTED RESEARCH PROGRAMS

INSTRUMENTATION

1. ICING INSTRUMENTATION

Joint NASA/industry/Air Force program to develop highly accurate instrumentation for measuring icing parameters in icing wind tunnels and in airborne operations behind a tanker or in natural ice.

a. Wind Tunnel Instrumentation to be used as a Standard for Calibration of Other Smaller Less Expensive Instrumentation

Joint NASA/industry program to develop highly accurate instrumentation for measuring the complete range of icing parameters (drop size, distribution, LWC, etc.) that we desired to meet all design and certification needs. This instrumentation will be used for calibrating smaller, less expensive airborne type instrumentation and for the development and/or improvement of icing facilities spray equipment for artificial icing.

b. Airborne Type Icing Parameter Measuring Instrumentation

Joint NASA/industry program to develop inexpensive, durable, and accurate instrumentation for airborne measurement of icing parameters. Literature search of all current data on instrumentation and contacts with manufacturers and inventors. Obtain information on principle of operation, reliability, accuracy, parameter measured, MTBF,* maintenance records, etc. Test existing and new concepts for icing rate, LWC, drop size/distribution, and OAT; all instrumentation required for icing definition, forecasting, and pilot reports. Instrumentation will be tested/calibrated against standard instrumentation developed in (a).

METEOROLOGICAL EFFORTS FOR ICING CRITERIA

2. ICING INTENSITY DEFINITIONS

Combined interagency study between NASA and FAA to develop quantitative icing intensity definitions that can be immediately interpreted by a trained pilot and applied to his specific aircraft. Study should include use and non-use of standardized and calibrated inexpensive instrumentation (see item 1) in conjunction with icing definitions. An objective of the study would be to establish quantitative icing intensity definitions that could be proposed as an addition to the FAR's which do not presently contain any such definitions.

*Mean Time Between Failure

TABLE XXII (continued)

3. COLLECTION OF ICING CLOUD DATA FOR USE IN CORRELATING ICING PARAMETERS FOR FORECASTING, ICING CLIMATOLOGY, AND ICING ENVIRONMENT MODELING

The Air Force (AFFDL) has plans (Ref. 125) to instrument a C-130E aircraft extensively for obtaining icing cloud data; both standard meteorological measurements and measurements on LWC, droplet size/distribution and temperature will be made for correlation and relationship to standard weather analysis.

A joint NASA/Air Force effort is suggested here, since the Air Force plans include commercial aircraft in their icing cloud measurements program. One of NASA's functions would be to correlate the measured data for comparison and updating of the early NACA data. Program modifications as required, could be made so that sufficient data at the lower altitudes, which apply to both helicopters and general aviation, would be taken to improve statistical models in this range.

4. VERIFICATION OF ICING ENVIRONMENT MODELS

Various models of the icing environment exist presently or are foreseen for the future. Research to expand the data base in order to verify new models to be used for design and certification is required. Efforts should be coordinated with the Air Weather Service Organization for measured meteorological data pertaining to the standard icing parameters. Correlation of statistical data will be required to support theoretical models and identify where more data are required. The research will also help to identify where improvements in forecasting are required.

5. MIXED ICING CONDITIONS (ICE PARTICLES & SUPERCOOLED WATER DROPLETS)

Study of producing and controlling mixed conditions in an icing wind tunnel and controlling particles formed from droplet freezeout and snow from cooling coils. Determine effects on accreted ice for shape and size, density and adhesion. Assess relationship to natural environment.

6. ICEPHOBIC COATINGS SOLID AND FLUID: PERMANENT OR SEMIPERMANENT

Investigate the fundamental mechanisms of ice adhesion, ice fracture, and ice shedding and their relationship with icephobic materials for aircraft ice protection. Investigate icephobic materials for wings, propellers, empennage, engine cowl, engine inlets, and engine components. Test for chemical degradation of properties, duration, reliability, limit of icing conditions, and adhesion in combination with other protection system or methods. Investigate the erosion properties of both fluid "oozing" type and semipermanent icephobics and their compatibility with other materials.

TABLE XXII (continued)

7. ANTIFREEZE FLUID SYSTEMS

Investigate alcohols, glycols, etc. for compatibility with various aircraft materials. Determine limits of their use, etc. Investigate fuel additives for jet-fuels and for carburetor ice protection. Test the same additives for JP-4 and for gasoline and their limits of use.

ICING WIND TUNNEL TESTING

8. ICING RESEARCH TUNNEL TESTING OF AIRFOILS

Program to test full size models, full size sections, or scale models of new airfoils, with or without slat and/or flap configurations. Test new 230XX, 00XX, 6-series, new LS, MS, Eppler, supercritical airfoils, and other new airfoils for ice collections rates, collection efficiency, ice shapes, etc. Measure C_L and C_D and determine K_0 in a range from .001 to 1.0 for all the airfoils. Tests should obtain data at angles of attack and ranging from -6° to +16° in $\Delta\alpha = 4$-5° increments. The ice shapes should be determined for temperatures ranging from -22°F to +32°F. Data from tunnel tests should be compared with computer codes to verify the codes, and should also be verified by flight tests in natural ice to expand a reliable data base.

9. METHODS FOR ICE SIMULATION (MOULDING, CASTING TECHNIQUES DEVELOPMENT WITH WAXES, PLASTICS, AND ICE DIELECTRIC SIMULATION)

Research study to develop techniques for making simulated ice shapes for dry air tests. Investigate moulding techniques, accuracy requirements necessary for simulation for swept/unswept models, and materials to use. Dielectric and other properties for simulated ice accretion on radomes and antennas will be investigated. Investigate methods of attachment to aircraft structure.

10. AERODYNAMIC EFFECTS ON AIRFOILS USING SIMULATED ICE FOR CERTIFICATION

Determine aerodynamic effects on airfoils with simulated ice shapes, based on certification requirements. Data will improve safety when flight testing aircraft with ice shapes. Coordinated program of wind tunnel tests will be proposed for reducing flight test program scope as well.

11. RATE OF BLOCKAGE OF AUXILIARY AIR INLETS & VENTS IN ICING

Develop methods of estimating or predicting rate of blockage of auxiliary air inlets and/or vents by ice buildup. Test various sizes and shapes of auxiliary inlets in various icing conditions to verify method of prediction and to ascertain the extent of the blockage.

TABLE XXII (continued)

12. CURVED ENGINE INLETS INCLUDING TURBOPROP ENGINE INLETS

Combined NASA and industry research program to determine ice protection requirements and methods for S-shaped turboprop and other engine air inlets. Flow distortion caused by icing and ice shedding in the S-shaped inlet can cause engine stall. Explore and evaluate effects of ice accretion and ice shedding.

13. FLIGHT CONTROL SURFACE FLUTTER

Research program to determine vibration and flutter caused by icing on control surface. Determine limit for icing of unprotected surfaces of typical G/A aircraft. This program could be combined with items 15 and 18 and possibly item 14. Program would be intended to provide additional data base to verify analytical ice accretion prediction methods developed in other, but associated, research programs.

14. WING-TAIL INTERACTION IN ICING

Test for the interaction between the wing and tail as ice accretes on the leading edge surfaces of both components. Measure aero effects of changing angle of attack of wing and tail requirements due to ice accretions. Requires full size (complete) aircraft in large wind tunnel facility. How the LWC and droplets are affected by flow field and if the LWC get centrifuged out before it hits the tail, are questions to be addressed.

15. HORIZONTAL TAIL STALL AND ICING

Tests of T-tail, V-tail, and conventional tails for aero (stall and pitching moments) characteristics with ice accretions or simulated ice accretions. Limits for allowable ice accretions will be determined by characteristics measured for incremental buildup of accreted ice.

16. SCALE MODEL ICE TESTING

Research study to develop techniques for applying scale model test results to full scale components. Ice tests on both scale and full size models will be accomplished to develop the necessary correlation equations. Large and small wind tunnel facilities will be utilized in testing. Results will be compared with test data from flight tests in natural ice. Verification flight tests in natural icing should be coordinated with the test programs of items 8, 24, and 25.

TABLE XXII (continued)

17. ICE SHEDDING INCLUDING UNSYMMETRICAL SHEDDING OF ICE FROM WINGS AND HORIZONTAL STABILIZER Investigate the mechanism(s) of ice shedding including natural shedding characteristics of wedge shapes. Study the aerodynamic effects of unsymmetrical shedding of ice from the wing and/or tail of an aircraft (G/A typical). In particular, the roll characteristics (wing shedding) and stability problems (horizontal stabilizer shedding) should be investigated for various sizes and shapes of real or simulated ice. Tests can be accomplished in the large AWT (full size aircraft) and on scale models in the IRT.
18. BALANCE HORN DESIGN FOR WING/TAIL ICING Test various designs of balance horns on the movable sections of the horizontal and vertical stabilizers (rudder and elevators) for methods to prevent ice accretion from interferring with stability and control. Gaps between fixed and moving parts, ice shields (heated and unheated), and heated leading edges, etc. will be tested. Rubber tab on fixed portion to help remove ice on movable portion.
19. PNEUMATIC BOOT FUNDAMENTALS Investigate new lightweight pneumatic boot systems in conjunction with industry for wings, tail, etc. for conventional locations. Determine compatibility with other systems. Determine optimum cycle times, etc. Penalties for residual ice accumulation and investigation of principles of ice fracturing.
20. ENGINE HEAT FOR ICE PROTECTION Determine best method of application of bleed air for anti-deicing; cyclic, intermittent, etc. Investigate piccolo tube, single skin vs double skin techniques. Evaluate the internal heat transfer coefficients. Conduct research to determine best use of limited hot air available from small jet engines. Explore other methods of extracting engine heat for ice protection, i.e., hot engine oil, exhaust gases. Application of waste heat for ice protection.
21. NEW ICE PROTECTION SYSTEM STUDY Possible joint venture between NASA and industry.

TABLE XXII (continued)

21. NEW ICE PROTECTION SYSTEM STUDY (continued)

a. Electroimpulse

Evaluate the feasibility of candidate electroimpulse deicing systems on airfoil models (wing, tail, and propeller). Determine the design criteria and major installation problems. Evaluate the system performance for various icing conditions. Assess typical weight and power requirements, system complexities.

b. Microwave

Evaluate feasibility of candidate microwave deicing systems on airfoil models (wing, tail leading edges and propellers). Assess the microwave system requirements and system complexities and the installation problems and environmental sensitivities. Evaluate system performance under various icing conditions; power requirements, etc. Assess limitations of its use; i.e., what ice sensitive components can the system be used with.

22. ICE PROTECTION TRADEOFF STUDIES

Develop the methodology required to evaluate systems for weight power, reliability, availability, cost, maintenance. Evaluate combinations of systems best suited for typical G/A and light transport type of aircraft. Include instrumentation in total integrated systems.

23. ANTI-ICING CONSIDERATIONS OF COMPOSITES

Research program to evaluate methods of ice protection of airframe and engine components made of composite materials. Systems should consider electrical and pneumatic boots, electroimpulse, microwave, and hot air systems. Initial investigation should determine where composites will be used on leading edges, etc. Study should include the use of carbon fibre leading edges, the long term fatigue characteristics when pulse or vibration systems are considered. Tests should be conducted to find the thinnest skins practical and the thermal characteristics of the materials. The effects of antifreeze fluids on composite materials should be investigated.

24. COMPUTER CODE FOR AIRFOIL(S) ICE ACCRETION

Develop computer codes for predicting ice collection and collection efficiency on airfoils to compare with icing tunnel tests and natural ice flight tests. Develop program for calculating A/I system performance which can also predict deicing characteristics of marginal A/I system.

TABLE XXII (continued)

25. COMPUTER PROGRAM (CODE) DEVELOPEMENT FOR UNHEATED AIRFOILS ICE SHAPES Develop method of predicting ice accretion based on dynamic situation with increasing ice buildup. Requires changing geometry, efficiency of catch flow field, etc., and effect on local catch efficiency. Develop program to predict ice shape (configuration). Compare and verify by test data.
26. THREE-DIMENSIONAL COMPUTER CODES FOR ICE ACCRETION (SWEPT WINGS, ETC.) Three-dimensional computer programs are applicable to ice accretion on swept leading edge models and engine inlets. Evaluation of the requirements of such a model should precede its development to assess the extent of improved accuracy of the technique over two-dimensional techniques. The use of the code is to support the initial decision as to the need of an anti/deicing system and also to predict the performance of the system in meeting the certification requirements. Justification of program may be through reduced wind tunnel and/or flight test time required to verify ice accretion prediction and ice protection system performance.
27. FROST ACCUMULATION DURING GROUND OPERATION - PROTECTION METHODS AND PREVENTION Research study of the formation of frost on parked aircraft and limitations for takeoff. Investigate dangers of melting and refreeze prevention and/or protective measures. Assessment of lift and drag penalties. Investigate analytical simulation models and verification testing.
28. COMPUTER CODE FOR ICE SHEDDING CHARACTERISTICS Develop a computer code (analytical model) for ice shedding as a function of time for all altitudes and temperatures associated with icing. Verify the computer model with icing/altitude wind tunnel for airfoils and other body shapes.
29. CARBURETOR ICING RESEARCH Research program to further explore the use of Teflon for coating carburetor components such as the throttle plate and shaft to prevent the deposition of ice. Test combined systems using Teflon coated components and fuel additive to prevent ice depositions and ice crystals which form blockages.

TABLE XXII (continued)

30. JET ENGINE OR FAN-JET ENGINE SPINNERS

Possible NASA/industry joint program to investigate the effect of spinner shape on ice buildup. Several engines are unheated because of shedding characteristics of the configuration (conical) of the spinners. Along with this study would be a study of the droplet trajectories in the inlet and the areas of ice accretion on the rotating components. Research could lead to reduced penalties associated with engine ice protection systems. Research should be directed toward the development of a methodology for predicting the ice shedding characteristics of spinners with and without the addition of icephobic materials.

OTHERS

31. COMPUTERIZED DATA FILE ON ICING

NASA and industry combined effort to continue adding all literature on icing to the computerized data file. Add all old and recent documents from DDC, NTIS, NASA, etc. Add bibliographies on general aviation, large transport, and military including helicopters (VSTOL) to the file. Improve "lookup" tables of data coding and techniques for reviewing and storing information. Resulting file would provide user with immediate accessibility to any or all icing technology data.

32. TRAINING FILMS FOR GENERAL AVIATION PILOTS

Program to produce training films for G/A pilots. Movie films will contain latest up to date information on forecasting techniques, icing definitions, metro data, safety procedures in icing encounters, importance of using A/I systems provided, etc.

33. ICING TANKER FACILITY

Combined NASA, Air Force, and industry research program directed toward the improvement in the design of the tanker spray systems to provide droplet sizes 20-50μm approximating natural ice conditions, including distribution. Design spray rig for minimum induced turbulence by the rig itself. Latest reports indicate attempts to obtain drop sizes in proper range have been unsuccessful to date. Instrumentation to measure icing parameters in flight accurately, is required. Combine efforts with item 1. NASA icing wind tunnel facilities will be used to test designs of nozzle elements and instruments to measure parameters and ranges of control of these parameters. Results will be compared with tanker flight test data.

RESEARCH STUDY AREA	82	83	84	85	86	87	88	89	90	91
	FISCAL YEAR									
	SHORT TERM					LONG TERM				
FACILITIES										
IRT Improvements	----	----	----							
Alt Tunnel Rehabilitation	----	----	----	----	----	----	----			
ICING INSTRUMENTATION										
W/T Std Instrument Development	----	----	----							
Airborne Icing Measurement Inst						----	----	----		
METEOROLOGICAL EFFORTS										
Icing Intensity Definition	----									
Verify Icing Environmental Model				----						
Mixed Icing Conditions							----			
Data Collection for Forecasting	----	----	----	----	----	----	----			
MATERIALS DEVELOPMENT & EVALUATION										
Ice Phobics Development Effort	----	----	----	----	----					
Ice Phobics: Intensify Effort						----	----	----	----	----
Antifreeze Fluids		----								
ICING WIND TUNNEL TESTING										
Airfoils	----	----								
Simulated Ice on Airfoils			----	----						
Ice Blockage of Inlets Vents					----					
Curved Inlets						----				
Flight Control Surface Flutter							----			
Wing-Tail Interaction								----		
Horizontal Tail Stall									----	
Ice Shedding										----
Methods for Ice Simulation			----							
Mixed Icing Conditions								----		
Scale Model Ice Testing									----	----
ICE PROTECTION SYSTEMS										
New Systems: Microwave, E.M. Impulse	----	----	----	----	----	----				
Balance Horn Design	----									
Boot Fundamentals		----								
Trade Studies			----							
Application to Advanced Composites					----	----				
Engine Heat		----								
ANAL. METHODS FOR PREDICTION/CERTIF.										
Airfoil Ice Accretion			----	----						
3-D Ice Accretion					----	----				
Ground Frost Accumulation								----	----	
Airfoil Ice Shapes			----	----						
Ice Shedding Characteristics									----	----
PROPULSION										
Carburetor Icing			----	----						
Jet Fan-Jet Spinners					----	----				
OTHERS										
Computer Icing File	----	----								
FAA Training Film		----	----							
Tanker Spray System Development			----	----	----	----				
Flt Test Verification - Natural Ice				----	----	----	----	----		

Figure 35. Short Term and Long Term Research Plan

Altitude Wind Tunnel (AWT) are shown first, since much of the subsequent effort is predicated on their availability. Note that AWT rehabilitation will not be completed until the 1987 fiscal year, and as a result, several full or large-scale model test programs are scheduled after that date.

The two areas listed first in the program plan concern instrumentation and meteorology. Both of these areas have already been discussed above, and their importance can be summarized thusly: (1) development of highly accurate and/or calibrated instrumentation is required to establish quantitative icing intensity data for immediate use in forecasting, and to accurately quantify the results of the wind tunnel and flight testing outlined later in the program, and (2) meteorological efforts are required in order to improve the accuracy and efficiency of forecasting and to utilize the improved instrumentation in gathering data which will update icing environment models which could allow increased aircraft utilization.

In the next area of research, icephobics development is shown as an ongoing effort. It is recommended that icephobics research should be carried on at a moderate level until a promising icephobic material family is identified. At this point, research should be intensified to develop an icephobic that can be applied to wings, propellers, empennage, engine cowls, engine inlets, etc. What is most attractive about an icephobic is that it comprises a "passive" system which can easily be applied to existing aircraft, is low in weight, and hopefully, will be of low cost. If a highly effective icephobic could be quickly developed, then the goal of increased aircraft utilization in icing environments would be more easily attainable.

As far as icing wind tunnel testing is concerned, the plan is laid out in order of the items which industry felt are needed first, except that full-scale aircraft or large-scale model testing is deferred until the AWT rehabilitation is complete. The short term needs are to provide icing data on the newer airfoils - both accretion and penalty data. Wing-tail interactions, horizontal tail stall, and ice shedding research should utilize the large wind tunnel. Scale model testing will require the use of both the IRT and the AWT, and if this research study is successful, it would allow future scale model test results to be applied to full-scale components with confidence, reducing the need for expensive and time consuming full-scale testing or flight testing in natural ice. Wind tunnel test results will also be used to validate analytical models developed concurrently or after testing is completed.

Included under ice protection systems is an effort to develop new systems such as those utilizing microwave and electromagnetic impulse principles. These types of systems are not ready for application right now and will probably not be in universal use for a good many years. It has been estimated that it would take up to eight years to fully develop a system such as the microwave system (reference 134). However, because of the potentially substantial payoffs to the class of aircraft under study, it would appear wise to begin studying these systems immediately, carrying on their study into the long term phase of the research plan. Results of initial development efforts for these systems would be available for use in the systems trade study effort proposed later in the program.

Short term research studies should be carried out in the areas of balance horn design, boot fundamentals, improved waste engine heat utilization, etc. There has been an indication that trade studies of the various systems would be of use to the industry, and these have been scheduled to follow the previously mentioned system studies. Advanced composites are being utilized more and more by military and large aircraft manufacturers. However, for the general aviation and light transport sector, systems compatible with advanced composites do not currently pose a pressing urgency, and have been deferred in the program to cross over from the short to the long term.

Analytical techniques involve prediction models for ice accretion, ice shapes, and penalties. In the program plan, it was decided that model development of ice accretion and ice shape prediction for the new and future generation airfoils should not be undertaken until verification data are generated in the wind tunnel. Three-dimensional ice-accretion models would follow after development of the two-dimensional ice accretion codes.

Analytical studies and model development of the aerodynamic effects of ground frost accumulation, as well as ice shedding characteristic studies, require correlation with data taken in the AWT, and so are scheduled as long term research items.

In the area of propulsion, the carburetor icing study is of great importance to the general aviation class of aircraft, and has been scheduled for the short term. The use of passive spinners on engines to shed ice and the fact that some engine shedding characteristics are not fully understood, comprise a research study area to follow into the long term.

The remaining efforts ("Others") are shown in the plan schedule to occur in the short term. A computerized icing data file would contain bibliographies and data on icing from NASA, DDC, NTIS, and the general literature. This file would be available for interrogation by all interested parties when addressing their problems concerning icing or during the course of the subsequent efforts detailed in the plan. A training film on aircraft icing was universally accepted as a sound idea, and early production of that film would be in order for training of general aviation and light transport pilots. A longer term effort would entail a joint effort of NASA and others, to improve tanker spray systems for use in flight testing for development or certification. This effort and several others may require the use of large facilities, and thus is forced into the longer term.

FUNDING REQUIREMENTS

The funding requirements for each of the listed research items are difficult to define. They are highly variable since so much depends on the specific statement of work that is finally developed for each item. For example, a statement of work for the development of a computer model could include the following tasks:

1. Develop equations which define the problem.

2. Write the computer program

   a. using a specified computer language.

   b. for use with specific computing system (e.g., IBM, CDC, etc.).

   c. interfaceable with other existing codes.

3. "Debug" and perform specified test cases.

4. Verify accuracy using existing analytical or test data.

5. Document and prepare a "User's Manual."

6. Costs for "computer time."

In addition to the above, tasks must be added for administrative purposes, such as:

1. Interim and final reporting (technical and financial).

2. Oral presentations with attendant travel requirements.

3. Final report publication and reproduction.

The complexity of the phenomenon being modeled will be a major factor for determining the scope and cost of the effort, but all the above factors will also be contributors and can sometimes magnify this cost. The sponsoring agency can thus affect scope by controlling requirements for what the program must accomplish, by establishing reasonable accuracy constraints, providing in reduced form the data to be used for verification, and minimizing administrative requirements, where feasible.

For the purposes of the program plan, each analytical effort was assumed to demand one to two-man effort, at a cost of about $90,000 per man-year. As noted above, this figure is variable, depending on the technical and administrative requirements.

Wind tunnel testing is another research area where costs can be highly variable. In addition to the administrative tasks discussed above, a typical test program would also include the following technical tasks:

1. Detailed test plans (run schedule and test conditions).

2. Design of test model to specified scale.

3. Fabrication (including material costs).

4. Wind tunnel tests.

   a. Coordination and facility scheduling.

   b. Model installation.

   c. Instrumentation and recording equipment.

   d. Tunnel operating costs.

   e. Travel and accommodation of test team personnel.

5. Data reduction and analysis.

6. Final report preparation.

Two of the major cost contributors to such an effort are the model design and fabrication and the testing activity itself. The scope of the effort will be affected by the scale and complexity of the model, the instrumentation requirements (i.e., number and types of measurements), and the number of test conditions and data points required. Test costs can be as much as several thousand dollars per hour of actual test time, and while much of the testing would occur in the NASA icing wind tunnels, this cost must be accounted for in determining the funding requirements for any prolonged test activity. As an example of these costs, a moderately sized 120 hour dry air wind tunnel test program on a 0.1-scale complex nacelle inlet was recently priced at about $400,000, including wind tunnel costs.

Estimated funding requirements for the program are presented in figure 36. Some of the research items are neither test programs or model developments and are more difficult to cost out. Their actual costs will also depend on the final work packages, but estimates are presented anyway, based on the funding activity which is felt appropriate relative to the other programs. Note that the amounts are given in 1980 dollars. In just five years with an 8 percent inflation rate, 100,000 1980 dollars will translate to $146,933.

Incidentally, in Appendix A of NASA-CP-2086 (NASA/FAA Workshop on Aircraft Icing, reference 85), the SAE Icing Research Panel concluded that the cost of work packages required to meet research requirements could vary from 1/2 million to 2 million in 1975 dollars. These costs are not unlike what are estimated here. Further, in FAA-ED-04-2 (reference 122), "Helicopter Operations Research and Development Plan," costs are estimated for various efforts in icing research during a five year span. As it turns out, the FAA yearly totals are in the same ball park, although rationales are not presented to back up their estimates. The FAA feels that peak icing research funding of about $2,700,000 per year is required during 1982 and 1983. This compares to the $2,430,000 and $2,760,000 presented in figure 36.

These cost figures are to be regarded as relative numbers to compare one program with another and are in no way absolute values. Changes in the inflation rate, more explicit detailed information on individual programs, scientific breakthroughs, etc., could all change these estimates in a dramatic way.

RESEARCH STUDY AREA	FISCAL YEAR									
	SHORT TERM					LONG TERM				
	82	83	84	85	86	87	88	89	90	91
Icing Instrumentation	150	200	200			150	150	150		
Meteorological Efforts	350	200	200	500	200	200	600			
Materials Development & Evaluation	200	500	200	200	200	300	300	300	300	300
Icing Wind Tunnel Testing	400	500	650	500	500	500	500	800	1000	900
Ice Protection Systems	400	750	350	300	450	600				
Analytical Methods for Prediction/Certification			180	180	90	90		90	180	135
Propulsion			300	300	400	400				
Others *	80	280	680	650	650	580	500	500		
TOTALS	1580	2430	2760	2630	2440	2770	2050	1690	1480	1335

* Icing Data File, G. A. Training Film, Icing Tanker Facility, Verification Flight Tests in Natural Ice

Figure 36. Estimated Funding Requirements in Thousands of 1980 Dollars

Section VI

CONCLUDING REMARKS

This research study has identified the requirements for a research and development program to meet the needs of the light transport and general aviation industry. During the course of the study, the present icing technology data base including analytical techniques and facilities generally available to the industry has been assessed. Many areas where the data base is weak or nonexistent have been revealed and it is these areas which have been addressed in the research programs suggested herein. Along with the suggested research programs, there are a number of general and specific conclusions that can be reached as a result of this study as follows:

1. It is the consensus of opinion of the majority of icing experts that there is a need for a great deal of work with respect to the light transport and general aviation aircraft categories icing operations and certifications, specifically in the areas of:

   a. Icing intensity definitions.

   b. Improvement and updating of FAR 25 envelopes to include specific flight operational characteristics of general aviation as well as those of transport category aircraft.

   c. Icing weather forecasting, including real time reporting.

   d. Certification of aircraft on a basis other than "all or nothing," i.e., partial certification for flight under limited icing conditions.

   e. Standardization of icing certification requirements for specific types of aircraft.

2. Any effort to expand the utilization of light transport and general aviation aircraft (where this can be interpreted to mean an increased number of inadvertent or deliberate penetrations of icing conditions), makes mandatory the requirement for improving the skills and knowledge of the pilot/crew with regard to the nature and hazards of aircraft icing. Also required is a thorough understanding of the limitations of his particular aircraft and ice protection systems provided, in the icing conditions forecasted and/or encountered.

3. The short term and long term research plan list of specific research requirements will provide NASA LeRC with a basis for an overall icing research program to meet national needs. It is recommended that the NASA LeRC incorporate the suggested research program for light transport and general aviation into their overall icing research program.

4. Many of the research requirements outlined in the program contribute to the need for the rehabilitation of the NASA LeRC AWT with icing research capabilities. As a result, rehabilitation of the NASA LeRC IRT and AWT facilities is recommended. The improvements and additions suggested in section IV are to be considered in this recommendation.

5. There is a general consensus of opinion that the NASA LeRC should be the center of aircraft icing expertise for basic research and consultation and should act as a clearing house for exchange of information for industry involvement. However, it is also recommended that NASA LeRC have an input to the Air Force (AFFDL) icing programs to achieve mutual benefits and savings to both agencies. It is recommended that these joint efforts be in such technology areas where AF facilities and experimental work will augment the NASA programs, particularly in low altitude climatology and instrumentation.

6. The Mark IV computerized data management file was successful in that it provided a means to effectively retrieve reference materials as required to accomplish the program tasks, as well as providing for a bibliography of icing technology information. Further development of the Mark IV or similar computer management file is recommended in order to realize more fully the total capability of the system in providing a means of storing and retrieving icing technology data at all levels of detail. Particularly, the file should be structured so that specific information found in the literature may be retrieved through file interrogation in output formats acceptable for direct use in reporting.

7. The results of the study indicated that from a purely technical standpoint (involving ice protection system methods, ice sensitive components, ice accretion, etc.) there is very little difference between the research requirements for light transport and general aviation aircraft, and any other type of fixed wing aircraft except in two major areas of difference:

   a. Physical differences.

      (1) Operational characteristics including altitude, scheduled/nonscheduled routes, crew training, aircraft size, and icing exposure.

      (2) Energy or power levels available for aircraft ice protection subsystems.

b. Nonphysical, regulatory (see No. 1, Conclusion).

(1) FAA rules and regulations on certification, including FAR 25, Appendix C envelopes are not tailored to meet operational characteristics of general aviation type (i.e., no allowances for partial certification, etc.)

(2) Low altitude climatology and statistical models, real time forecasting, and quantitative icing definitions need more specific direction towards general aviation.

The program that has been presented includes research specifically oriented towards general aviation aircraft as well as research which is applicable to all classes of aircraft.

8. The assessment of new and/or potential concepts for ice protection systems revealed the existence of such concepts as microwave and electro-impulse deicing systems which in theory will provide great savings in cost, weight, and power for ice protection. It is recommended that further research is warranted and should be conducted on these concepts to determine their feasibility for application to light transport and general aviation aircraft.

9. The study revealed the need for considerable new research to be conducted in the general area of icing instrumentation for both airborne and icing wind tunnel application. Specifically, it is recommended that research be directed towards the development of highly accurate instrumentation for measuring icing parameters, i.e., LWC, droplet size/distribution, etc. for all ranges of values, to serve as an industry standard.

10. It is recommended that improvements to the NASA LeRC IRT Facility include modern standardized instrumentation recording and data reducing (processing) equipment.

Section VII

APPENDICES

APPENDIX A-1

LIST OF REFERENCES

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APPENDIX A-2

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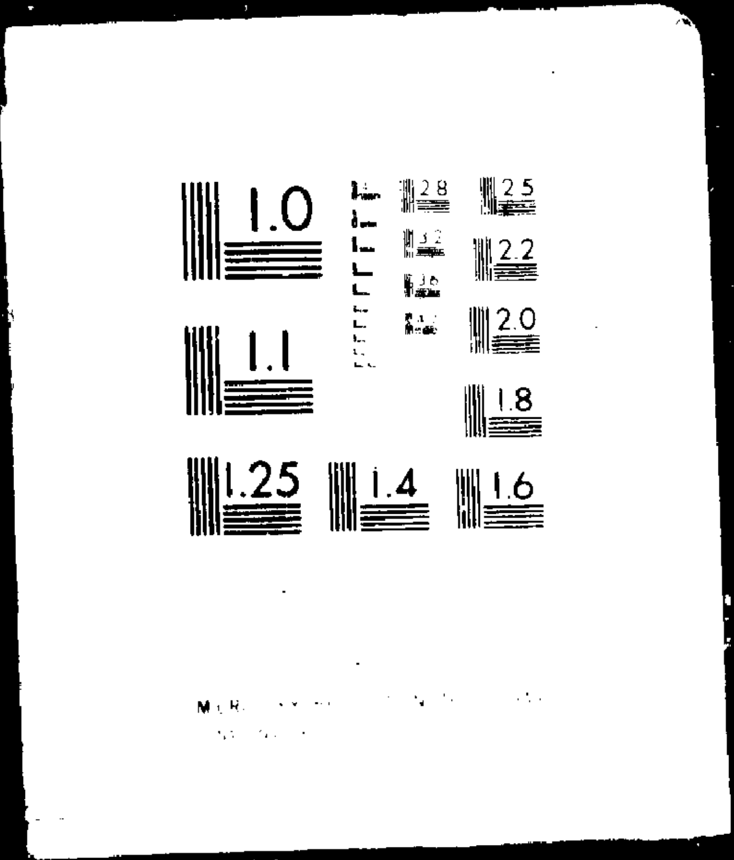

APPENDIX B

LOOKUP TABLES OF CODES
USED IN ICING RESEARCH DATA FILE

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TABLCL 000   TABLE OF ICE SENSITIVE COMPONENTS
TABLCL 001
TABLCL 002   COMPONENT NAME OR          COMMENTS, MAJOR PROBLEM
TABLCL 003   SIMPLE DESCRIPTION
TABLCL 004                            A WHERE, HOW DOES ICE FORM
TABLCL 005                            B WHEN DOES ICE FORM
TABLCL 006                            C IS IT A PROBLEM, WHY
TABLCL 007   NONE LISTED
TABLCL 008   AIRCRAFT ENGINES, GENERAL
TABLCL 009
TABLCL 010
TABLCL 100   JET ENGINES
TABLCL 110   A MAIN INLET
TABLCL 111                            A PRIMARILY MUSHROOM ON INLET LIP.
TABLCL 112                              NO NODULES ALONG LENGTH RUNBACK IF
TABLCL 113                              HEATED. HEAVY FORMATIONS ON PRO
TABLCL 114                              TUBERANCES.
TABLCL 115                            B GROUND SUBCOOLED CONDITIONS
TABLCL 116                              INFLIGHT SUBCOOLED CONDITIONS
TABLCL 117                            C ICE SHEDDING IS MAIN PROBLEM
TABLCL 118                              SOME LOSS IN POWER
TABLCL 119
TABLCL 120   B BLOW IN DOORS
TABLCL 121                            A LEADING EDGE WHEN OPEN
TABLCL 122                              SLUSH ICE COULD BE HEAVY
TABLCL 123                              ICE ON EDGE, SEALS
TABLCL 124                            B GROUND ONLY TAXI SLUSH
TABLCL 125                              OTHERWISE LIGHT IN SUBCOOLED COND.
TABLCL 126                            C BLOCKAGE FROM SLUSH CANNOT
TABLCL 127                              CLOSE DOORS
TABLCL 128
TABLCL 129
TABLCL 130   C INLET NOISE SUPPRESSION
TABLCL 131                            A NO FORMATION OF ICE FROM DIRECT
TABLCL 132                              IMPINGEMENT. NOISE SUPPRESSION
TABLCL 133                              IS ACCOMPLISHED BY COATING DUCTS
TABLCL 134                            B GROUND RUNUP FREEZING RAIN & FROST
TABLCL 135                            C ICE SHEDDING INTO ENGINE
TABLCL 136
TABLCL 137
TABLCL 138
TABLCL 139
TABLCL 140   D NOSE CAPS
```

A PRIMARILY MUSHROOM AT NOSE
B SAME AS MAIN INLET
C SAME AS MAIN INLET

E SCREENS

A ALL FORMS AT EACH WIRE
B GROUND RUNUP, TAXI, FLIGHT, ETC.
C ALMOST IMMEDIATE BLOCKAGE DUE TO CLOSE SPACING. EXTREME THREAT TO AIRCRAFT SINCE ALL ENGINES FAIL SIMULTANEOUSLY

F INLET GUIDE VANES

A PRIMARILY MUSHROOM ON LEADING EDGES, BRIDGING POSSIBLE
B GROUND RUNUP, TAXI, FLIGHT, ETC.
C CAN HAVE BLOCKAGE IN SHORT PERIODS SHEDDING, JAMMING CAN CAUSE COMP STALL, INTERFERENCE WITH ROTOR BLADES.

G ROTOR BLADES

A SAME AS 160F
B SAME AS 160F
C SAME AS 160F

H FRAME STRUTS

A PRIMARILY MUSHROOM ICE ON THE STRUT LEADING EDGES
B GENERALLY IN FLIGHT

```
TABLCL 184                                 C DAMAGE FROM SHEDDING, DECREASING
TABLCL 185                                      ENGINE TORQUE, INCREASED FUEL
TABLCL 186                                      FLOW
TABLCL 187
TABLCL 188
TABLCL 189
TABLCL 200      FANJET ENGINES, HIGH BYPASS
TABLCL 210     A APPR ITEMS FROM 100
TABLCL 211                                 A APPR FOR ITEMS FROM 100
TABLCL 212                                 B   A, B, C, D, F, G
TABLCL 213                                 C
TABLCL 219
TABLCL 220     B FAN
TABLCL 221                                 A PRIMARILY MUSHROOM LE OF FAN BLADE
TABLCL 222                                    AERO HEATING AT TIPS
TABLCL 223                                 B GROUND WITH ADIABATIC EXPANSION,
TABLCL 224                                    & SUBCOOLED CLOUDS DURING GROUND
TABLCL 225                                    TAXI & FLIGHT CONDITIONS.
TABLCL 226                                 C SHEDDING, STALL, ASYMMETRIC LOADING
TABLCL 227                                    AND ENGINE ROUGHNESS.
TABLCL 228
TABLCL 229
TABLCL 230  C BYPASS
TABLCL 231                                 A LIGHT ICING AT TURNS, SPLITTERS,
TABLCL 232                                    ETC.
TABLCL 233                                 B SAME AS FAN EXCEPT THAT FAN PRESS.
TABLCL 234                                    RATIO PROVIDES SOME ADIABATIC
TABLCL 235                                    HEATING.
TABLCL 236                                 C NONE IDENTIFIED TO DATE.
TABLCL 237
TABLCL 238
TABLCL 239
TABLCL 300   TURBOPROP ENGINES
TABLCL 310  A APPR ITEMS FROM 100
TABLCL 311                                 A   A, D, F, G, H
TABLCL 312                                 B
TABLCL 313                                 C
TABLCL 314
TABLCL 315
TABLCL 316
TABLCL 317
TABLCL 318
TABLCL 319
```

B PARTICLE SEPARATORS

A ICE FORMATION DEPENDS UPON TYPE OF SEPARATOR. MULTIPLE INLETS COLLECT ICE AT INLETS AND CENTER DIVIDER IN THE FLOW CHAIN

B GROUND RUNUP, FREEZING RAIN AND FROST GENERALLY IN FLIGHT.

C BLOCKAGE OF THE AIRFLOW PATHS WOULD OCCUR RAPIDLY FOR SOME DESIGNS.

C SCREENS

A ICE FORMS AT EACH WIRE

B GROUND RUNUP, TAXI, FLIGHT, ETC.

C ALMOST IMMEDIATE BLOCKAGE DUE TO CLOSE SPACING, EXTREME THREAT TO AC SINCE ALL ENGINES CAN FAIL SIMULTANEOUSLY.

A PULL PROPELLERS

A ICE FORMS NEAR HUB ON LE OF BLADES AERO HEATING AT TIPS.

B GROUND RUNUP, TAXI, INFLIGHT.

C MAY CAUSE UNDUE VIBRATION. SHEDDING CAN CAUSE DAMAGE TO AC

B PUSH PROPELLERS

A SAME AS PULL PROPELLERS EXCEPT THAT BLADES CAN BE DAMAGED BY UPSTREAM ICE SHEDDING.

B SAME AS PULL PROPELLERS

C SAME AS PULL PROPELLERS

C ENGINE COWLING

A MOSTLY MUSHROOM ICE FORMS ON LE OF COWL WITH RUNBACK IF HEATED

```
TABLCL 363                                    B SAME AS WITH JET ENGINE
TABLCL 364                                    C ICE SHEDDING IS MAIN PROBLEM
TABLCL 365
TABLCL 366
TABLCL 367
TABLCL 338
TABLCL 369
TABLCL 400   PISTON ENGINES
TABLCL 410  A ENGINE COWLING
TABLCL 411                                    A MOSTLY MUSHROOM ICE FORMS ON
TABLCL 412                                       COWL LE
TABLCL 413                                    B GENERALLY INFLIGHT
TABLCL 414                                    C ICE SHEDDING AND STRIKING OTHER
TABLCL 415                                       COMPONENTS, BLOCKAGES
TABLCL 416
TABLCL 417
TABLCL 418
TABLCL 419
TABLCL 420  B CARBURETOR
TABLCL 421                                    A MOSTLY CONDENSATION OF WATER FROM
TABLCL 422                                       AIR INTAKE
TABLCL 423                                    B ON GROUND IN FROST CONDITIONS IN
TABLCL 424                                       FLIGHT DURING DESCENT TO LAND
TABLCL 425                                    C FREEZE IN JETS CAUSING ENGINE
TABLCL 426                                       STALL. ICE CAN FORM AT ABOVE FREEZ
TABLCL 427                                       ING AMBIENT CONDITIONS
TABLCL 428
TABLCL 429
TABLCL 430  C PULL PROPELLERS
TABLCL 431                                    A SAME AS WITH TURBOPROP ENGINES
TABLCL 432                                    B SAME AS WITH TURBOPROP ENGINES
TABLCL 433                                    C SAME AS WITH TURBOPROP ENGINES
TABLCL 434
TABLCL 435
TABLCL 436
TABLCL 437
TABLCL 438
TABLCL 439
TABLCL 440  D PUSH PROPELLERS
TABLCL 441                                    A SAME AS WITH TURBOPROP ENGINES
TABLCL 442                                    B SAME AS WITH TURBOPROP ENGINES
TABLCL 443                                    C SAME AS WITH TURBOPROP ENGINES
TABLCL 444
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TABLCL 445
TABLCL 446
TABLCL 447
TABLCL 448
TABLCL 449
TABLCL 500    AC INST NOT ICING
TABLCL 510   A PITOT STATIC TUBE
TABLCL 511                                  A ICE FORMS ON PITOT HEAD OR MAST OR
TABLCL 512                                    INSIDE SENSING LINES
TABLCL 513                                  B ON GROUND FROM FREEZING RAIN, COND
TABLCL 514                                    IMPACT ICE IN FLIGHT, FREEZING IN
TABLCL 515                                    LINES DURING CLIMB TO ALTITUDE
TABLCL 516                                  C CAUSES ERRONEOUS READINGS IN INST
TABLCL 517                                    USING PITOT STATIC PRESSURES
TABLCL 519
TABLCL 520   B ALT & ROC ORIFICES
TABLCL 521                                  A ICE FORMS AT ORIFICE INLET OR
TABLCL 522                                    INSIDE SENSING LINES
TABLCL 523                                  B ON GROUND FROM FREEZING RAIN, COND
TABLCL 524                                    INFLIGHT FROM IMPACT OR RUNBACK
TABLCL 525                                    ICE
TABLCL 526                                  C CAUSES ERRONEOUS INDICATIONS OF
TABLCL 527                                    ALT & ROC
TABLCL 528
TABLCL 529
TABLCL 530   C YAW VANES
TABLCL 531                                  A MOSTLY MUSHROOM ICE FORMS ON LE OF
TABLCL 532                                    VANE & VANE ARM
TABLCL 533                                  B GENERALLY IN FLIGHT
TABLCL 534                                  C CAN CAUSE ERRORS IN INST SENSING,IE,PROB
TABLCL 535                                    -LEMS WITH STALL WARNING SYSTEMS
TABLCL 536
TABLCL 537
TABLCL 538
TABLCL 539
TABLCL 540   D TOTAL HEAD PROBE
TABLCL 541                                  A SAME AS PITOT STATIC TUBE
TABLCL 542                                  B SAME AS PITOT STATIC TUBE
TABLCL 543                                  C SAME AS PITOT STATIC TUBE
TABLCL 544
TABLCL 545
TABLCL 546
TABLCL 547
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ORIGINAL PAGE IS
OF POOR QUALITY

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TABLCL 548
TABLCL 549
TABLCL 550  E TOTAL TEMP PROBE
TABLCL 551                                  A MOSTLY MUSHROOM ICE FORMS ON TOTAL
TABLCL 552                                     TEMP PROBE
TABLCL 553                                  B GENERALLY INFLIGHT
TABLCL 554                                  C ICE ON SENSOR WILL CAUSE ERROR IN
TABLCL 555                                     AIR TOTAL TEMP MEASUREMENT
TABLCL 556
TABLCL 557
TABLCL 558
TABLCL 559
TABLCL 600   FUSELAGE
TABLCL 610  A WINDSHIELD
TABLCL 611                                  A ANY TYPE OF ICE MAY COVER SURFACE
TABLCL 612                                     OF WINDSHIELD
TABLCL 613                                  B ON GROUND, FREEZING RAIN, FROST,
TABLCL 614                                     ETC.TAXI,INFLIGHT FROM IMPACT ICE
TABLCL 615                                  C OBSCURES VISION OF THE CREW
TABLCL 616
TABLCL 617
TABLCL 618
TABLCL 619
TABLCL 6[illegible]  B WING/FUSE JUNCTURES
TABLCL 621                                  A SAME AS A WING EXCEPT AT THE FUSE
TABLCL 622                                     WHICH MAY BE CLEAR WHEN BLENDED
TABLCL 623                                     BODIES ARE USED.
TABLCL 624                                  B SAME AS WING
TABLCL 625                                  C ICE SHEDDING TO HORIZ STAB OR
TABLCL 626                                     ENGINE INLETS WHEN SIDE INLETS
TABLCL 627                                     ARE USED.
TABLCL 628
TABLCL 629
TABLCL 630  C STATIC VENTS & BREATHER TUBES
TABLCL 631                                  A NO FORMATION UNLESS FACING FORWARD
TABLCL 632                                     EXCEPT FOR FREEZING RAIN. RUNNING
TABLCL 633                                     WATER COULD ENTER VENTS, FREEZE
TABLCL 634                                  B ON GROUND, LOW AIRSPEEDS
TABLCL 635                                  C DEPENDS ON VENT FUNCTION
TABLCL 636
TABLCL 637
TABLCL 638
TABLCL 639
```

TABLCL 640	D SCOOPS	
TABLCL 641		A ICE FORMATION ON LIP LE OF SCOOP,
TABLCL 642		INTERNALLY IN DUCT BENDS
TABLCL 643		B GROUND RUNUP, TAXI, PRIMARILY IN
TABLCL 644		FLIGHT
TABLCL 645		C REDUCE OR CLOSE OFF AIRFLOW
TABLCL 646		
TABLCL 647		
TABLCL 648		
TABLCL 649		
TABLCL 650	E DRAINS	
TABLCL 651		A ICE FORMATION AT DRAIN OUTLET AND
TABLCL 652		DRAIN LINE
TABLCL 653		B FREEZING RAIN, FOG, OR COND ON
TABLCL 654		GROUND. IMPACT ICE RUNBACK
TABLCL 655		INFLIGHT
TABLCL 656		C CLOSE OFF OF DRAIN OR CLOGGING OF
TABLCL 657		LINES
TABLCL 658		
TABLCL 659		
TABLCL 660	F OTHER JUNCTURES	
TABLCL 661		A ICE FORMATION DEPENDS ON CONFIGUR
TABLCL 662		-ATION OF JUNCTURE. SAME AS WING
TABLCL 663		FUSE IN SOME CASES
TABLCL 664		B SAME AS WING FUSE
TABLCL 665		C ICE SHEDDING DAMAGE,INCREASED DRAG
TABLCL 666		
TABLCL 667		
TABLCL 668		
TABLCL 669		
TABLCL 670	G ANTENNAS	
TABLCL 671		A PRIMARILY MUSHROOM ICE ON LE OF
TABLCL 672		ANTENNA AND MAST
TABLCL 673		B GENERALLY INFLIGHT
TABLCL 674		C SHEDDING DAMAGING OTHER AC COMPO
TABLCL 675		-NENTS. DEGRADATION OF ELECTRONIC
TABLCL 676		EQUIPMENT PERFORMANCE
TABLCL 677		
TABLCL 678		
TABLCL 679		
TABLCL 680	H RADOMES	
TABLCL 681		A MUSHROOM ICE ON NOSE/SIDES OF
TABLCL 682		RADOME, FREEZING RAIN

TABLCL 683		B GENERALLY INFLIGHT
TABLCL 684		C SHEDDING AND DAMAGING ENGINE/AC
TABLCL 685		COMPONENTS, DEGRADATION OF RADAR
TABLCL 686		PERFORMANCE
TABLCL 687		
TABLCL 688		
TABLCL 689		
TABLCL 690	I EO WINDOWS	
TABLCL 691		A SAME AS WINDSHIELD
TABLCL 692		B SAME AS WINDSHIELD
TABLCL 693		C DEGRADES PERFORMANCE OF ELECTRO
TABLCL 694		OPTICAL EQUIPMENT
TABLCL 695		
TABLCL 696		
TABLCL 697		
TABLCL 698		
TABLCL 699		
TABLCL 700	TAIL SURFACES	
TABLCL 710	A HORIZONTAL	
TABLCL 711		A PRIMARILY MUSHROOM ICE ON LE
TABLCL 712		B FREEZING RAIN, FROST ON GROUND
TABLCL 713		GENERALLY INFLIGHT
TABLCL 714		C INCREASES DRAG, REDUCES CONTROL
TABLCL 715		AND STABILITY
TABLCL 716		
TABLCL 717		
TABLCL 718		
TABLCL 719		
TABLCL 720	B ELEVATOR	
TABLCL 721		A ICE ON SURFACE, PRIMARILY IN HINGE
TABLCL 722		OR HORN AREAS
TABLCL 723		B FREEZING RAIN, FROST ON GROUND
TABLCL 724		INFLIGHT
TABLCL 725		C INCREASE DRAG, BLOCK MOVEMENT OF
TABLCL 726		ELEVATORS REDUCING CONTROL OF AC
TABLCL 727		
TABLCL 728		
TABLCL 729		
TABLCL 730	C VERTICAL	
TABLCL 731		A PRIMARILY MUSHROOM ICE ON LE
TABLCL 732		B GENERALLY INFLIGHT
TABLCL 733		C INCREASES DRAG AND STALL SPEED
TABLCL 734		MAY REDUCE CONTROL AND STABILITY

```
TABLCL 735
TABLCL 736
TABLCL 737
TABLCL 738
TABLCL 739
TABLCL 740  D RUDDER
TABLCL 741                      A NO IMPACT FORMATION, MAY GET ICE
TABLCL 742                         IN HINGES FROM RUNBACK WATER
TABLCL 743                      B ON GROUND FROM FREEZING RAIN OR
TABLCL 744                         FROST GENERALLY NOT INFLIGHT
TABLCL 745                      C REDUCES CONTROL AND STABILITY
TABLCL 746                         MAY BLOCK RUDDER MOVEMENT
TABLCL 747
TABLCL 748
TABLCL 749
TABLCL 750  E T - TAIL SURFACES
TABLCL 751                      A PRIMARILY MUSHROOM ICE ON LE
TABLCL 752                         ICE MAY FORM IN HINGE AREA
TABLCL 753                      B GENERALLY INFLIGHT, ON GROUND
TABLCL 754                         FROM FREEZING RAIN AND FROST
TABLCL 755                      C INCREASED DRAG
TABLCL 756
TABLCL 757
TABLCL 758
TABLCL 759
TABLCL 760  F V - TAIL SURFACES
TABLCL 761                      A SAME AS VERTICAL STABILIZER
TABLCL 762                      B GENERALLY IN FLIGHT, FREEZING RAIN
TABLCL 763                         FROST ON GROUND
TABLCL 764                      C INCREASED DRAG, CONTROL AND
TABLCL 765                         STABILITY. PROBLEM IF ICE FREEZES
TABLCL 766                         IN HINGED CONTROL SURFACES
TABLCL 767
TABLCL 768
TABLCL 769
TABLCL 800    WINGS
TABLCL 810  A SWEPT & STRAIGHT
TABLCL 811                      A ALL FORMS OF ICE ON LE, PRIMARILY
TABLCL 812                         UPPER HORN OF MUSHROOM. ICE RUNBACK
TABLCL 813                         ICE BEHIND LEADING EDGE
TABLCL 814                      B ON GROUND FROM FREEZING RAIN AND
TABLCL 815                         FROST, TAXI, INFLIGHT
TABLCL 816                      C INCREASED DRAG AND STALL SPEED.
```

CONTROL, STABILITY, AND SHEDDING PROBLEMS

B AILERONS

A NO IMPACT FORMATION, ICE MAY FORM IN HINGED AREA
B ON GROUND FROM FREEZING RAIN AND FROST
C BIND OR JAMMING OF AILERON MOVEMENT

C FLAPS

A PRIMARILY MUSHROOM ICE ON LE OF OPEN (EXTENDED) FLAP
B GENERALLY INFLIGHT
C PREVENTS OR DISTURBS AIRFLOW OVER FLAP. REDUCES EFFICIENCY OF FLAP. INCREASES DRAG, SHEDDING

D SLATS

A PRIMARILY MUSHROOM ICE ON LE OF SLAT AND WING WITH SLAT OPEN. ICE ON SLAT TRACK
B GENERALLY INFLIGHT
C INCREASED DRAG, REDUCED LIFT AND FLAP EFFICIENCY

E SLOTS

A FORM OF ICE DEPENDS ON SLOT CONFIGURATION AND LOCATION
B FREEZING RAIN/FROST ON GROUND. INFLIGHT IMPACT ICE
C REDUCED EFFICIENCY OF SLOT BY REDUCING OR DISTURBING AIRFLOW

```
TABLCL 860  F FENCES AND V/G
TABLCL 861                                  A PRIMARILY MUSHROOM ICE ON LE
TABLCL 862                                  B GENERALLY INFLIGHT
TABLCL 863                                  C PRIMARY PROBLEM CAN COME FROM
TABLCL 864                                     SHEDDING SINCE SOME FORMS OF ICE
TABLCL 865                                     IMPROVE FUNCTION OF V/G SOME
TABLCL 866                                     INCREASED DRAG
TABLCL 867
TABLCL 868
TABLCL 869
TABLCL 870  G CANARD
TABLCL 871                                  A SAME AS WING
TABLCL 872                                  B SAME AS WING
TABLCL 873                                  C SAME AS WING
TABLCL 874
TABLCL 875
TABLCL 876
TABLCL 877
TABLCL 878
TABLCL 879
TABLCL 880  H GENERAL, MANY COMPONENTS, ENTIRE AIRCRAFT
TABLCL 881    AIRFOILS, COMBINATIONS
TABLCL 882    ICING INSTRUMENTS
TABLCL 883
TABLCL 884
TABLCL 885
TABLCL 886
TABLCL 887
TABLCL 888
TABLCL 889
TABLCL 900   CLASSICAL COMPONENTS
TABLCL 910  A CYLINDERS
TABLCL 920  B SPHERES
TABLCL 930  C FLAT PLATES
TABLCL 940  D RIBBONS
TABLCL 950  E HEMI SPHERES
TABLCL 960  F ELIPSOIDS
TABLCL 970  G CONES
TABLCL 980  H RECTANGULAR HALF-BODIES
TABLCL 990  I WEDGES
TABLCL 060     ABBREVIATIONS/MNEMONICS
TABLCL 061      SUPPR=SUPPRESSION
TABLCL 062      LE=LEADING EDGE
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TABLCL 063      AC=AIRCRAFT
TABLCL 064      ROC=RATE OF CLIMB
TABLCL 065      ALT=ALTITUDE
TABLCL 066      INST=INSTRUMENTATION
TABLCL 067      COND=CONDENSATION
TABLCL 068      FUSE=FUSELAGE
TABLCL 069      STAB=STABILIZER
TABLCL 070      EO=ELECTRO-OPTICAL
TABLCL 071      V/G=VORTEX GENERATORS
TABLCL 072      APPR=APPROPRIATE
TABLCL 090     GUIDE TO REVIEWER
TABLCL END DATE/TIME 16 JUN 1980 / 08:44:13 PST
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TABLIPM  00    TABLE OF ICE PROTECTION/PREVENTION METHOD
TABLIPM  01
TABLIPM  02       THE METHOD IS DEFINED BY THE TRANSPORT MEDIA AT THE
TABLIPM  03            ANTI DE-ICING INTERFACE(SUCH AS HOT AIR) & THE FLOW
TABLIPM  04            CONFIGURATION (DOUBLE SKIN)
TABLIPM  05 NOT APPLICABLE
TABLIPM  06 NOT DISCUSSED OR MINIMAL DISCUSSION
TABLIPM  07 PREVENTION VIA OPERATIONAL PROCEDURES
TABLIPM  08 HOT AIR CONT-TUBE OR SINGLE SKIN-INT
TABLIPM  09 HOT AIR CONT-TUBE OR SINGLE SKIN-PICCOLO TUBE CHORDWISE
TABLIPM  10 HOT AIR CONT-TUBE OR SINGLE SKIN-PICCOLO TUBE SPANWISE
TABLIPM  11 HOT AIR CONT-DOUBLE SKIN-INT
TABLIPM  12 HOT AIR CONT-POROUS FLOW
TABLIPM  13 HOT AIR CONT-SLOT/EXTERNAL
TABLIPM  14 HOT AIR CYCLIC-TUBE OR SINGLE SKIN-INT
TABLIPM  15 HOT AIR CYCLIC-TUBE OR SINGLE SKIN-INT-PICCOLO TUBE CHORDWISE
TABLIPM  16 HOT AIR CYCLIC-TUBE OR SINGLE SKIN-INT-PICCOLO TUBE SPANWISE
TABLIPM  17 HOT AIR ONE SHOT-TUBE OR SINGLE SKIN-PICCOLO TUBE CHORDWISE
TABLIPM  19 HOT AIR ONE SHOT-TUBE OR SINGLE SKIN-PICCOLO TUBE SPANWISE
TABLIPM  20 GENERAL, MANY METHODS
TABLIPM  21 HOT AIR CYCLIC - SLOT/EXTERNAL
TABLIPM  22 HOT AIR CONT. & CYCLIC - SLOT/EXTERNAL
TABLIPM  23
TABLIPM  24 ELECTRICAL-INTERNAL,WOVEN WIRE PADS
TABLIPM  25 ELECTRICAL-INTERNAL, COATINGS
TABLIPM  26
TABLIPM  27 ELECTRICAL-EXTERNAL, WOVEN WIRE PADS
TABLIPM  28 ELECTRICAL-EXTERNAL, COATINGS
TABLIPM  29
TABLIPM  30 PNEUMATIC-CHORDWISE TUBES
TABLIPM  31 PNEUMATIC-SPANWISE TUBES
TABLIPM  32
TABLIPM  33 FLUID SYSTEMS (POROUS)-GLYCOL BASED
TABLIPM  34 FLUID SYSTEMS (POROUS)-ALCOHOL BASED
TABLIPM  35 FLUID SYSTEMS (POROUS)-OTHER
TABLIPM  36
TABLIPM  37 ACOUSTIC - TYPE I
TABLIPM  38 ACOUSTIC - TYPE II
TABLIPM  39
TABLIPM  40 MICROWAVE - TYPE I
TABLIPM  41 MICROWAVE - TYPE II
TABLIPM  42
TABLIPM  43 ELECTRO-IMPULSE - TYPE I
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TABLIPM  44 ELECTRO-IMPULSE - TYPE II
TABLIPM  45
TABLIPM  46 ICE PHOBIC -FREEZING DEPRESSANT
TABLIPM  47 ICE PHOBIC -LIQUID FILM, LOW VISCOSITY, LOW ADHESION
TABLIPM  48 ICE PHOBIC -SOLID COATING OR TAPE, LOW ADHESION
TABLIPM  49
TABLIPM  50 ICE SHIELDS - UNHEATED
TABLIPM  51 ICE SHIELDS - HEATED ELEVATOR OR RUDDER HORNS
TABLIPM  52 LOW REFLECTIVE PAINT
TABLIPM  53 GROUND APPLIED (ETHYLENE GLYCOL & WATER)
TABLIPM  54 FUEL ADDITIVES
TABLIPM  55
TABLIPM  80      ABBREVIATIONS/MNEMONICS
TABLIPM  81        INT=INTERNAL
TABLIPM  82        CONT=CONTINUOUS
TABLIPM  83
TABLIPM  84
TABLIPM  85
TABLIPM  86
TABLIPM  87
TABLIPM  88
TABLIPM  89
TABLIPM  90      GUIDE TO REVIEWER
TABLIPM  91        IF THE DATA SOURCE DISCUSSES A SINGULAR SPECIFIC ICE
TABLIPM  92          PROTECTION METHOD, USE ONLY ONE AS INDICATED IN THE LIST
TABLIPM  93          IF SEVERAL ARE DISCUSSED, USE THE GENERAL CALLOUTS
TABLIPM  94          INDICATED IN THE LIST.
TABLIPM  95
TABLIPM  96
TABLIPM  97
TABLIPM  98
TABLIPM  99
TABLIPM END DATE/TIME 16 JUN 1980 / 08:44:13 PST
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TABLSOA 00    TABLE OF STATE OF ART CATAGORIES
TABLSOA 01
TABLSOA 02
TABLSOA 03
TABLSOA 04     OPERATIONAL USE-IN COMMON USE OFF THE SHELF
TABLSOA 05     OPERATIONAL USE-OFF THE SHELF NOT IN COMMON USE
TABLSOA 06     OPERATIONAL USE-DES CONCEPT DEV-POTENTIAL USE/GOOD IDEA
TABLSOA 07     OPERATIONAL USE-DES CONCEPT DEV-IDEA NOT TOO GOOD
TABLSOA 08     OPERATIONAL USE-NEW IDEAS
TABLSOA 09     OPERATIONAL USE-IMPROVEMENTS
TABLSOA 10     RES LAB USE-OFF THE SHELF, IN COMMON USE
TABLSOA 11     RES LAB USE-OFF THE SHELF, NOT IN COMMON USE
TABLSOA 12     RES LAB USE-NEW CONCEPT-SINGLE PURPOSE ONE TIME DEV ARTC
TABLSOA 13     RES LAB USE-NEW CONCEPT-NOT DEVELOPED
TABLSOA 14     RES LAB USE-NEW IDEAS
TABLSOA 15
TABLSOA 16
TABLSOA 17
TABLSOA 18
TABLSOA 19
TABLSOA 20     IMPROVEMENTS
TABLSOA 21
TABLSOA 22
TABLSOA  23
TABLSOA  24
TABLSOA  25
TABLSOA 80     ABBREVIATIONS
TABLSOA 81        DES=DESIGN  DEV=DEVELOPMENT  RES=RESEARCH
TABLSOA 82        LAB=LABORATORY  ARTC=ARTICLE
TABLSOA 90     GUIDE TO USERS
TABLSOA END DATE/TIME 16 JUN 1980 / 08:44:13
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TABLDA 00     TABLE OF DATA AVAILABILITY
TABLDA 01         THIS CATEGORY IS FOR INFORMATION ONLY
TABLDA 02         NOT A SORT CATEGORY
TABLDA 03
TABLDA 04      PUBLIC LITERATURE, JOURNALS, ETC
TABLDA 05      GOVERNMENT LITERATURE - UNRESTRICTED
TABLDA 06      GOVERNMENT LITERATURE - RESTRICTED (ALL) LEVELS
TABLDA 07      CONTRACTOR LITERATURE - AVAILABLE
TABLDA 08      CONTRACTOR LITERATURE - PROPRIETARY
TABLDA 09      CONTRACTOR LITERATURE - RESTRICTION
TABLDA 10
TABLDA 11
TABLDA 12
TABLDA 13
TABLDA 14
TABLDA 15
TABLDA 16
TABLDA 17
TABLDA 18
TABLDA 19
TABLDA 20
TABLDA 80       ABBREVIATIONS
TABLDA 90       GUIDE TO USERS
TABLDA END DATE/TIME 16 JUN 1980 / 08:44:13
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TABLSD1  00    TABLE OF SOURCE DATA CATEGORIES -DATA BASE/FACILITY TYPE
TABLSD1  01
TABLSD1  02      PROBLEM IDENTIFICATION, SOLVING
TABLSD1  03      REPORTING, BASIC CATAGORIES
TABLSD1  04
TABLSD1  05
TABLSD1  06        COMMENTARY ONLY
TABLSD1  07        STATISTICAL STUDY OR SURVEY
TABLSD1  08        OPERATIONAL EXPERIENCE REPORTING
TABLSD1  09        EMPIRICAL EQUATIONS
TABLSD1  10        TEST FACILITY USED AS BACKGROUND
TABLSD1  11            TUNNEL TEST CONVENTIONAL, ICING
TABLSD1  12            TUNNEL TEST FREE JET, ICING
TABLSD1  13            TUNNEL TEST DIRECT CONNECT, ICING-ENGINE
TABLSD1  14            TUNNEL TEST CONVENTIONAL, DRY AIR
TABLSD1  15            TUNNEL TEST FREE JET, DRY AIR
TABLSD1  16            TUNNEL TEST DIRECT CONNECT, DRY AIR
TABLSD1  17            FLIGHT TEST, TANKER
TABLSD1  18            FLIGHT TEST, NATURAL ICE
TABLSD1  19            FLIGHT TEST, DRY AIR
TABLSD1  20            SPRAY RIG, FAN BLOWN
TABLSD1  21            SPRAY RIG, WIND BLOWN
TABLSD1  22            ICING TEST CELL
TABLSD1  23            NATURAL ICE & TANKER FLIGHT TESTS
TABLSD1  24            TUNNEL TESTS & FLIGHT TESTS (DRY AIR)
TABLSD1  25            TUNNEL TESTS & FLIGHT TESTS (ICING)
TABLSD1  26        COMPUTER PROGRAM & FACILITY
TABLSD1  27        LABORATORY TEST SETUP (APPROPRIATE EQUIPMT)
TABLSD1  28
TABLSD1  29
TABLSD1  30      APPLICATION ANALYSIS
TABLSD1  31
TABLSD1  32
TABLSD1  33
TABLSD1  34
TABLSD1  35
TABLSD1  80         ABBREVIATIONS
TABLSD1  90         GUIDE TO REVIEWER
TABLSD1 END DATE/TIME 16 JUN 1980 / 06:44:13 PST
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TABLSD3  00    TABLE OF SOURCE DATA , SUBCATEGORY - METHOD OF EXPRESSION
TABLSD3  01
TABLSD3  02      METHOD OF EXPRESSION - WHAT IS THE GENERAL OR HIGHEST
TABLSD3  03        (MOST ACCURATE OR MOST SOPHISTICATED) METHOD OF
TABLSD3  04        EXPRESSION OF THE DOCUMENT.
TABLSD3  05
TABLSD3  06        DESCRIPTIVE  QUALITATIVE
TABLSD3  07        DESCRIPTIVE  QUANTITATIVE(DRAWINGS, ETC.)
TABLSD3  08        MATHEMATICAL EQUATIONS AND PROCEDURES (GENERAL)
TABLSD3  09        COMPUTER PROGRAMS/DATA
TABLSD3  10        EXPERIMENTAL OBSERVATIONS
TABLSD3  11        EXPERIMENTAL MEASUREMENTS
TABLSD3  12        INTERPOL, EXTRAPOL/PREDICTION METHODS(CORRELATION FUNCTIONS
TABLSD3  13        SCALE MODELING
TABLSD3  14        SPECIFIC EQUATIONS - BREGUET
TABLSD3  15        SPECIFIC EQUATIONS - WETTED SURFACE, TOTAL TEMPERATURE
TABLSD3  16        SPECIFIC EQUATIONS/METHOD - ICE ACCRETION PREDICTION METHOD
TABLSD3  17        SPECIFIC EQUATIONS/METHOD - PENALTIES
TABLSD3  18
TABLSD3  19
TABLSD3  20
TABLSD3  21
TABLSD3  22
TABLSD3  23
TABLSD3  24
TABLSD3  25
TABLSD3  80        ABBREVIATIONS
TABLSD3  81          INTERPOL=INTERPOLATION
TABLSD3  82          EXTRAPOL=EXTRAPOLATION
TABLSD3  90        GUIDE TO REVIEWER
TABLSD3 END DATE/TIME 16 JUN 1980 / 08:44:13 PST
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TABLSD04  00    TABLE OF SOURCE DATA.SUBCATEGORY - PROG. R & D PHASES.
TABLSD04  01
TABLSD04  02    ICING PROGRAM PHASE - WHAT PHASE OF THE RESEARCH
TABLSD04  03      OR ACQUISITION CYCLE DOES THE REPORT DEAL WITH
TABLSD04  04
TABLSD04  05
TABLSD04  06    GENERAL
TABLSD04  07    EXPLORATORY - SEARCH FOR PROBLEMS. IDEAS. ETC.
TABLSD04  08    BASIC RESEARCH OR STUDY(PHENOMENA, MATERIALS. NEW TECHNOLOGY)
TABLSD04  09    APPLIED RESEARCH (EVALLATE. APPLY. EXTEND - TECHNOLOGY)
TABLSD04  10    STATISTICAL
TABLSD04  11
TABLSD04  12    CONCEPTUAL DESIGN
TABLSD04  13    DESIGN
TABLSD04  14    DEVELOPMENT
TABLSD04  15    COMBINATIONS OF 12 THRU 14
TABLSD04  16
TABLSD04  17    VERIFICATION
TABLSD04  18
TABLSD04  19    CERTIFICATION
TABLSD04  20    COMBINATIONS OF 17 THRU 20
TABLSD04  21
TABLSD04  22
TABLSD04  23
TABLSD04  24
TABLSD04  25
TABLSD04  26
TABLSD04  27
TABLSD04  28
TABLSD04  29
TABLSD04  30
TABLSD04  80          ABBREVIATIONS
TABLSD04  81
TABLSD04  82
TABLSD04  83
TABLSD04  84
TABLSD04  90          GUIDE TO REVIEWER
TABLSD04 END DATE/TIME 16 JUN 1980 / 08:44139
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TABLSD2  00    TABLE OF SOURCE DATA, SUBCATEGORY - PHENOMENA
TABLSD2  01      THIS TABLE DEFINES THE SCIENTIFIC/ENGINEERING
TABLSD2  02      DISCIPLINE OR PHENOMENA INVOLVED IN THE DATA SUCH AS:
TABLSD2  03      PHYSICAL, THERMODYNAMIC, ACOUSTIC, ELECTRODYNAMIC,
TABLSD2  04      CHEMICAL, ETC.
TABLSD2  05
TABLSD2  06        NOT DISCUSSED
TABLSD2  07        HEAT TRANSFER(DRY AIR) EXTERNAL
TABLSD2  08        HEAT AND MASS TRANSFER(WET AIR) EXTERNAL
TABLSD2  09        HEAT TRANSFER INTERNAL
TABLSD2  10        TOTAL HEAT-MASS TRANSFER
TABLSD2  11        HEAT BALANCE INTERNAL/EXTERNAL
TABLSD2  12        COMBINATIONS OF 06 THRU 12
TABLSD2  13        TOTAL SYS HEAT & MASS XFER  ANALYSIS(WING OR AIRCRAFT)
TABLSD2  14        FLOW FIELDS
TABLSD2  15
TABLSD2  16        WATER DROP TRAJ/COLLECTION EFFICIENCIES (CLEAN AIRFOIL)
TABLSD2  17        WATER DROP TRAJ/COLLECTION EFFICIENCIES (ICED SURFACE)
TABLSD2  18        ICE ACCRETION CONDITIONS &/OR DATA (UNSWEPT)
TABLSD2  19        ICE ACCRETION CONDITIONS &/OR DATA (SWEPT)
TABLSD2  20        ICE SHEDDING, CONDITIONS &/OR DATA
TABLSD2  21        AERO EFFECTS OF ICE ACCRETION - LOCALIZED
TABLSD2  22        TOTAL AIRCRAFT EFFECTS ANALYSIS/DATA ETC.
TABLSD2  23        CONDENSATION ICE (CARBURETORS/FET ENGINE INLETS)
TABLSD2  24        METEOROLOGICAL
TABLSD2  25        ICE ADHESION
TABLSD2  26
TABLSD2  27
TABLSD2  28
TABLSD2  29
TABLSD2  30
TABLSD2  31
TABLSD2  33
TABLSD2  80        ABBREVIATIONS
TABLSD2  81          XFER=TRANSFER
TABLSD2  82          EXT=EXTERNAL
TABLSD2  90        GUIDE TO REVIEWERS
TABLSD2 END DATE/TIME 16 JUN 1980 / 08:44:13 PST
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TABLIC 00    TABLE OF ICING CONDITIONS
TABLIC 01
TABLIC 02
TABLIC 03
TABLIC 04     NO ICING CONDITIONS
TABLIC C5     LIQUID WATER CONTENT (LWC)
TABLIC 06     DROPLET SIZE, MEDIAN DIAMETER
TABLIC 07     DROPLET SIZE, MEAN EFFECTIVE DIAMETER
TABLIC 08     DROPLET SIZE, AVERAGE DIAMETER
TABLIC 09     AIR VELOCITY
TABLIC 10     AMBIENT TEMPERATURE
TABLIC 11     ALTITUDE
TABLIC 12     DROPLET SIZE DISTRIBUTION
TABLIC 13     LWC, TEMPERATURE
TABLIC 14     DROP SIZE, LEC
TABLIC 15     DROP SIZE, TEMPERATURE, LWC
TABLIC 16     WIND TUNNEL, ICING COND
TABLIC 17     WIND TUNNEL, DRY AIR COND
TABLIC 18     FLIGHT TEST, ICING COND
TABLIC 19     FLIGHT TEST, DRY AIR COND
TABLIC 20     TANKER TEST, ICING COND
TABLIC 21     SPRAY RIG ICING COND
TABLIC 22     CERTIFICATION DEFINITION (05, 06, 11)
TABLIC 23     OTHER COMBINATIONS
TABLIC 24     HORIZONTAL EXTENT
TABLIC 25     VERTICAL EXTENT
TABLIC 26     LOCALE
TABLIC 27     SEASON
TABLIC 28     COMMUTER PROFILE
TABLIC 29     GENERAL AVIATION PROFILE
TABLIC 30     TRANSPORT PROFILE
TABLIC 31     HELICOPTER PROFILE
TABLIC 32     STRATOS PROFILE (CONTINUOUS)
TABLIC 33     CUMULUS PROFILE
TABLIC 34     MAX CONTINUOUS - CERTIFICATION DATA
TABLIC 35     INTERMITTENT MAX - CERTIFICATION DATA
TABLIC 36     OTHER (MAX. CONT. & INTERMITTENT MAX.)
TABLIC 37     WATER DROPLET/ICECRYSTAL COMBINATION
TABLIC 38     SNOW, FROST
TABLIC 39     FREEZING RAIN
TABLIC 40     WATER IN FUEL (FREEZING CONDITIONS)
TABLIC 41     ICE PROPERTIES
TABLIC 42
TABLIC 43
TABLIC 44
TABLIC 45
TABLIC 80     ABBREVIATIONS
TABLIC 81        LWC=LIQUID WATER CONTENT
TABLIC 82        COND=CONDITION
TABLIC 83        MAX=MAXIMUM
TABLIC 84        CONT.=CONTINUOUS
TABLIC 90     GUIDE TO USERS
TABLIC END DATE/TIME 16 JUN 1980 / 08:44:13 PST
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TABLPN1  00     TABLE OF PENALTIES ASSOCIATED WITH ICING/ANTI-ICING
TABLPN1  01
TABLPN1  02       PENALTIES ARE RELATED PRIMARILY TO THE PARENT AIRCRAFT
TABLPN1  03       PENALTIES ARE GENERALLY DIVIDED INTO CATAGORIES SUCH
TABLPN1  04       AS PERFORMANCE RELATED, SAFETY RELATED, RELIABILITY
TABLPN1  05       RELATED, COST RELATED OR USAGE RESTRICTION RELATED.
TABLPN1  06
TABLPN1  07     NODATA
TABLPN1  08     NOT APPLICABLE
TABLPN1  09     GENERAL
TABLPN1  10     COMPONENT PENALTIES
TABLPN1  11     ENGINE BLEED PENALTY (COMPRESSOR LOSSES) &/OR DELTA FUEL
TABLPN1  12       WEIGHT
TABLPN1  13       POWER (ELECTRICAL)
TABLPN1  14       COST
TABLPN1  15       RELIABILITY
TABLPN1  16     AIRCRAFT ASSOCIATED PENALTIES
TABLPN1  17       WEIGHT (FUEL)
TABLPN1  18       WEIGHT (TOTAL STRUCTURE & FUEL ETC.
TABLPN1  19       POWER
TABLPN1  20       DRAG
TABLPN1  21       RANGE EFFECT (BERGUET EQUATION)
TABLPN1  22       PAYLOAD EFFECT
TABLPN1  23       LANDING PERFORMANCE
TABLPN1  24       TAKE-OFF PERFORMANCE
TABLPN1  25       STALL EFFECT
TABLPN1  26       CRUISE SPEED
TABLPN1  27       MAXIMUM SPEED
TABLPN1  28       RELIABILITY
TABLPN1  29       SAFETY
TABLPN1  30       COST
TABLPN1  31       OPERATIONAL COST
TABLPN1  32       OPERATIONAL FLIGHT RESTRICTIONS
TABLPN1  33
TABLPN1  34
TABLPN1  35
TABLPN1  36
TABLPN1  80     ABBREVIATIONS ETC.
TABLPN1  81       PWR=POWER
TABLPN1  82       ASSOC=ASSOCIATED
TABLPN1  83       MAX=MAXIMUM
TABLPN1  84
TABLPN1  85
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TABLPR 00    TABLE OF PENALTIES RATING
TABLPR 01        MODIFIES THE PENALTY DATA BY A JUDGEMENT RANKING
TABLPR 02
TABLPR 03
TABLPR 04     NOT APPLICABLE OR NO DATA
TABLPR 05     NO SIGNIFICANT EFFECT
TABLPR 06     SMALL EFFECT
TABLPR 07
TABLPR 08     MODERATE EFFECT
TABLPR 09
TABLPR 10     SEVERE EFFECT
TABLPR 11     SEVERE - SAFETY EFFECT
TABLPR 12     CATASTROPHIC EFFECT
TABLPR 13
TABLPR 14
TABLPR 15
TABLPR 16
TABLPR 17
TABLPR 18
TABLPR 19
TABLPR 20
TABLPR 80      ABBREVIATIONS
TABLPR  90
TABLPR END DATE/TIME 16 JUN 1980 / 08:44:13
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TABLTI	00	TABLE OF TYPES OF INSTRUMENTATION (ICING)
TABLTI	01	
TABLTI	02	
TABLTI	03	
TABLTI	04	
TABLTI	05	
TABLTI	06	
TABLTI	07	
TABLTI	08	
TABLTI	09	DYE TRACER-IMPINGEMENT CHARACTERISTICS
TABLTI	10	ROTATING SINGLE CYLINDER
TABLTI	11	KEILY PROBE-DROP SIZE DISTRIBUTION IN CLOUDS(GND BAS)
TABLTI	12	GSFC LASER NEPHELOMETER - LWC - WATER DROP COUNTER
TABLTI	13	ROTATING MULTICYLINDERS - DROPSIZE & LIQUID WATER CONT
TABLTI	14	FIXED LARGE DIAMETER CYLINDER - DROPLET SIZE
TABLTI	15	NASA ICING METER - LIQUID WATER CONTENT
TABLTI	16	HEATED WIRE METER-JOHNSON WILLIAMS-LIQUID WATER CONTENT
TABLTI	17	OIL SLIDE DROP SNATCHER - DROPLET SIZE
TABLTI	18	LASER BEAM (ASP) - MRI - KNOLLENBERG
TABLTI	19	FORWARD SCATTERING SPECTROMETER PROBE-PMS-KNOLLENBERG
TABLTI	20	ICING SPHERE
TABLTI	21	NGL "HOT ROD"-ACCRETION ROD - LIQUID WATER CONTENT
TABLTI	22	VERNIER ACCRETION METER(VAM)-ICE ACCRETION - LWC
TABLTI	23	EVAPORATIVE TOTAL WATER PROBE LWC METER - RUSKIN
TABLTI	24	DYNAMIC ICE DETECTOR/ICE SEVERITY-STALLABRASS/RINGER
TABLTI	25	ICING ONSET DETECTOR - ROSEMOUNT - VIBRATING ROD
TABLTI	26	ICE DETECTOR - RESISTANCE TYPE
TABLTI	27	ICE DETECTOR - PRESSURE TYPE
TABLTI	28	ICE DETECTOR - MECHANICAL SCRAPER
TABLTI	29	ICE DETECTOR - INFERENTIAL (HEATED WIRE & CYLINDER)
TABLTI	30	ICE DETECTOR - SOVIET CO-4A
TABLTI	31	ICING PREDICTOR - RADAR
TABLTI	32	ICING PREDICTOR - OTHER
TABLTI	33	MICROWAVE ICE DETECTOR
TABLTI	34	NUCLEAR ICE ACCRETN MTR-ATTENUATION(RADIOACTIVE SOURCE)
TABLTI	35	ICING RATE METER - TEDDINGTON INFERENTIAL METER
TABLTI	36	ICING RATE METER - TV RASTER ACCRETION METER
TABLTI	37	ICING RATE METER - ROSEMOUNT
TABLTI	38	TEMPERATURE PROBE - AIR TEMPERATURE
TABLTI	39	PITOT - STATIC PROBE - ALTITUDE, AIR VELOCITY
TABLTI	40	BETA RADIATION ICE DETECTOR
TABLTI	41	
TABLTI	42	PHOTOGRAPHY - ICE SHAPE & SIZE

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TABLTI    43      WEIGHING (SCALES) - ICE SIZE, DENSITY
TABLTI    44
TABLTI    45      ICE CRYSTAL SIZING - FORMVAR REPLICATOR
TABLTI    46      ICE CRYSTAL SIZING - ICE PARTICLE COUNTER,MEE INDUSTRIES
TABLTI    47      ICE PARTICLE COUNTER (UW - IPC)TURNER & RADKE
TABLTI    48      FIBER-OPTICS PARTICLE-SIZING SYSTEM (FOPSS)
TABLTI    49      PARTICLE-SIZING INTERFEROMETER (PSI)
TABLTI    50      BACK SCATTERING PARTICLE SIZING SYSTEM (BSPSS)
TABLTI    51      HOLOGRAM SYSTEM
TABLTI    52
TABLTI    53      MORE THAN ONE TYPE
TABLTI    54
TABLTI    55
TABLTI    56
TABLTI    57
TABLTI    58
TABLTI    59
TABLTI    60
TABLTI    80       ABBREVIATIONS ETC.
TABLTI    81         ACCRETN=ACCRETION
TABLTI    82         DET=DETECTION
TABLTI    83         GND BAS=GROUND BASED
TABLTI    84         IPC=ICE PARTICLE COUNTER
TABLTI    85         LWC=LIQUID WATER CONTENT
TABLTI    86         MRI=METEOROLOGY RESEARCH, INC.
TABLTI    87         MTR=METER
TABLTI    88         NRC=NATIONAL RESEARCH COUNCIL
TABLTI    89         UW=UNIVERSITY OF WASHINGTON
TABLTI    90       GUIDE TO REVIEWER
TABLTI END DATE/TIME 16 JUN 1980 / 08:44:13 PST
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TABLIP 00	TABLE OF INSTRUMENT PHENOMENOLOGY
TABLIP 01	PRINCIPLE OF OPERATION OF INSTRUMENT
TABLIP 02	
TABLIP 03	
TABLIP 04	TEMPERATURE
TABLIP 05	PRESSURE
TABLIP 06	DIFFERENTIAL PRESSURE
TABLIP 07	VIBRATION – NATURAL FREQUENCY BASED ON MASS
TABLIP 08	ELECTRICAL RESISTANCE
TABLIP 09	PROXIMITY
TABLIP 10	OPTICAL
TABLIP 11	MICROWAVE
TABLIP 12	ELECTROMAGNETIC
TABLIP 13	ACOUSTIC
TABLIP 14	MECHANICAL
TABLIP 15	OTHER
TABLIP 16	MORE THAN ONE
TABLIP 17	INFRARED SYSTEM
TABLIP 18	INDUCED AIR FLOW & OPTICAL SENSOR
TABLIP 19	
TABLIP 20	
TABLIP 21	
TABLIP 22	
TABLIP 23	
TABLIP 24	
TABLIP 25	
TABLIP 80	ABBREVIATIONS
TABLIP 90	GUIDE TO USERS

TABLIP END DATE/TIME 16 JUN 1980 / 08:44:13

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TABLIU 00    TABLE OF INSTRUMENT UTILIZATION & CONTROL
TABLIU 01
TABLIU 02
TABLIU 03
TABLIU 04     FORECASTING
TABLIU 05     STATISTICAL RESEARCH (NATURAL CONDITIONS)
TABLIU 06     FLIGHT DATA ACCUMULATION (NON-UTILIZATION IN FLIGHT)
TABLIU 07     WEATHER BALLOONS
TABLIU 08     WEATHER STATION
TABLIU 09     AIRBORNE PILOT UTILIZED - COMMUTER AIRCRAFT
TABLIU 10     AIRBORNE PILOT UTILIZED - GENERAL AVIATION
TABLIU 11     AIRBORNE PILOT UTILIZED - HELICOPTER
TABLIU 12     AIRBORNE PILOT NON-UTILIZED - TELEMETERED
TABLIU 13     AIRBORNE PILOT NON-UTILIZED OPERATIONAL A/C DATA BASE
TABLIU 14     RESEARCH - WIND TUNNEL
TABLIU 15     RESEARCH - TANKER
TABLIU 16     AUTOMATIC - PILOT NON-CONTROLLED SENSING & PROTECTION
TABLIU 17     AUTOMATIC - PILOT NON-CONTROLLED (NO LITES OR DISPLAYS)
TABLIU 18     PILOT INTERACTIVE - AUTO SENSING - INTERACTS WITH DISPLAY
TABLIU 19     PILOT INTERACTIVE - OBSERVATION
TABLIU 20     OTHER
TABLIU 21     MORE THAN ONE
TABLIU 22
TABLIU 23
TABLIU 24
TABLIU 25
TABLIU 26
TABLIU 27
TTABLIU 28
TABLIU 29
TABLIU 30
TABLIU 80     ABBREVIATIONS
TABLIU 90     GUIDE TO USERS
TABLIU END DATE/TIME 16 JUN 1980 / 08:44:13
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TABLRSI  00     TABLE OF RESEARCH & SERVICE INDEXES
TABLRSI  01
TABLRSI  02
TABLRSI  03
TABLRSI  04
TABLRSI  05
TABLRSI  06
TABLRSI  07
TABLRSI  08     NOT APPLICABLE FOR NASA RESEARCH OR SERVICE TO INDUSTRY
TABLRSI  09     ITEM OF INTEREST, BUT SUFFICIENT RESEARCH ACCOMPLISHED.
TABLRSI  10     PAST RESEARCH OF QUESTIONABLE QUALITY BUT LOW IMPACT
TABLRSI  11     PAST RESEARCH OF QUESTIONABLE QUALITY & HAS HIGH IMPACT.
TABLRSI  12     NEW RESEARCH NEEDED - LOW IMPACT, MEDIUM PRIORITY
TABLRSI  13     NEW RESEARCH NEEDED - HIGH IMPACT, HIGH PRIORITY.
TABLRSI  14     RESEARCH METHOD & DATA OF VALUE TO LIGHT AIRCRAFT
TABLRSI  15
TABLRSI  16
TABLRSI  17
TABLRSI  18     SERVICE ITEM OF INTEREST - PRESENT KNOWLEDGE
TABLRSI  19
TABLRSI  20
TABLRSI  21
TABLRSI  22
TABLRSI  23
TABLRSI  24
TABLRSI  25
TABLRSI  80     ABBREVIATIONS/MNEMONICS
TABLRSI  81       RES=RESEARCH
TABLRSI  90     GUIDE TO REVIEWER
TABLRSI  99
TABLRSI END DATE/TIME 16 JUN 1980 / 08:44:13 PST
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TABLRR 000      TABLE OF SCALE RATINGS FOR LITERATURE

TABLRR  01      EXCELLENT
TABLRR  02      VERY GOOD
TABLRR  03      GOOD
TABLRR  04      MEDIUM
TABLRR  05      FAIR
TABLRR  06      OF NO USE TO THE ICING RESEARCH PROGRAM
END TABLRR DATE/TIME 16 JUN 1980 / 08:44:13 PST
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APPENDIX C

ICING RESEARCH DATA FILE INTERROGATIONS

The 141 references in Appendix A were reviewed from the standpoint of the objectives of this study. The resulting codes, data and comments were input into a computerized data file for subsequent manipulation and interrogation. In this appendix are a number of such interrogations which provided information about the literature and were used in arriving at the conclusions and recommendations of this report. Note that the first interrogation presented provides the reference comments for every one of the documents reviewed. Thses comments are in essence, mini-abstracts for each reference.

The other interrogations were made from the standpoint of the various task requirements, and deal with analytical methods, new ice protection methods, instrumentation, penalty data, etc.

ICING RESEARCH DATA FILE SEARCH FOR
RESEARCH STATUS OF ALL REFERENCES REVIEWED

OUTPUT: Ref No., Research Status, Comments Regarding Ref

REFERENCE NUMBER	RESEARCH STATUS	NASA ICING RESEARCH PROGRAM COMMENTS REGARDING REFERENCES
1	RES NEED/HI PRIORITY	MAJOR PROBLEM IS GEN'L ACTIVITY OF LT TRANSPORT A/C IN ICING CONDITIONS. DATA USES FAR 25 CONT MAX CONDITIONS AS A DATA BASE. REF SUGGESTS TANKER & NAT ICE TESTS. *CONSIDERED COSTLY AND UNCONTROLLED*
2	RES NEED/HI PRIORITY	NTSB RECOMMENDS PILOT EDUCATIONAL PROG.(ADVISORY CIRCULAR. THERE WERE 360 ACCIDENTS IN LAST 5 YRS INVOLVING CARB. ICING. REFERENCE STRESSES PROCEDURAL PREVENTION METHODS INCLUDING JUDICIAL USE OF HEATING.
3	RES NEED/LO PRIORITY	DATA COVERAGE- CONVENTIONAL EDUCATIONAL VALUE. PROBLEM CITED- LOSS OF UTILIZATION. NO PROBLEM SOLVING RESEARCH CITED. *SUGGEST RESEARCH NEEDED TO REDUCE COST.COMPLEXITY OF ANTI-ICE METHODS.
4	RES NEED/HI PRIORITY	TEFLON + FUEL ADDITIVE,ASTM ICE TOWER. THERE WERE 44 ACCIDENTS IN 66-67,298 ENG PROBLEMS,MOSTLY FUEL-CAUSED, HARD TO CONTROL, NOT READILY RECOGNIZED.
5	RES NEED/HI PRIORITY	PROPOSED CERTIFICATION METHOD. RESEARCH TO DETERMINE ICEING SEVERITY. RESEARCH INVOLVED DRY AIR,TANKER,NATURAL, AND SIMULATED ICE CONDITIONS. TESTS ENCOUNTERED 1.5 TIMES FAR25 CONDITIONS.
6	RES NEED/HI PRIORITY	FAR METHOD HAS NO STD PROCEDURES. ENCOUNTER PROBLEMS TOO SMALL BY NATL ICE TESTS. PAPER DESCRIBES LESS EXPENSIVE METHOD. TUNNEL TESTS COMPARED WITH FLT TEST - GOOD CORRELATION.
7	RES NEED/LO PRIORITY	STUDY FOR HI BYPASS RATIO ENGINE MAY HAVE VALUE TO HI BYPASS ENGINE LIGHT TRANSPORT A/C.
8	N/A TO RES PROGRAM	REF. DESCRIBES A/I SYSTEM FOR THE LEAR JET. DESCRIBES HOW PROBLEMS WERE SOLVED. PROTUBERANCES (WING) HEATED WITH HOT AIR.
9	RES NEED/HI PRIORITY	COVERS COMPLETE METHOD FOR CERTIFICATION FOR ALL ICE SENSITIVE COMPONENTS & SURFACES. DISCUSSES DRY AIR, SIMULATED ICE SHAPE(FLT),W/T,NATL ICE(FLT),GROUND SLUSH SPRAY. GOOD OVERALL OUTLINE.
10	REF VALUE TO PROGRAM	GOOD REPORT ON OPERATIONAL TECHNIQUES TO FOLLOW FOR INTENTIONAL OR UNINTENTIONAL PENETRATION OF A THUNDERSTORM.

NASA ICING RESEARCH PROGRAM
COMMENTS REGARDING REFERENCES

REFERENCE NUMBER	RESEARCH STATUS	COMMENTS
11	N/A TO RES PROGRAM	REPORT COVERS GENERAL TESTING OF HELICOPTERS IN ICING. INCLUDES ROTORS,ENGINE INLET,AIRFRAME,ICING CONDITIONS.
12	RES NEED/LO PRIORITY	A WING SURFACE USES HOT AIR JET FROM SLOTS FOR ICE PROTECTIO N. JET SYSTEM REDUCES/ELIMINATES RUNBACK ICE BARRIERS. LOW THERMAL INERTIA ALLOWS CYCLIC OPERATION. BEST DISCHARGE ANGLE IS 15 DEGREES.
13	RED VALUE TO PROGRAM	DESCRIPTION AND CAPABILITIES OF THE ICING W/T AT UNIV. OF QUEAT CHICOUTIMI. SUPERCOOLED DROPLET PROD CLAIMED FOR W/T. ALL TYPES ICE ARE PRODUCED BY W/T.
14	RES NEED/LO PRIORITY	INTERESTING METHOD FOR MEASURING AIR TEMP FUNDAMENTALLY WORKING IN THE OXYGEN ABSORPTION BAND.
15	RED VALUE TO PROGRAM	THIS REPORT DESCRIBES GROUND AND AIRBORNE TEST FACILITIES FOR EVALUATING ENGINE A/E SYSTEMS.ADVANTAGES AND DISADVANTAGES OF FOUR MEANS OF EVAL. OF INST. AND EQUIP. ARE IDENTIFIED. SOME RANKING OF INSTRUMENTS IS GIVEN.
16	INTERESTING, SUA	GOOD DATA ON NUMBER OF PEOPLE IN GA IN VARIOUS AREAS. CURRENT STATUS-GA A/C OPERATE IN SAME ICING CONDITIONS AS AIRLINES. SHORT DISCUSSION OF HOW GA MEETS FAR 25 ICING REQ WITH TANKER AC ANALYSIS AND NAT ICE FLIGHT TESTS.
17	RES NEED/HI PRIORITY	EXCELLENT REPORT - NEW CONCEPTS FOR DEFINING ICING INTENSITIE S FOR GA/LT AIRCRAFT. SUGGESTS NEW FORECASTING TO GO ALONG WITH ICING DEF. DEF. BASED ON ICE ACCUMULATION ON 3IN SPHERE.
18	RES NEED/LO PRIORITY	EXTENSIVE WIND TUNNEL TESTS WERE MADE ON AN ICE DETECTOR UNDER A VARIETY OF SIMULATED ICE CONDITIONS.
19	RES NEED/HI PRIORITY	REPORT DISCUSSES NEW FAA PART 24 REGULATIONS DEVELOPMENT FOR GA AND TRANSPORT A/C UP TO 30 PASSENGERS. SOME MATERIAL ON ICING. NUMERICAL DATA ON ACCIDENTS/NO. OF NEW PILOTS/NEW GA.
20	RED VALUE TO PROGRAM	REPORT STATES GRD TEST FAC PROVIDE BEST CAPABILITY FOR CONDUC TING TURBINE ENG ICING TESTS. MATH MODEL OF FLOW IN ICING TEST CELL.EVAL IMPORTANCE OF SIMULATING ICING PARAMETERS.

REFERENCE NUMBER	RESEARCH STATUS	NASA ICING RESEARCH PROGRAM COMMENTS REGARDING REFERENCES
21	OF INTEREST-SUFF RES	DISCUSSION OF THE AEDC FACILITIES.NEW IMPROVEMENTS DISCUSSED INCLUDING DOUBLING OF THE PRESENT AIRFLOW CAPACITY BY 1982. IMPROVED HOLOGRAPHY. MATH MODELING OF ICING ENVIRONMENT.
22	RES NEED/HI PRIORITY	GENERAL OVERVIEW OF ICING PROBLEM AND RES ON ICING PARAMETERS AT NASA LEWIS. INSTRUMENTATION, TEST FACILITIES, ICE DETECT ICING RATE METER, NEW INST NEEDED. OLD TECH STILL OK.
23	RES NEED/FI PRIORITY	ARTICLE FROM AGARD SYMPOSIUM ON INST TO MEASURE ICING PARAMETERS. EXCELLENT REPORT OF STATISTICAL DATA ON PROBABILITIES, ETC.
24	RES NEED/FI PRIORITY	HUMAN FACTORS PROBLEMS IN ICING NOT YET SOLVED. CONTINUING NEED FOR PILOT TRAINING IN EFFECT OF ICING. RECOGNITION OF ICING. NEED FOR ICE DETECTION RESEARCH.
25	N/A TO RES PROGRAM	OPERATIONS COMMITTEE SUMMARY REPORT. RESEARCH NEEDED IN ICE PHOBIC COATINGS.FORECASTING. FROST EFFECTS AND FORECASTING TERMINOLOGY.
26	RES NEED/HI PRIORITY	DISCUSSION OF PERKINS REPORT(022).DISCUSSES RESEARCH REQUIRED IN INST FOR LWC,DROP SIZE,OAT,ICE CRYSTAL CONTENT.FACILITIES MIX TYPES,FORECASTING,AND METEOROLOGICAL REQUIRED RESEARCH.
27	REQ VALUE TO PROGRAM	SHORT SECT ON ICING RES REQUIRED. ANAL MODELING,WIND TUNNEL SIMULATION,ICING TUNNELS,GROUND RIGS.INFLIGHT TANKER TESTING. INFLIGHT NATURAL ICE TESTS.
28	INTERESTING, SUA	KLM HELICOPTERS USE RADAR FOR IFR FLIGHTS TO OIL RIGS.VARIOUS APPROACH AIDS ARE DISCUSSED. BLACK DOTS ON SPONSONS USED FOR ICE DETECTION. ELECT HEATED ROTOR BLADES. ICE DETECTORS.
29	RES NEED/FI PRIORITY	EXCELLENT REPT ON ELECT IMPULSE A/I SYSTEM. DETAILS ON SYSTEM POWER REQ,NO.OF INDUCTORS.OPTIMUM DESIGN REQ. TESTS WERE CONDUCTED IN WT,NAT ICE,AND SIMULATED ICE. NEW RES. REQUIRED.
30	REQ VALUE TO PROGRAM	GOOD DISCUSSION OF TKS SYSTEM USED FOR WINGS AND STABILIZER OF TRANSPORT. POROUS PANELS ARE USED (STAINLESS STEEL).FLUID CONSUMPTION IS PROPORTIONAL TO PANEL AREA.

REFERENCE NUMBER	RESEARCH STATUS	NASA ICING RESEARCH PROGRAM COMMENTS REGARDING REFERENCES
31	RES NEED/HI PRIORITY	DISCUSSES POSSIBILITY FO G/A OPERATION IN IFR AS REQUIREMENT IN FUTURE. PROBLEMS OF A/C ICING. NEW TECHNIQUES AND A/I SYSTEM ARE NEEDED BY G/A FOR CERTIFICATION. NEW SMALL TANKER.
32	RED VALUE TO PROGRAM	DESCRIPTION OF ANAL METHODS DEVELOPED BY BOEING FOR ENGINE NAL INLET ICING ANAL. EXTENSIVE USE OF DIGITAL COMP PROGRAMS TO CALC AIR VEL,H2O IMPINGE,THERMAL REQ.,ETC.VERY ACCURATELY
33	RED VALUE TO PROGRAM	GRUMMAN REP ON ICING INST USED ON GULFSTREAM II TESTS. HEATED WIRE LWC METER WITH OIL SLIDE DROP SIZE. DISTRIBUTION METER JW METER USED FOR COMPARISON.
34	RED VALUE TO PROGRAM	DISCUSSION OF ROSEMOUNT VIBRATING ROD ICE DETECTION SYSTEM. QUALIFIED TO MIL-D-8181D. HIGHLY SENSITIVE-EXHIBITS EXCELLENT REPEATABILITY,1-3% LT ICING, 1-1.5% HEAVY ICING.
35	RES NEED/HI PRIORITY	FACTORS INVOLVED IN MECHANISM OF ICING AND PRINCIPLES OF ICE DETECTION ARE DISCUSSED. DESCRIPTION OF SIMPLE HOT ROD AND OF THE TEDDINGTON INFERENTIAL ICING RATE METER ARE GIVEN.
36	RES NEED/HI PRIORITY	EXCELLENT SURVEY OF CURRENT ICING INSTRUMENTATION AVAILABLE AND UNDER DEVELOPMENT FOR MEASURING OAT,CLOUD LWC, DROPLET DISTRIBUTION, AND CONCENTRATION OF ICE PARTICLES.
37	RES NEED/HI PRIORITY	OPTICAL ICE PARTICLE COUNTER. DESIGN AND DEVELOPMENT DETAILS REPORT. REJECTS LIGHT SCATTER BY WATER. ICE CRYSTALS DETECTED COUNTED IN 20 TO 200 MICRONS SIZE.
38	OF INTEREST-SURF RES	SURFACE CONDITION ANALYZER SYSTEM.INVESTIGATION OF BASIC PRINCIPLES OF OPERATION AND CONCEPT FOR POSSIBLE USE BY THE NAVY. USES TEMP.THERMAL COND. AND RESISTANCE MEASUREMENTS.
39	RES NEED/HI PRIORITY	ACCIDENT REPORT FOR 30 PASSENGER TRANSPORT WHICH CRASHED DUE TO SNOW/ICE ON WINGS AND TAIL PRIOR TO TAKE-OFF. ICE INTERFERED WITH LATERAL CONTROL. CAUSED LOSS OF LIFT.
40	RED VALUE TO PROGRAM	STATISTICAL REPORT ON ACCIDENTS DUE TO CARBURETOR ICING. PROCEDURES FOR AVOIDING CARB ICE ARE COMPLEX.SURVEY INDICATES CARB TYPE AIRCRAFT WILL DOMINATE G/A FOR NEAR FUTURE.SUGGESTS THE PROBLEM IS TECHNICALLY SOLVABLE.

NASA ICING RESEARCH PROGRAM
COMMENTS REGARDING REFERENCES

REFERENCE NUMBER	RESEARCH STATUS	
41	INTERESTING, SOA	LOSS OF SPEED. INEFFECTIVENESS OF DEICE BOOTS WITH RIME ICE. INABILITY OF ENGINE AIR INLET A/I SYSTEM TO KEEP ICE OFF LIP. BOOTS. LACK OF A/I OUTBOARD OF BOOTS.EVAL OF REFLECTIVE PAINT
42	INTERESTING, SOA	EVALUATION OF UH-1H HELICOPTER ELECTROTHERMAL ROTOR BLADE ICE PROTECTION SYSTEM. FEASIBLE CONCEPT. POOR RELIABILITY. CH47C ICING SPRAY SYSTEM TANKER HELICOPTER WAS USED.
43	RED VALUE TO PROGRAM	NAVAL TEST FACILITY(NAPTC) DESCRIPTION, ICE TUNNEL TESTING METHODS. SYSTEMS. AND INSTRUMENTATION. TURBOFAN. TURBOPROP. TURBOJET ENG. SIMULATES ALT,TEMP,SPEED, ICE . HUMIDITY. ETC.
44	RED VALUE TO PROGRAM	CERTIFICATION OF A300. FAIL NOT EQUIPPED WITH ANTI/DEICING SYSTEM. CERTBY ANAL OF ICE SHAPES. ICING WT TESTS AT NASA LRC FLT TESTS WITH ICE SHAPES. ANAL,TESTS,RESULTS ARE DESCRIBED.
45	RED VALUE TO PROGRAM	TESTS OF DOW CORNING E2460-40-1 MATERIAL AS AN ICE PHOBIC ON HELICOPTER ROTOR BLADES. ICE-PHOBIC MATERIAL INCREASE SHED- DING AT -10 DEGC BUT DOES NOT PROVIDE ADEQUATE PROTECTION.
46	RES NEED/HI PRIORITY	SINGLE PILOT IFR ACCIDENT DATA REPORT GIVES CAUSES AND DATA ON ICING RELATED ACCIDENTS. SUGGESTS RESEARCH ON LOW COST,LOW POWER A/I SYSTEMS AND IMPROVED FORECAST/DETECTION TECHNIQUES.
47	RES NEED/HI PRIORITY	REPORT IS DETAILED ANAL OF MATH MODEL FOR FROST FORMATION ON AN AIRFOIL. FIRST PHASE OF STUDY. FROST COLLECTION OF FLAT PLATE AND AIRFOIL. COMPARISONS OF MODEL V. AVAIL EXP DATA.
48	OF INTEREST-SUFF RES	TEST OF PARTICLE SEPARATOR TO BE USED IN AIR INLET DOOR FOR THE A/C TEST AND EVALUATION FACILITY NATC,PATUXENT RIVER, MD. TESTS IN FROST OR ICE FOG.
49	RED VALUE TO PROGRAM	USE OF METRO REPORTS FROM PILOTS IN ANAL OF METRO SITUATION SUPPLEMENTARY DATA,CLOUDS,WEATHER,FRONT,ICING CONDITIONS, UPPER AIR ANAL,THICKNESS,TURBULENCE,OCEANIC REPTS OF SPEC VAL
50	RED VALUE TO PROGRAM	AIRBORNE CALIBRATION OF CANBERRA ICING TANKER SPRAYCLOUD. THE DROPLET VMD AND DIST WERE NOT MEASURED SATISFACTORILY DUE TO INST LIMITATIONS. LWC CAN BE REPRODUCED DOWN TO -21 DEGC PER AVP970

REFERENCE NUMBER	RESEARCH STATUS	NASA ICING RESEARCH PROGRAM COMMENTS REGARDING REFERENCES
51	RES NEED/HI PRIORITY	STUDY OF THE PROCESS OF FRACTURING A LAYER OF ICE ON A METAL SURFACE BY ACOUSTIC VIBRATIONS. ELASTICITY OF ICE DEPENDS ON THICKNESS. RAPID DEFORMATIONS ICE BEHAVES AS BRITTLE BODY.
52	RED VALUE TO PROGRAM	WING SURFACE ROUGHNESS CAUSES AND EFFECTS ON A/C ARE GIVEN AND DISCUSSED. RELATIVE TO LARGE A/C BUT APPLICABLE TO G/A. STALL SPEED IS INCREASED DRAMATICALLY BY SURFACE ROUGHNESS.
53	RES NEED/HI PRIORITY	METHODS FOR PREDICTING ICE SHAPES AND EFFECTS OF ICE SHAPES ARE DISCUSSED. W/T TESTS ARE USED FOR BOTH. 2-DIM AN IS APPLIED TO 3-DIM WING. SIMULATED ICE HAPES USED IN W/T. TECHNIQUE IS USED DURING DESIGN STAGE OF A/C. WINGS. HI LIFT DEVICES.
54	RES NEED/HI PRIORITY	COMPARISON OF W/T AND FLIGHT TESTING. BOTH NATURAL AND ARTIFICIAL ICE. DISADVANTAGES OF FLIGHT TESTING. PROBLEMS OF TUNNEL TESTING ARE GIVEN. AREAS FOR MORE RES INCLUDE BOTH.
55	RED VALUE TO PROGRAM	AN ELECTRO-IMPULSE DEICING METHOD IS DESCRIBED AND MATH. EQUATIONS ARE GIVEN. BASIC CONCERN IS THE MECHANISM OF CRACK FORMATION. MORTAR IS SUBSTITUTED FOR ICE IN TESTS. MORE RES. IS REQUIRED.
56	N/A TO RES PROGRAM	DEFINITION OF ICING PROBLEMS ON LONG RANGE ARCTIC SURFACE EFFECTS VEHICLE(SEV). SOA LITERATURE SEARCH ON ICE FORMATION DEALS WITH SURFACE CRAFT. N/A TO NASA RES PROG ON GEN A/C.
57	N/A TO RES PROGRAM	STUDY OF ALL-WEATHER CAPABILITY OF NAVY AIRSHIP (LIGHTER THAN AIR). ALCOHOL PROPELLER DEICING. ICE SHEDDING FROM PROPELLER DAMAGED AIRSHIP.
58	OF INTEREST-SUFF RES	ATMOS PHENOMENA WHICH CAUSES ICING PROBLEMS IS DISCUSSED. THE ICE PROT. METHODS,ICE DETECTION SYSTEMS ARE DISCUSSED WITH REGARD TO STATIONARY GAS TURBINE POER PLANTS.
59	INTERESTING. SOA	ACCIDENT REPORT. PILOT DID NOT FOLLOW PROPER PROCEDURES WHEN WARNED OF ICING CONDITIONS. A/C UNABLE TO CLIMB OVER MOUNTAIN RIDGE.
60	RED VALUE TO PROGRAM	LITERATURE STUDY OF ICE ADHESION. A SURVEY OF 300 MFGS PRODUCED 100 REPLIES. 15 TO 20 PRODUCTS APPEAR OF SPECIAL INTEREST LOW CONTACT ANGLE,POOR WETTING,AIR,ETC,WEAKENS ADHESION BOND.

NASA ICING RESEARCH PROGRAM
COMMENTS REGARDING REFERENCES

REFERENCE NUMBER	RESEARCH STATUS	COMMENTS
61	RED VALUE TO PROGRAM	ICING NOZZLE OPTIMIZATION PROGRAM FOR NKC-135A TANKER A/C. ATTEMPT TO OBTAIN SMALL DROPLETS AND CONDUCT LIMITED CALIB. MODIFIED NOZZLES PROVIDED MED OF 26 TO 212 MICRONS(RANGE)
62	RED VALUE TO PROGRAM	FORMULATION OF DEFINITIONS & ASSUMPTIONS STIPULATING CRITERIA FOR A/C ICING.RADIOSONDE AND EMPIRICAL A/C ICING DATA IS USED TO DEVELOP PROC FOR PROBABILITY OF ICING.
63	RED VALUE TO PROGRAM	MECHANISM OF ICE ADHESION.LABORATORY TESTS OF STRENGTH OF ICE ADHESION TO VARIOUS MATERIALS.METHODS OF REDUCING ADHESION OF ICE.
64	INTERESTING, SOA	TRANSLATION OF RUSSIAN REPT. GENERAL DISC. OF OCCURENCE OF ICE AND METHODS OF ICE REMOVAL. GENERAL SOA TECHNIQUES ARE DISCUSSED. NOTHING NEW OR UNUSUAL IN THIS REPORT.
65	INTERESTING, SOA	SIMULATED LANDINGS WERE MADE IN NAT'L ICE FLT TESTS WITH ICE ON THE TAIL SURFACES. EVALUATION OF STABILITY AND CONTROL. THIS WAS A POOR TRANSLATION OF A FOREIGN PAPER.
66	RES NEED/LO PRIORITY	A COLLECTION OF CLIMATOLOGICAL DATA WAS EVALUATED IN ORDER TO DETERMINE A METHOD TO PREDICT THE DANGER(PROB) OF ICING BASED ON HUMIDITY MEASUREMENTS. SYSTEM WAS 73% EFFECTIVE.
67	RES NEED/HI PRIORITY	ICEPHOBIC TAPE TESTED ON HELICOPTER ROTOR BLADES TO PROMOTE SHEDDING. TAPE HELPED IN NAT'L ICE TESTS - DID NOT HELP IN THE TANKER TESTS. ICING TOO SEVERE. MORE RESEARCH REQUIRED.
68	INTERESTING, SOA	DESCRIBES DESIGN AND TESTING OF EAPS A/I SYSTEM FOR FRONT FRAME AND SEVERAL OTHER ICE-SENSITIVE AREAS. BLEED AIR WAS USED FOR FRONT FRAME. OTHER SURFACES WERE ELECTRICALLY HEATED
69	INTERESTING, SOA	EVALUATION OF BUFFALO ENG INLET DUCT A/I SYST. VIA TANKER TESTS. FAR 25 CONDITIONS SIMULATED AS MUCH AS POSSIBLE. TESTING WAS RESULT OF ENG STALLS DURING LIGHT ICING.
70	INTERESTING, SOA	SAMPLES OF CIRRUS CLOUD SYSTEMS WERE MEASURED FROM AN A/C TO DETERMINE ICE CRYSTAL TYPE AND SIZE. OBSERVATIONS ON NUCLEATION AND CRYSTAL GROWTH WERE ANALYZED.

NASA ICING RESEARCH PROGRAM

REFERENCE NUMBER	RESEARCH STATUS	COMMENTS REGARDING REFERENCES
71	INTERESTING, SOA	ICE PARTICLE SHAPES,SIZES,WATER DROP SIZE,CONCENTRATIONS AND OTHER DATA OBTAINED BY AIRBORNE PARTICLE CAMERA. MEASUREMENTS MADE ON A FRAME-BY-FRAME BASIS.
72	RED VALUE TO PROGRAM	TESTS OF W/S STATIC ELECTRICAL CHARGING DUE TO CONTACT WITH ICE CRYSTALS. W/S GLASS PUNCTURES AND WORSE MAY OCCUR. EFFECT ON ELECTRIC CIRCUITS IS DISCUSSED.
73	RED VALUE TO PROGRAM	SAME MATERIAL AS IN REFERENCE 62
74	RED VALUE TO PROGRAM	DESCRIPTION OF THE ARC ICING TUNNELS AND THEIR PROBLEMS.RANGE OF ICING PARAMETERS AND NATURE OF TESTS UNDERTAKEN. TUNNEL PROVIDES FOR ICING TESTS DURING ANY SEASON OF THE YEAR.
75	RED VALUE TO PROGRAM	COMPLETE HANDBOOK ON ICING TECHNOLOGY UP TO 1967. RUSSIAN/ENG TRANSLATION. INTERESTING DATA ON PENALTIES. GEN DATA IS STANDARD. LITTLE VALUE TO THIS RESEARCH PROGRAM.
76	PAST RES POOR-HI IMP	CALIBRATION OF A T-33 TANKER A/C FOR ICING FLIGHT TESTS USING A KNOLLENBERG PROBE AND ICING SPHERE. PROBLEMS WITH THE EQUIPMENT LEAVES DOUBT AS TO RESULTS OF SYST. CALIB. ACCURACY
77	INTERESTING, SOA	CONFIRMATORY TESTS OF T-23F AIRPLANE FOR 57 FLYING HOURS. EVALUATION OF A/I AND DEICING SYSTEMS WERE NOT ACCOMPLISHED.
78	RED VALUE TO PROGRAM	ANTI-ICING AND DEICING KIT INSTALLED IN U-8F A/C AND TESTED FOR FUNCTIONAL SUITABILITY.W/S A/I AND PROPELLER DEICING ARE THE SYSTEMS.
79	INTERESTING, SOA	REPORT ON PRODUCT IMPROVEMENT. RELATIVE SUITABILITY OF AN ELECTRICALLY HEATED GLASS W/S AND ELECT HTD PLASTIC W/S. IMPROVED ABRASION RESISTANCE FOR GLASS W/S.
80	RED VALUE TO PROGRAM	FAA CIRCULAR ON FUEL ADDITIVE PFA-55MB AND MIL-I-27686 FOR ANTI-ICING OF FUEL SYSTEMS IN TURBINE A/C ENGINES. ADDITIVE CONCENTRATIONS ARE GIVEN.

REFERENCE NUMBER	RESEARCH STATUS	NASA ICING RESEARCH PROGRAM COMMENTS REGARDING REFERENCES
81	REQ VALUE TO PROGRAM	INFO ON ANTI-ICING FUEL ADDITIVES FOR AVIATION GASOLINE AND FUEL SYSTEMS. EFFECTS OF ICE IN FUEL AND THE DIFFERENCE BETWEEN GASOLINE AND TURBINE ENGINE FUEL ARE DISCUSSED.
82	INTERESTING, SOA	DESCRIBES PROCEDURES THAT MAY BE USED FOR APPROVING THE ADDITIVES FOR USE IN CERTIFICATED A/C.
83	REQ VALUE TO PROGRAM	INFO ON POTENTIAL HAZARDS ASSOCIATED WITH A/C CONTROL SURFACE FLUTTER CAUSED BY IMBALANCE FROM DEPOSITIONS OF ICE, SLUSH, OR SNOW. ONE EIGTH INCH OF ICE HAS CAUSED ACCIDENTS.
84	REQ VALUE TO PROGRAM	FAA GUIDE ON ICE PROTECTION. METHODS OF ICE PROT. ARE LISTED. FAR 25 DATA IS DISCUSSED. A/C OPERATIONAL FACTORS ARE DISCUSSED. OBJECTIVES OF A/I SYSTEM DESIGN ARE GIVEN & DISCUSSED.
85	INTERESTING, SOA	ICING TEST FACILITY IN CANADA. LOW SPEED AND HIGH SPEED WIND TUNNELS. HELICOPTER ICING SPRAY RIG. ENGINE ICING TEST CELL.
86	INTERESTING, SOA	USA, EUROPE, AND RUSSIAN ICING REGULATIONS AND ICING CONDITIONS ARE GIVEN AND DISCUSSED. PARAMETERS ARE LISTED AND CERTAIN ICING PARAMETER VALUES ARE TABULATED. FAR-25&JAR-25, CAR-7, AND JAR-E, ETC.
87	RES NEED/HI PRIORITY	INVESTIGATION OF MICROWAVE ICE PROTECTION CONCEPT FOR HELICOPTER ROTOR BLADES. ANAL TECHNIQUES HAVE BEEN VERIFIED. LAUNCH EFFICIENCIES HI ENOUGH TO DEMONSTRATE CONCEPT WERE REALIZED.
88	REQ VALUE TO PROGRAM	COMPARISON OF LIGHTWEIGHT(80LBS) DE-ICING SYSTEM AND HEAVYWT ANTI-ICING SYSTEM(144LBS) IS MADE UNDER THE SAME ICING CONDITIONS. ONLY THE 144 LB SYSTEM WAS SATISFACTORY.
89	REQ VALUE TO PROGRAM	COMPARISON OF LT WT IMPROVED PNEU BOOT DE-ICING SYSTEM AND AN ELECTRO-THERMAL SYSTEM. BOOT SYSTEM IMPROVEMENT USED VACUUM PUMP INSTEAD OF 3000 PSI ACCUMULATOR. ELECTRO-THERMAL SYSTEM INCLUDED W/S AND PROPELLER DE-ICING.
90	N/A TO RES PROGRAM	METHODS DEVELOPED FOR PREDICTING ICING INTENSITY FROM STATISTICAL DATA MEASURED IN ICING CONDITIONS. MORE RESEARCH IS NEEDED TO IMPROVE ACCURACY OF METHOD. RUSSIAN TRANSLATION

REFERENCE NUMBER	RESEARCH STATUS	NASA ICING RESEARCH PROGRAM COMMENTS REGARDING REFERENCES
91	REQ VALUE TO PROGRAM	REPORT ON DEVELOPMENT OF THE BRITISH TKS FLUID A/I SYSTEM. BASIC A/I FLUIDS ARE GLYCOLS EXCEPT FOR W/S WHERE ALCOHOL (PRIMARILY ETHYL) IS USED. LOGISICS PROB. WITH FLUID SYSTEMS.
92	REQ VALUE TO PROGRAM	DATA ON ICING USED BY AIR WEATHER SERVICE(AWS) FORECASTERS IN FORECAST AND BRIEFINGS FOR AIR OPERATIONS. CONTAINS STANDARD DEFINITIONS OF ICING INTENSITY, ETC.
93	REQ VALUE TO PROGRAM	FUNDAMENTAL RELATIONSHIPS FOR DYNAMIC SIMILARITY BETWEEN MODEL AND PROTOTYPE ARE SHOWN WITH MATHEMATICAL EQUATIONS. LIMITS IN USE OF ICING W/T FOR SIMULATION ARE ESTIMATED.
94	REQ VALUE TO PROGRAM	A MATH THEORY WHICH ENABLES THE TRANSIENT HT CHARACTERISTICS OF 2-D BODIES TO BE DETERMINED IN ICING W/T USING SCALE MODEL MODELS. EQUATIONS AND GRAPHS SHOW RELATIONSHIPS BETWEEN W/T AND FULL-SCALE PROTOTYPE CONDITIONS.
95	INTERESTING, SOA	DESCRIPTION OF THE NAPIER ELECTRICAL HEATING SYSTEM FOR ANTI-ICING AND DE-ICING SYSTEMS FOR VARIOUS A/C COMPONENTS.
96	REQ VALUE TO PROGRAM	TESTS CONDUCTED IN AEDC J1 TEST CELL ON HOLOCAMERA TECHNIQUES FOR MEASURING DROPLET SIZE.DISTRIBUTION. SYSTEM WAS FEASIBLE. DROPS DOWN TO 5 MICRONS. REQUIRES ELECTRONIC DATA HANDLING.
97	RES NEED/HI PRIORITY	ICE ADHESION TESTS. ICE/STAINLESS ST PURE ADHESIVE BREAK DOWN TO -13C. TRANSITION BELOW -13C(SHEAR). EMPIRICAL EQUATIONS DEVELOPED FOR ADHESIVE STRENGTH.
98	RES NEED/HI PRIORITY	SPONGE RUBBER SUBSTRATE IS USED WITH LOW ADHESIVE MATERIAL TO INDUCE SHEDDING OF ICE. LAB TESTS OF VARIOUS MATERIAL COMBI-NATIONS. TECHNIQUE HAS APPLICATION FOR ROTATING BLADES.
99	REQ VALUE TO PROGRAM	PROBLEMS WITH ICING W/T ARE DESCRIBED. CIRC OF SNOW IN RETURN CIRCUIT FROM FREEZE OUT AND COOLING COILS FROST FORMATION WATER/GLYCOL SPRAY FORMS SLUSH SO SNOW CANT BLOW.
100	REQ VALUE TO PROGRAM	MATH METHOD FOR CALCULATING THE RATE OF ICING AND CLOUD WATER CONTENT FROM ICE ACCRETION ON A SINGLE ROTATING CYLINDER. THE EFFECT OF BLOWOFF IS DISCUSSED. LUDLAM LIMIT IS DISCUSSED.

REFERENCE NUMBER	RESEARCH STATUS	NASA ICING RESEARCH PROGRAM COMMENTS REGARDING REFERENCES
101	RES NEED/LO PRIORITY	A STUDY OF THE PARAMETERS WHICH AFFECT THE DENSITY AND STRUCTURE OF ICE ACCRETIONS. EQUATIONS DEVELOPED FOR DENSITY OF ICE COLLECTED ON CYLINDERS.
102	RED VALUE TO PROGRAM	EXCELLENT RPT OF VALUE TO ICE RES PROG. GOOD SECTIONS ON PROB AND SEVERITY OF ICING COND. A/I AND DEICING METHODS. CERTIF. REQ. AND ICING INTENSITY DEF. NEW A/I SYSTEMS.
103	RES NEED/HI PRIORITY	REVIEW OF ICE ACCRETION PREDICTION DATA BASE IN 1970.DATA AND METHODS. RESEARCH STUDY PLAN TO IMPROVE ICE ACCRETION PRED. TECHNIQUES BY NAA IS INCLUDED . APPLICABLE TO NASA RES STUDY.
104	N/A TO RES PROGRAM	SPECIFICATION FOR ADVANCED LIFT FAN SYS(LFX).SHOWS A/I FLIGHT REQUIREMENTS ENVELOPE. GUIDE VANES ANTI-ICED WITH BLEED AIR. NON-CONTINUOUS SYSTEM
105	RED VALUE TO PROGRAM	ADS-3 SUMMARIZES SOA OF ICING TECHNOLOGY UP THRU 1964. HANDBOOK ON ALL ASPECTS OF CALCULATING ICE ACCRETION AND ICE PROTECTION REQUIREMENTS
106	RED VALUE TO PROGRAM	THREE FLT SERIES TEST TO CALIBRATE KC-135 ICING SPRAY NOZZLES USING ML-130E WITH PMS SPECTROMETERS SAMPLING ARTIFICIAL CLOUD DATA USED TO PRODUCE AVE & INSTANTANEOUS 1SEC PARTICLE SIZE SPECTRA WITH LWC VALUES.
107	RED VALUE TO PROGRAM	SHEAR TESTS WERE MADE USING VARIOUS ICEPHOBIC MATERIALS ON FLAT SURFACES.THE MATERIALS REPRESENTED THE BEST IN INDUSTRY IN 1975.NONE FUNCTIONED AS ICEPHOBIC MATERIAL SUCCESSFULLY AT -4 DEGF. NO MATERIAL WAS ADEQUATE FOR THE ARMY.
108	RED VALUE TO PROGRAM	TECHNICAL REF DOCUMENT FOR A/C POWERPLANT ICE PROTECTION SYSTEM DESIGN. SEQUEL TO ADS-4 FOR AIRFRAME A/I DESIGNERS. INCLUDES UPDATED MATERIAL, WHERE AVAILABLE.
109	RES NEED/HI PRIORITY	THE DEGRADATION OF AERO EFF OF A 2-DIM NACA652A215 AIRFOIL DUE TO SIMULATED ICING CONDITIONS WAS STUDIED IN THE SWEDISH FFA ICING TUNNEL. SEVEN DIFFERENT SIMULATED ICE SHAPES WERE TESTED WITH 0, 20, AND 40 DEGREE FLAP ANGLES.
110	RED VALUE TO PROGRAM	STUDY OF ETHYLENE GLYCOL MONOMETHYL ETHER(EGME) AND SOME GLYCEROL ADDITIVES TO AVIATION FUEL AND THE ANALYSIS OF WATER IN THESE ADDITIVES, ETC., BY GAS CHROMATOGRAPHY.

NASA ICING RESEARCH PROGRAM
COMMENTS REGARDING REFERENCES

REFERENCE NUMBER	RESEARCH STATUS	COMMENTS REGARDING REFERENCES
111	INTERESTING. SUA	TEST OPERATIONS PROCEDURES(TOP) FOR US ARMY AIRCRAFT A/I OR DEICING EQUIPMENT TESTS. THE SCOPE OF THE DOCUMENT IS BROAD AND THE TEST PROCEDURE GENERAL TO ACCOMODATE NEW DESIGNS AND TECHNOLOGY.
112	OF INTEREST-SUFF RES	DRY AIR FLIGHT TEST EVALUATION OF CYCLIC HOT AIR TAIL L.E. DEICING SYSTEM. CYCLIC RATES INCORRECT.PLUS POOR DESIGN OF INTERNAL DUCTING. HEAT LOSSES WERE EXCESSIVE BETWEEN HOT AIR DUCT AND TAIL L.E.
113	RES NEED/HI PRIORITY	AIR FORCE GEOPHYSICS LAB(AFGL) WILL MEASURE RIMING RATES ALOFT USING ROSEMOUNT ICE DETECTOR MOUNTED ON WING TIP OF MC130E RES A/C. MOUNTING SITES FOR ID ARE STUDIED VIA COMPUTER STUDIES FOR SHADOWING AND FLUX DISTORTION, ETC.
114	N/A TO RES PROGRAM	REVISED LOAD CURVES AND VEHICLE ICE THICKNESS TABLES FOR SHEET ICE OPERATIONS AT ANTARCTICA. MATERIAL PROPERTIES ON SEA ICE WAS REVIEWED. ELASTIC FINITE ELEMENT COMPUTER CODE IS DISCUSSED. LOAD CURVES FOR SPECIFIED A/C ARE GIVEN.
115	RES NEED/HI PRIORITY	FEASIBILITY STUDY FOR MICROWAVE DE-ICING SYSTEM FOR HELICOPTER ROTOR BLADES. ANAL IS BASED ON COUPLING MICROWAVE ENERGY TO THE ICE LAYERS BY MEANS OF DIELCTRIC SURFACE WAVEGUIDES.
116	RED VALUE TO PROGRAM	A STUDY WAS MADE TO INVESTIGATE THE SENSITIVITY OF A NUMBER OF DIFFERENT TAIL DESIGNS WITH ICE ACCRETIONS. ICE SHAPES WERE DETERMINED IN W/T TESTS. THEN SIMULATED SHAPES WERE TESTED IN W/T DRY AIR.
117	RED VALUE TO PROGRAM	THE EFFECTS OF SIMULATED HOAR FROST ON LIFT AND DRAG CHARACTERISTICS OF A 2-D WING SECTION WITH AND WITHOUT HIGH LIFT DEVICES. THREE CONF. BASIC WING. 20 DEG TRAILING EDGE FLAP AND WING WITH 25 DEGREE SLAT PLUS 20 DEGREE TE FLAP
118	RED VALUE TO PROGRAM	METHODS FOR MAKING AND USING MOLDS FOR ICE SHAPES FROM WINGS AND FROM RUNWAYS ARE DESCRIBED. PROBLEMS WITH SILICONE RUBBER ARE DESCRIBED.
119	RED VALUE TO PROGRAM	2-DIM ICING WIND TUNNEL INVESTIGATION OF A NACA 65A215 WING SECTION WITH SINGLE SLOTTED FLAP BY THE SWEDISH AERONAUTICAL RESEARCH INSTITUTE.
120	RES NEED/HI PRIORITY	MEASUREMENTS WERE MADE OF THE EFFECTS OF RESIDUAL ICE ON AN AIRFOIL CONTAINING A PNEUMATIC BOOT DE-ICING SYSTEM.

NASA ICING RESEARCH PROGRAM
COMMENTS REGARDING REFERENCES

REFERENCE NUMBER	RESEARCH STATUS	COMMENTS REGARDING REFERENCES
121	INTERESTING, SUA	1969 FAA SYMPOSIUM ON A/C ICE PROTECTION. SERIES OF PAPERS BY DIFFERENT AUTHORS ON ENGINE AND AIRFRAME ICE ACCRETION AND SHEDDING AND ICE PROTECTION SYSTEMS.
122	RES NEED/HI PRIORITY	FAA HELICOPTER OPERATIONS R&D PLAN INCLUDING ICING STANDARDS SECTION. DISCUSSION INCLUDES SHORT TERM AND LONG TERM OBJECTIVES OF THE PROGRAM.
123	RED VALUE TO PROGRAM	ANAL STUDY OF ICING SIMULATION FOR TURBINE ENGINES IN ALT. TEST CELLS. DEVELOPMENTS OF MATHEMATICAL MODEL STUDY LENDS SUPPORT TO CONCEPT THAT GROUND TEST FACILITIES PROVIDE THE BEST CAPABILITY FOR CONDUCTING TURBINE ENG. ICE TESTS.
124	RED VALUE TO PROGRAM	CONVERSION OF A LARGE QUANTITY OF PUBLISHED THEORETICAL DATA OF WATER CATCH EFFICIENCY AND LIMITS OF IMPINGEMENT FOR AIRFOILS AND OTHER BODY SHAPES, INTO A KD MODIFIED INERTIA PARAMETER FORMAT.
125	RES NEED/HI PRIORITY	AIR FORCE AFFDL TECH MEMO ON AF AIRCRAFT ICING NEEDS-OUTLINES ICING PROBLEMS,RESEARCH REQUIREMENTS NEEDED TO HELP DETERMINE SOLUTIONS IN FIELDS OF TANKER TESTING,METEOR., ICING TUNNEL TESTING, OPERATIONS, ETC.
126	RED VALUE TO PROGRAM	ICE DETECTOR DEVELOPMENT FOR HELICOPTERS. ICE DETECTOR OVERCOMES PROBLEM OF SPEED DEPENDENCE.
127	N/A TO RES PROGRAM	ICING CELL TESTS OF HELICOPTER FRONT FUS.ENG INLETS.SCOOPS. ROTOR BLADES. ELECTRO-THERMAL AND FLUID A/I TESTS FOR ENG ICE INGESTION. NOTE FACILITY. GOOD ICING PHOTOS.SPECIAL PROBLEMS FOR HELICOPTERS.
128	RES NEED/HI PRIORITY	NASA LEWIS ICING TUNNEL WAS USED. ICE SHAPES TEST TUNNEL. NAIL ICE TEST,APU INLET.NO PROBLEM.FLOW DISTORTION TEST FOR INLETS.
129	RES NEED/HI PRIORITY	PROG SPONSORED BY FAA CONDUCTED IN NASA LEWIS TUNNEL. CORRELATIONS OF DATA ON UNHEATED AIRFOILS. ICE SHAPES/SHEDDING.
130	RED VALUE TO PROGRAM	SUMMARY OF THE ICING TEST FACILITIES IN EUROPE. PROBLEMS WITH ICING TESTS IN WIND TUNNELS. SCALE MODELING VS FULL-SCALE. BASIC EQUATIONS FOR SIMILITUDE. EXCELLENT PHOTOS.

NASA ICING RESEARCH PROGRAM
COMMENTS REGARDING REFERENCES

REFERENCE NUMBER	RESEARCH STATUS	COMMENTS
131	REQ VALUE TO PROGRAM	GENERAL SUMMARY AND HISTORICAL PERSPECTIVE OF ICING AND ICING RESEARCH NEEDS. OVERVIEW OF ICING EFFECTS ON A/C DESIGN,ICING ENVIRONMENTS,CERTIFICATION CRITERIA,NASA ROLE. FACILITIES,ETC
132	REQ VALUE TO PROGRAM	REPORT ON SAFETY HAZARD OF AIRCRAFT ICING. BREAKDOWN OF STRUCTURAL AND INDUCTION SYSTEM ICING ACCIDENTS. ACCURACY OF WEATHER FORECASTS OK. INADEQUATE ICING WEATHER BRIEFINGS ARE PROBLEM.
133	REQ VALUE TO PROGRAM	A REVIEW OF ICING SITUATION FROM G/A STANDPOINT. EXCELLENT SECTION ON PROBLEMS WITH FAA RULES AND REGULATIONS AND DEFINITIONS ON ICING CONDITIONS. NEED FOR WORK ON G/A REGS & CERTIFICATION.
134	REQ VALUE TO PROGRAM	OVERVIEW OF HELICOPTER IC PROT SYS.ROTOR BLADE ICE PROT MOST IMPORTANT PROBLEM. TECH PROBLEMS, METRO DESIGN CRITERIA AND INACCURACY OF FORECASTING. AMBIGUOUS ICING DEFINITIONS. ETC.
135	REQ VALUE TO PROGRAM	DISCUSSION OF THE ICING FACILITY NEEDS. CORRELATION BETWEEN NATURAL AND ARTIFICIAL ICE. CRITERIA FOR SIMULATION OF ICE. INST NEEDS,COMPUTATIONAL METHOD UPDATE. FUTURE FACILITY REQ.
136	INTERESTING, SOA	DESCRIPTION OF NGTE ICING TEST FACILITY AND IN PARTICULAR CELL 3 AND CELL 3 WEST. ICING AND DRY AIR TESTS. CAPACITY AND CHARACTERISTICS DISCUSSED. EQUIP. AND DATA REDUCT. TECHNIQUES
137	INTERESTING, SOA	ICING MEASUREMENT CAPABILITIES OF AEDC ENGINE ICING TEST FACILITIES ARE DESCRIBED. SPRAY CAPABILITIES AND MANIFOLDS CONTAINING NOZZLES ARE DESCRIBED.
138	INTERESTING, SOA	DESCRIPTION OF THE GENERAL ELECTRIC ENGINE TEST FACILITY AT PEEBLES,OHIO. COMPARISON TO PREDICTED LWC AND DROP SIZE WITH MEASURED VALUES OBTAINED FROM FACILITY. DATA SHOWN.
139	REQ VALUE TO PROGRAM	DESCRIPTION OF THE NRC DYNAMIC ICE DETECTOR FOR HELICOPTERS AND AN ICING SEVERITY METER DEVELOPED FROM THE DYNAMIC ICE DETECTOR. CIRCUITS DEVELOPED FOR TRACE, LT.,MOD.,HEAVY ICE.
140	INTERESTING, SOA	NGTE ENGINE TEST FACILITY. TEST IN CELL 3WEST OF OLYMPUS 593 INLET ANTI-ICING SYSTEM. ELEC CYCLIC AND HOT AIR CONT FOR INTAKE SUPPORT STRUTS.

REFERENCE NUMBER	RESEARCH STATUS	NASA ICING RESEARCH PROGRAM COMMENTS REGARDING REFERENCES
141	RES NEED/HI PRIORITY	THE NEW ROLE OF THE METEOROLOGIST IN THE ICING CLIMATOLOGY AND ICE PROT CERTIFICATION PROGRAMS IS GIVEN. CERTIFICATION, CLOUD PHYSICS, ICE FORMATION, ETC., ARE DISCUSSED.

ICING RESEARCH DATA FILE SEARCH FOR
REFERENCES CONTAINING ICING PENALTY DATA

OUTPUT: Ref No., Comments Regarding Penalty Data

REFERENCE NUMBER	COMMENTS REGARDING PENALTY DATA
1	PENALTIES DETERMINED FROM COMB. OF MEAS. & EQUNS.*SUGGEST AER O PENALTIES BE DETERMINED IN TUNNEL TESTS WITH SIMULATED ICE ON SECTIONS, AND SHOULD INCLUDE FLIGHT HANDLING QUALITIES IN ADDITION TO RANGE, DRAG, ETC.*
2	PENALTIES ARE ASSOC. WITH LACK OF CARB. HEATING
3	ICE SIMULATED IN AMES TUNNEL AND IN-FLIGHT. OK, EXCEPT HORIZ STAB REQUIRED ANTI-ICING FOR LANDING. NO PENALTIES DISCUSSED BUT PROOF OF GOOD FLIGHT HANDLING QUALITIES STRESSED.
4	EG. NO. OF ACCIDENTS. ALSO 14% POWER LOSS PENALTY RELATED TO USE OF HEAT.
5	PROBLEM- LIGHT A/C OPERATIONAL CONSTRAINTS BY FAA VS COSTLY S YSTEM AND TESTING.
11	INCREASE IN POWER REQ. SHOWN FOR GIVEN FLIGHT CONDITIONS. TORQUE INCREASES TO MAINTAIN LEVEL FLIGHT.
12	TESTS INDICATE MORE SURFACE AREA PROTECTION FOR THE SLOTTED JET AIR SYSTEM THAN SIMILAR CONVENTIONAL HOT AIR SYSTEMS.
15	QUALITATIVE COMPARISONS ARE MADE OF THE RELATIVE COSTS OF THE FOUR METHODS OF TESTING ENGINE A/I SYSTEMS.
29	PENALTIES FOR ELECT POWER AND FOR WEIGHT OF INDUCTORS AND NO. OF THYRISTORS ARE GIVEN. PENALTIES ARE RELATED TO RUSSIAN IL 18 AIRPLANE.
30	LOW POWER CONSUMPTION OF 75 WATTS FOR PUMP. RESERVOIR HOLDS 45 LITERS OF FLUID. GLYCOL BASED. TWO PUMPS ARE USED FOR RELIABILITY PURPOSES.

REFERENCE NUMBER	COMMENTS REGARDING PENALTY DATA
32	GENERAL STATEMENT THAT A/C PENALTIES CAN BE REDUCED BY ACCURATE DETERMINATION OF A/I REQUIREMENTS USING GOOD ANALYTICAL METHODS AS SHOWN IN THIS REPORT. STEP BY STEP ANAL PLAN IS SHOWN ALONG WITH THE TYPE OF COMPUTER CODES REQUIRED.
40	MAJOR PROBLEM IS CONCERNED WITH AIRCRAFT SAFETY. BETWEEN 65 TO 90 ACCIDENTS EACH YEAR INVOLVE CARB OR INDUCTION SYSTEM ICING AS A PROBABLE CAUSE OR FACTOR.
41	AT CONSTANT POWER AN AIRSPEED LOSS OF 20 TO 30 KNOTS OCCURS IN MODERATE ICING CONDITIONS REGARDLESS OF PAINT CONFIGURATION. 170 KCAS. ACCUM OF 0.5 TO 1.0 INCHES ICE.
44	EFFECTS ON BOTH LIFT AND DRAG ARE SHOWN FOR THE TAIL POLAR CHARTS.
47	EFFECT OF FROST ON RESULTING AERODYNAMIC PENALTIES WILL BE SUBJECT OF FOLLOW-ON REPORTS.
52	CHANGE IN MAX LIFT COEF VS ROUGHNESS IS PRESENTED FOR MUCH PUBLISHED DATA. STALL SPEED INCREASE AS FCN OF REDUCTION OF MAXIMUM LIFT COEFFICIENT.
53	PENALTY DATA GIVEN AS REDUCTION IN LIFT COEF AND INCREASE IN STALL SPEED. PENALTIES ARE IN THE SEVERE RANGE. ALL ICING IS CONSIDERED DANGEROUS. RES TECHNIQUES CONSIDERED VERY GOOD.
55	DEICING METHOD DRAMATICALLY REDUCES POWER REQUIREMENTS OVER THERMAL SYSTEMS. EFFICIENCY INCREASES WITH ICE THICKNESS. TOTAL WEIGHT AND DIMENSIONS ARE DECREASED.
57	ICING RATE OF 4000 LB/HR SHOWS DIRECT WT. PENALTY TO AIRSHIP.
58	BLEED AIR OR ELECTRICAL SYSTEMS ARE USED IN PREFERENCE TO ALCOHOL SYSTEMS WHICH PRESENT LOGISTICS PROBLEMS. THE MAJOR PENALTIES ARE FUEL COSTS AND RELIABILITY/MAINTENANCE RELATED.

REFERENCE NUMBER	COMMENTS REGARDING PENALTY DATA
59	AIRCRAFT CRASH DUE TO ICED CONDITIONS.
65	QUALITATIVE DISCUSSION OF AERO EFFECTS OF ASCENTS AND DESCENT AND HORIZ FLT WITH ICE AND THE UTILIZATION OF A/I SYSTEM.
69	MODIFICATIONS OF BLEED AIR REGULATOR AND INLET DUCT A/I SYST. IMPROVED THE A/I SYSTEM RELIABILITY.
72	STATIC ELECTRIC CHARGES CAUSED BY ICE CRYSTALS ON W/S CAN CAUSE EQUIP FAILURE AND REDUCED SAFETY AND RELIABILITY DUE TO DAMAGE OF DISCHARGES. COMPLETE BREAKUP AND LOSS OF FORWARD VISION THRU W/S CAN OCCUR.
75	COMPARISON OF ELECTROTHERMAL AND BLEED A/I SYSTEMS FOR WEIGHT,COMPLEXITY,RELIABILITY AND MAINTENANCE. DISCUSSES CHEMICAL SYSTEMS.
77	ARMY LACKS MAINTENANCE FACILITIES TO PROVIDE 3000 PSI FOR RECHARGE OF DEICING SYSTEM.
78	INCREASED CAPACITY OF ELEC POWER GENERATORS. NEW 300 AMPERE GENERATORSIZE WERE INSTALLED. UNUSUAL AMOUNT OF TROUBLE AND PROBLEMS ENCOUNTERED WITH NEW GENERATORS.
79	CONVERTING FROM PLASTIC TO GLASS WINDSHIELDS INCREASES A/C WEIGHT BY 15.6 POUNDS.
87	WEIGHT,POWER,AND COST DATA ARE SHOWN FOR VARIOUS HELICOPTER ROTOR BLADES BY HELICOPTER MODEL NUMBER. SOME SYSTEM INCREMENTAL WEIGHTS AND COSTS ARE TABULATED.
88	SYSTEMS WERE PNEUMATIC BOOTS ON VERT,HORIZ STAB AND L.E. OF THE WING. HEAVYWT SYSTEM IS SELF-CONTAINED.

REFERENCE NUMBER	COMMENTS REGARDING PENALTY DATA
89	PENALTY DATA ON WEIGHT AND ELECTRICAL POWER IS GIVEN. ELECTROTHERMAL SYSTEM (88LBS) IS LIGHTEST. IMPROVED LIGHTWT BOOT SYSTEM IS 123 LBS BUT STILL REQUIRES ELECTROTHERMAL ON THE W/S AND PROPS. STALL PENALTIES INCLUDED. BOOT SYS WAS BEST.
95	WEIGHTS OF HEATER ELEMENTS, CABLES, CONNECTIONS, ALTERNATORS AND CONTROL EQUIPMENT GIVEN FOR SINGLE ENGINE A/C(15000LB) AND FO FOUR ENGINE AIRCRAFT (100000 LBS). POWER REQ. LISTED.
98	WEIGHT PENALTY FOR ELECT HEATING OF HELICOPTER ROTOR BLADES ON BRITISH HELICOPTERS IS 100 KG OR MORE. COST OF ELECT YSYST IS PROHIBITIVE BECAUSE HEL WERE NOT SO EQUIPPED INITIALLY.
102	WEIGHT PENALTIES GIVEN FOR HELICOPTER SYSTEMS. POWER PENALTIES GIVEN FOR NEW A/I SYSTEMS. ELECTROIMPULSE. WEIGHT PENALTIES FOR NEW ELECTROTHERMAL SYSTEMS.
105	PENALTIES(WT & POWER) ARE GIVEN FOR THREE TYPICAL A/C IN G/A CATEGORY. VARIOUS ICE PROT SYS FOR EACH CATEGORY. SOA BASICALLY THE SAME TODAY. SOME SMALL JETS USE HOT AIR WING A/I.
109	THE DRAG INCREASES CONSIDERABLY FOR CONFIGURATIONS OF ICE EXHIBITING AN UPPER HORN. THE DRAG IS MORE NOTICEABLE FOR SMALLER FLAP ANGLES. FIGURES OF CL MAX VS ICE CONFIGURATION DATA IN THE REPORT.
110	FUEL SYSTEM BLOCKAGE BY ICE CRKSTALS CAN BE REDUCED BY FREEZING TEMPERATURE DEPRESSANTS. THE PURITY OF THE INHIBITOR MUST BE ASCERTAINED.
115	SYSTEM EXHIBITS LOW POWER, LOW WEIGHT, LOW COST WITH HIGH RELIABILITY AND HIGH MAINTAINABILITY.
116	BOTH DRAG AND STALL EFFECTS (PENALTIES) WERE DETERMINED FOR THE TAIL (HORIZ STAB) DESIGNS.
117	LOSS IN CL MAX FOR WING VARIED FROM 10 TO 30 PERCENT. WITH FLAP THE WING LOSES BETWEEN 20 AND 32 PERCENT IN CL MAX.

REFERENCE NUMBER	COMMENTS REGARDING PENALTY DATA
118	MOLDS OF ICE FORMED ON THE RUNWAYS WERE USED TO DETERMINE RUNWAY FRICTION CHARACTERISTICS FOR COMPARISONS OF VARIOUS RUNWAY CONDITIONS IN SWEDEN.
119	DRAG COEFFICIENTS AND LIFT COEF ARE MEASURED FOR BOTH HORN AND ROUNDED ICE SHAPES WITH AND WITHOUT FLAPS EXTENDED.
120	LIFT COEF AND DRAG COEF WERE MEASURED FOR CLEAN WING AND WING
121	DRAG POLARS SHOWN FOR FLAPPED WING WITH AND WITHOUT ICE ACCRETION (LARGE TRANSPORT A/C)
125	EFFECTS OF ICE ACCRETION ON LIFT AND DRAG ARE DISCUSSED RELATIVE TO THE NEED FOR FURTHER RESEARCH REQUIREMENTS.
128	LIFT,DRAG,FLUTTER, CG SHIFT.
129	PROVIDES A GOOD LISTING OF PENALTIES. MINIMAL DATA FOR ICE SHEDDING TIME PREDICTIONS.
130	SOME QUALITATIVE DATA SHOWN ON LIFT,WITH OR WITHOUT ICE.
132	WITH SINGLE ENGINE A/C ON VFR DANGER IS INADVERTENT ENTRY INTO ICING CONDITIONS. FOR MULTI-ENGINED A/C ACCIDENTS OCCURRED WHILE ON IFR CONDITIONS.
134	EIGHT BLADE PROT SYSTEMS ARE LISTED. ESTIMATED PENALTIES ARE SHOWN. VIBRATORY AND MICROWAVE SYSTEMS ARE COMPARED WITH ELECTROTHERMAL SYSTEMS. DATA ON ICEPHOBIC SYSTEM IS GIVEN.

ICING RESEARCH DATA FILE SEARCH FOR
REFERENCES DISCUSSING ANALYTICAL METHODS

OUTPUT: a) Ref No., Applicable Component, Ref Comments
b) Ref No., Comments Regarding Icing Phenomena

REFERENCES WHICH DISCUSS METHODS OF ANALYSIS

REF	COMPONENT	REFERENCE COMMENTS
1	GENERAL-MANY COMPONENTS ON A/C	MAJOR PROBLEM IS GEN'L ACTIVITY OF LT TRANSPORT A/C IN ICING CONDITIONS. DATA USES FAR 25 CONT MAX CONDITIONS AS A DATA BASE. REF SUGGESTS TANKER & NAT ICE TESTS. *CONSIDERED COSTLY AND UNCONTROLLED*
3	GENERAL-MANY COMPONENTS ON A/C	DATA COVERAGE- CONVENTIONAL EDUCATIONAL VALUE. PROBLEM CITED- LOSS OF UTILIZATION. NO PROBLEM SOLVING RESEARCH CITED. *SUGGEST RESEARCH NEEDED TO REDUCE COST.COMPLEXITY OF ANTI-ICE METHODS.
5	GENERAL-MANY COMPONENTS ON A/C	PROPOSED CERTIFICATION METHOD. RESEARCH TO DETERMINE ICEING SEVERITY. RESEARCH INVOLVED DRY AIR.TANKER.NATURAL. AND SIMULATED ICE CONDITIONS. TESTS ENCOUNTERED 1.5 TIMES FAR25 CONDITIONS.
7	AIRFOILS,COMBINATIONS	STUDY FOR HI BYPASS RATIO ENGINE MAY HAVE VALUE TO HI BYPASS ENGINE LIGHT TRANSPORT A/C.
17	NONE LISTED	EXCELLENT REPORT - NEW CONCEPTS FOR DEFINING ICING INTENSITIES FOR GA/LT AIRCRAFT. SUGGESTS NEW FORECASTING TO GO ALONG WITH ICING DEF. DEF. BASED ON ICE ACCUMULATION ON 3IN SPHERE.
20	AIRCRAFT ENGINES,GENERAL	REPORT STATES GRD TEST FAC PROVIDE BEST CAPABILITY FOR CONDUCTING TURBINE ENG ICING TESTS. MATH MODEL OF FLOW IN ICING TEST CELL.EVAL IMPORTANCE OF SIMULATING ICING PARAMETERS.
22	NONE LISTED	GENERAL OVERVIEW OF ICING PROBLEM AND RES ON ICING PARAMETERS AT NASA LEWIS. INSTRUMENTATION, TEST FACILITIES, ICE DETECT ICING RATE METER. NEW INST NEEDED. UDO TECH STILL OK.
23	ICING INSTRUMENTS	ARTICLE FROM AGARD SYMPOSIUM ON INST TO MEASURE ICING PARAMETERS. EXCELLENT REPORT OF STATISTICAL DATA ON PROBABILITIES, ETC.
32	JET ENG.MAIN INLET	DESCRIPTION OF ANAL METHODS DEVELOPED BY BOEING FOR ENGINE NAC INLET ICING ANAL. EXTENSIVE USE OF DIGITAL COMP PROGRAMS TO CALC AIR VEL.H2O IMPINGE,THERMAL REQ..ETC.VERY ACCURATELY
34	AIRFOILS,COMBINATIONS	CERTIFICATION OF A300. TAIL NOT EQUIPPED WITH ANTI/DEICING SYSTEM. CERTBY ANAL OF ICE SHAPES. ICING WT TESTS AT NASA LRC FLT TESTS WITH ICE SHAPES. ANAL,TESTS,RESULTS ARE DESCRIBED.

REFERENCES WHICH DISCUSS METHODS OF ANALYSIS

REF	COMPONENT	REFERENCE COMMENTS
47	AIRFOILS,COMBINATIONS	REPORT IS DETAILED ANAL OF MATH MODEL FOR FROST FORMATION ON AN AIRFOIL. FIRST PHASE OF STUDY. FROST COLLECTION OF FLAT PLATE AND AIRFOIL. COMPARISONS OF MODEL V. AVAIL EXP DATA.
55	NONE LISTED	AN ELECTRO-IMPULSE DEICING METHOD IS DESCRIBED AND MATH. EQUATIONS ARE GIVEN. BASIC CONCERN IS THE MECHANISM OF CRACK FORMATION. MORTAR IS SUBSTITUTED FOR ICE IN TESTS. MORE RES. IS REQUIRED.
75	GENERAL-MANY COMPONENTS ON A/C	COMPLETE HANDBOOK ON ICING TECHNOLOGY UP TO 1967. RUSSIAN/ENG TRANSLATION. INTERESTING DATA ON PENALTIES. GEN DATA IS STANDARD. LITTLE VALUE TO THIS RESEARCH PROGRAM.
87	JET ENG.ROTOR BLADES	INVESTIGATION OF MICROWAVE ICE PROTECTION CONCEPT FOR HELI-COPTER ROTOR BLADES. ANAL TECHNIQUES HAVE BEEN VERIFIED. LAUNCH EFFICIENCIES HI ENOUGH TO DEMONSTRATE CONCEPT WERE REALIZED.
97	NONE LISTED	ICE ADHESION TESTS. ICE/STAINLESS ST PURE ADHESIVE BREAK DOWN TO -13C. TRANSITION BELOW -13C(SHEAR). EMPIRICAL EQUATIONS DEVELOPED FOR ADHESIVE STRENGTH.
100	ICING INSTRUMENTS	MATH METHOD FOR CALCULATING THE RATE OF ICING AND CLOUD WATER CONTENT FROM ICE ACCRETION ON A SINGLE ROTATING CYLINDER. THE EFFECT OF BLOWOFF IS DISCUSSED. LUDLAM LIMIT IS DISCUSSED.
101	CLASSICAL-CYLINDER	A STUDY OF THE PARAMETERS WHICH AFFECT THE DENSITY AND STRUC-TURE OF ICE ACCRETIONS. EQUATIONS DEVELOPED FOR DENSITY OF ICE COLLECTED ON CYLINDERS.
105	GENERAL-MANY COMPONENTS ON A/C	ADS-4 SUMMARIZES SOA OF ICING TECHNOLOGY UP THRU 1964. HAND-BOOK ON ALL ASPECTS OF CALCULATING ICE ACCRETION AND ICE PROTECTION REQUIREMENTS
108	AIRCRAFT ENGINES,GENERAL	TECHNICAL REF DOCUMENT FOR A/C POWERPLANT ICE PROTECTION SYSTEM DESIGN. SEQUEL TO ADS-4 FOR AIRFRAME A/F DESIGNERS. INCLUDES UPDATED MATERIAL, WHERE AVAILABLE.
113	ICING INSTRUMENTS	AIR FORCE GEOPHYSICS LAB(AFGL) WILL MEASURE RIMING RATES ALOFT USING ROSEMOUNT ICE DETECTOR MOUNTED ON WING TIP OF MC130E RES A/C. MOUNTING SITES FOR ID ARE STUDIED VIA COMPU-TER STUDIES FOR SHADOWING AND FLUX DISTORTION, ETC.

REFERENCES WHICH DISCUSS METHODS OF ANALYSIS

REF	COMPONENT	REFERENCE COMMENTS
115	JET ENG.ROTOR BLADES	FEASIBILITY STUDY FOR MICROWAVE DE-ICING SYSTEM FOR HELICOP-TER ROTOR BLADES. ANAL IS BASED ON COUPLING MICROWAVE ENERGY TO THE ICE LAYERS BY MEANS OF DIELECTRIC SURFACE WAVEGUIDES.
123		ANAL STUDY OF ICING SIMULATION FOR TURBINE ENGINES IN ALT. TEST CELLS. DEVELOPMENTS OF MATHEMATICAL MODEL STUDY LENDS SUPPORT TO CONCEPT THAT GROUND TEST FACILITIES PROVIDE THE BEST CAPABILITY FOR CONDUCTING TURBINE ENG. ICE TESTS.
124	AIRFOILS,COMBINATIONS	CONVERSION OF A LARGE QUANTITY OF PUBLISHED THEORETICAL DATA OF WATER CATCH EFFICIENCY AND LIMITS OF IMPINGEMENT FOR AIRFOILS AND OTHER BODY SHAPES. INTO A RD MODIFIED INERTIA PARAMETER FORMAT.
129	AIRFOILS,COMBINATIONS	PROG. SPONSORED BY FAA CONDUCTED IN NASA LEWIS TUNNEL. CORRELA-TIONS OF DATA ON UNHEATED AIRFOILS. ICE SHAPES/SHEDDING.
130	AIRFOILS,COMBINATIONS	SUMMARY OF THE ICING TEST FACILITIES IN EUROPE. PROBLEMS WITH ICING TESTS IN WIND TUNNELS. SCALE MODELING VS FULL-SCALE. BASIC EQUATIONS FOR SIMILITUDE. EXCELLENT PHOTOS.

REFERENCES WHICH DISCUSS METHODS OF ANALYSIS

REF NO	COMMENTS RE ICE PHENOMENA
1	NEW RESEARCH IS REQ'D. ICE FORMATION DATA IS EMPIRICAL AND NEEDS ADDITIONAL RES. UNDER CONTROLLED CON. * SUGGEST TESTS IN ICE TUNNELS BY COMPONENT OR FULL SCALE SECTION.*
3	CONVENTIONAL EQUATIONS.
5	SPHERICAL PROBE ICE ACCUMULATION IN NATURAL ICE COMPARED WITH FAR 25.
20	REPORT DISCUSSES RELATIONSHIPS BETWEEN FREESTREAM AND ENGINE COMPRESSOR FACE ICING CONDITIONS AND OTHER FACTORS AFFECTING ICING SIMULATION.
22	REVIEW OF OLD NACA DATA FROM 3200 ICING ENCOUNTERS OVER THE US, ATLANTIC,PACIFIC, AND ARCTIC OCEANS.
44	ICE ACCRETION WAS DETERMINED BY TESTS AT NASA LEWIS FOR THE SWEPT TAIL AIRFOIL SHAPES FOR FAR 25 CONDITIONS. GLAZE AND RIME ICE SHAPES DETERMINED.
47	BOTH CONVENTIONAL AND NEWLY DEVELOPED HEAT AND MASS TRANSFER COEFFICIENTS ARE USED.
75	CLOUD PHYSICS AND METEROLOGICAL FACTORS WHICH LEAD TO A/C ICING PROBLEMS ARE DISCUSSED IN DETAIL. PROBABILITIES AND ICING INTENSITIES ARE ALSO DISCUSSED.
97	ADHESIVE PROPERTIES BETWEEN ICE/STAINLESS ST AND ICE /POLY-STYRENE, AND IC/POLYMETHYLMETHACRYLATE[illegible] WERE STUDIED AND THE DATA PRESENTED.
105	SUMMARY OF MEASURED CLOUD CONDITIONS. FAR AND BRITISH CERTIFICATION CONDITIONS. ICING EXCEEDANCE PROBABILITY DATA. FREQ DISTRIBUTIONS IN ICING-TYPES OF ICE.PHYSICS OF ICE-ACCRETION.

REFERENCES WHICH DISCUSS METHODS OF ANALYSIS

REF NO	COMMENTS RE ICE PHENOMENA
108	ATMOS ENV DESIGN POINTS; ENGINE WATER INGESTION RATES; WATER DROPLET IMPINGEMENT ON ENGINE SURFACES; A/I NEED/NON-NEED; ICE ACCUMULATION AND LIMITS; DESIGN AND TEST VERIFICATION.
113	3-DIM FLOW ABOUT WING AND WING TIP WERE COMPUTED VIA COMPUTER AND TRAJECTORIES OF WATER DROPS RANGING IN DIA. FROM 10 TO 7000 MICRONS WERE COMPUTED FOR FOUR TO SITE LOCATIONS.
115	CONSIDERATIONS FOR ROTOR ICE INCLUDE UNFROZEN WATER CONTENT, AIR CONTENT,WATER IMPURITY RATE OF GROWTH,CRYSTAL STRUCTURE AT TEMP FROM 0 DEGC TO -40 DEGC.
123	A PARAMETRIC STUDY WAS PERFORMED TO DETERMINE THE EFFECTS OF THE TEST CELL INLET AND WATER SPRAY CONDITIONS ON THE THERMODYNAMIC AND KINETIC STATE OF FLOW IN THE TEST SECTION.
125	APPLICATION OF THE KO PARAMETER TO SCALE MODELS PROVIDES CRITERIA FOR MODEL TESTING IN AN ICING WIND TUNNEL.
129	EXCELLENT EMPIRICAL METHOD FOR PREDICTING ICE SHAPES AND SIZE FOR SWEPT AIRFOILS.
130	EXCELLENT EQUATIONS FOR SIMILITUDE LAWS (AERO, THERMO, ICE DEPOSITS,WATER DROPS)9 TESTING TECHNOLOGY AND VALIDITY OF SCALE TESTING.

ICING RESEARCH DATA FILE SEARCH FOR
REFERENCES WHICH DEAL WITH NEW ICE PROTECTION METHODS

OUTPUT: Ref No., Component, Penalty, Ref Comment

REPORTS CONCERNING MICROWAVE - TYPE I

REF	COMPONENT	PENALTY	REFERENCE COMMENTS
87	JET ENG.ROTOR BLADES	ENG ELEC POWER	INVESTIGATION OF MICROWAVE ICE PROTECTION CONCEPT FOR HELI-COPTER ROTOR BLADES. ANAL TECHNIQUES HAVE BEEN VERIFIED. LAUNCH EFFICIENCIES HI ENOUGH TO DEMONSTRATE CONCEPT WERE REALIZED.
115	JET ENG.ROTOR BLADES	ENG ELEC POWER	FEASIBILITY STUDY FOR MICROWAVE DE-ICING SYSTEM FOR HELICOP-TER ROTOR BLADES. ANAL IS BASED ON COUPLING MICROWAVE ENERGY TO THE ICE LAYERS BY MEANS OF DIELECTRIC SURFACE WAVEGUIDES.

REPORTS CONCERNING ICE PHOBIC- LOW VISC.ADH..ETC

REF	COMPONENT	PENALTY	REFERENCE COMMENTS
45	JET ENG.ROTOR BLADES	NO DATA	TESTS OF DOW CORNING E2660-40-1 MATERIAL AS AN ICE PHOBIC ON HELICOPTER ROTOR BLADES. ICE-PHOBIC MATERIAL INCREASE SHEDDING AT -10 DEGC BUT DOES NOT PROVIDE ADEQUATE PROTECTION.
60	GENERAL-MANY COMPONENTS ON A/C	NO DATA	LITERATURE STUDY OF ICE ADHESION. A SURVEY OF 300 MFGS PRODUCED 100 REPLIES. 15 TO 20 PRODUCTS APPEAR OF SPECIAL INTEREST. LOW CONTACT ANGLE,POOR WETTING,AIR,ETC,WEAKENS ADHESION BOND.
63	GENERAL-MANY COMPONENTS ON A/C	NO DATA	MECHANISM OF ICE ADHESION.LABORATORY TESTS OF STRENGTH OF ICE ADHESION TO VARIOUS MATERIALS.METHODS OF REDUCING ADHESION OF ICE.
107	JET ENG.ROTOR BLADES	NO DATA	SHEAR TESTS WERE MADE USING VARIOUS ICEPHOBIC MATERIALS ON FLAT SURFACES.THE MATERIALS REPRESENTED THE BEST IN INDUSTRY IN 1975.NONE FUNCTIONED AS ICEPHOBIC MATERIAL SUCCESSFULLY AT -4 DEGF. NO MATERIAL WAS ADEQUATE FOR THE ARMY.

REPORTS CONCERNING ICE PHOBIC- FREEZING DEPRESS.

REF	COMPONENT	PENALTY	REFERENCE COMMENTS
4	PISTON ENG.CARBURETOR	A/C TOTAL WE	TEFLON + FUEL ADDITIVE.ASTM ICE TOWER. THERE WERE 44 ACCIDENTS IN 66-67.29% ENG PROBLEMS.MOSTLY FUEL-CAUSED. HARD TO CONTROL, NOT READILY RECOGNIZED.
110	NONE LISTED	A/C SAFETY	STUDY OF ETHYLENE GLYCOL MONOMETHYL ETHER(EGME) AND SOME GLYCEROL ADDITIVES TO AVIATION FUEL AND THE ANALYSIS OF WATER IN THESE ADDITIVES, ETC., BY GAS CHROMATOGRAPHY.

REPORTS CONCERNING ELECTRO IMPULSE - TYPE I

REF	COMPONENT	PENALTY	REFERENCE COMMENTS
29	NONE LISTED	ENG ELEC POWER	EXCELLENT REPT ON ELECT IMPULSE A/I SYSTEM. DETAILS ON SYSTEM POWER REQ,NO.OF INDUCTORS,OPTIMUM DESIGN REQ. TESTS WERE CONDUCTED IN W/T,NAT ICE,AND SIMULATED ICE. NEW RES. REQUIRED.
55	NONE LISTED	ENG ELEC POWER	AN ELECTRO-IMPULSE DEI..IG METHOD IS DESCRIBED AND MATH. EQUATIONS ARE GIVEN. BASIC CONCERN IS THE MECHANISM OF CRACK FORMATION. MORTAR IS SUBSTITUTED FOR ICE IN TESTS. MORE RES. IS REQUIRED.

REPORTS CONCERNING ACOUSTIC - TYPE I

REF	COMPONENT	PENALTY	REFERENCE COMMENTS
51	NONE LISTED	NO DATA	STUDY OF THE PROCESS OF FRACTURING A LAYER OF ICE ON A METAL SURFACE BY ACOUSTIC VIBRATIONS. ELASTICITY OF ICE DEPENDS ON THICKNESS. RAPID DEFORMATIONS ICE BEHAVES AS BRITTLE BODY.

ICING RESEARCH DATA FILE SEARCH FOR
INSTRUMENT DATA FOR REF WHOSE DATA BASE IS A TEST FACILITY

OUTPUT: Ref No., Instrument, Instrument Comment

REFERENCES WHICH ADDRESS TEST FACILITIES

REF NO	INSTRUMENT	INSTRUMENT COMMENT
14	AIR TEMPERATURE PROBE	RADIOMETRIC TEMPERATURE MEASURING DEVICE WORKING AT 60 GHZ IN THE OXYGEN ABSORPTION BANDIN ICING CONDITIONS. PROBLEMS BECAUSE OF HIGH FREQ KLYSTRON FAILURE DURING AIRPLANE TESTS. USED IN BALLOONS AND AIRCRAFT.
18	ICE DETECTOR, PRESSURE TYPE	PITOT/STATIC ICE DETECTION DEVICE INEXPENSIVE DEVICE DESIGNED FOR GA.DESIGN BASED ON HEAVIER, MORE RUGGED TECHNIQUES THAN PRIOR DIFFERENTIAL PRESSURE DESIGNS.
23	MORE THAN ONE TYPE	NEW ICING PARAMETER INST FOR MEASURING LWC. USES LN2-COOLED ROD. DATA SHOWS SIGNIFICANT INCREASE IN LWC AS MEASURED BY ROT CYL NACA1CSS.
33	MORE THAN ONE TYPE	INST USED FOR TESTS IN NATURAL ICING FLIGHT TESTS. USED FOR CERTIFICATION TESTS. SHOWS INST DESIGN WAS SIMPLE, EFFECTIVE. AND ACCURATE INST STD. INST HELPED TO SHORTEN ICING TRIALS TIME.
34	ICING ONSET DET.-VIBRATING ROD	ICE DETECTOR CAN BE USED FOR AUTOMATIC CONTROL WITH OR WITHOUT DISPLAYS.ETC. ONE OF FEW ICE DETECTORS AVAILABLE. MORE RESEARCH IN CHEAP, ACCURATE, RELIABLE DETECTORS REQUIRED.
35	MORE THAN ONE TYPE	INFERENTIAL METER(DETECTORS) HAVE ADVANTAGES OVER ICE ACCRETION DETECTORS BECAUSE IT DEPENDS ONLY UPON H2O EVAPORATION AND TEMP MEASUREMENT. ICING INDICATION IS INSTANTANEOUS.
36	MORE THAN ONE TYPE	THE BASIC PRINCIPLES OF OPERATION AND UTILITY ARE GIVEN FOR ALL INSTRUMENTS. HELICOPTER USE IS PRIME MOTIVE OF SURVEY BUT INST AND DATA ARE OF HIGH VALUE TO G/A AND LIGHT TRANSP RES PROG REQUIREMENTS WITH RESPECT TO SOA AND AVAILABILITY.
37	ICE PARTICLE COUNTER, UW-IPC	FUTURE RESEARCH WOULD DETERMINE FEASIBILITY OF DETECTING BOTH WATER DROPLETS AND ICE CRYSTALS WITH SAME INST-THUS PROVIDING RATIO WITH ONLY ONE INST. INST COULD BE USED FOR RESEARCH AND OPERATION ON A/C, AS WELL AS IN ICING TUNNELS.
38	ICE DETECTOR, RESISTANCE TYPE	CALSPAN EVALUATION OF SCAN AIRPORT RUNWAY ICE,WATER,FROST,DETECTION SYSTEM. SYSTEM IS ONLY 20-25% ACCURATE. THERE IS ONLY MINOR INTEREST HERE FOR NASA RESEARCH PROGRAM.
40	MORE THAN ONE TYPE	SEVERAL TYPES OF ICE DETECTORS HAVE BEEN DESIGNED FOR CARB ICE DETECTION, BUT NONE ARE CONSIDERED SATISFACTORY DUE TO PROBLEM IN LOCATING THE SENSING ELEMENTS.

ORIGINAL PAGE IS
OF POOR QUALITY

REFERENCES WHICH ADDRESS TEST FACILITIES

REF NO	INSTRUMENT	INSTRUMENT COMMENT
43	MORE THAN ONE TYPE	CLOSE CIRCUIT TV IS ALSO USED IN THIS FACILITY.
50	MORE THAN ONE TYPE	APPARENTLY THE INST USED FOR CALIB WERE NOT ADEQUATE TO MEET THE REQUIREMENTS.
58	MORE THAN ONE TYPE	A HOLLEY ICING CONDITION DETECTOR IS USED WITH A ROSEMOUNT ICE DETECTOR.
61	LASER BEAM(ASP),MRI-KNOLLENBRG	KNOLLENBERG CLOUD PHYSICS INST USED FOR CALIB SPRAY CLOUD. HOWEVER, DROPLET DISTRIBUTION WAS NOT MEASURED.
62	MORE THAN ONE TYPE	RADIOSONDE INST. AND INST FOR ICING PARAMETERS WHEN MEASURED DURING 49 FLTS. LWC,TEMPS,ICING TYPE,ETC.FOR COMPARISON WITH RADIOSONDE DATA. GOOD CORRELATION WITH FORECAST DATA.
70	MORE THAN ONE TYPE	MRI FORMVAR REPLICATOR,ONE SCATTERING PROBE AND TWO OPTICAL ARRAY PROBES WERE USED.
75	MORE THAN ONE TYPE	SEVERAL BASIC ICE DETECTION SYSTEMS ARE DISCUSSED IN GENERAL.
76	LASER BEAM(ASP),MRI-KNOLLENBRG	ICING SPHERE USED WAS CALIBRATED AGAINST KNOLLENBERG SYSTEM. TWO SPHERES 4 AND 6 INCH DIAM. WERE USED.
87	ICE DETECTOR, MICROWAVE	IT IS POSSIBLE THAT THE UTILIZATION MAY INCLUDE G/A-TYPE AIRCRAFT AT SOME FUTURE DATE.
96	HOLOGRAM SYSTEM	LARGEST SOURCE OF ERROR(COMPONENT OF ERROR) IS NOISE IN BOTH RECORDING AND RECONSTRUCTION PHASES. OPTICAL COMPONENTS MUST BE EXTREMELY CLEAN OF DUST PARTICLES.

REFERENCES WHICH ADDRESS TEST FACILITIES

REF NO	INSTRUMENT	INSTRUMENT COMMENT
100	ROTATING SINGLE CYLINDER	SATISFACTORY PERFORMANCE FOR MANY YEARS HAS BEEN THE CANADIAN EXPERIENCE WITH THE SINGLE ROTATING CYLINDER INSTRUMENT.
102	MORE THAN ONE TYPE	SHORT SECTION ON ICING INST. ICE DETECTORS IN GENERAL HAVE NOT GIVEN SATISFACTORY PERFORMANCE AND RELIABILITY ALTHOUGH THEY HAVE REACHED OPERATIONAL STATUS. RESEARCH REQUIRED FOR CHEAP RELIABLE ICE DETECTOR. PROBLEMS ARE NUMEROUS.
103	HOLOGRAM SYSTEM	HOLOGRAPHIC SYSTEM FOR MEASURING DROP SIZE AND NUMBER USING A PULSED RUBY LASER AT AEDC UPGRADES ACCURACY OF SOA OF CONTROL OF WIND TUNNEL ICING PARAMETERS. DROP SIZE, CONCENTRATION AND DISTRIBUTION.
105	MORE THAN ONE TYPE	ICE DETECTOR SOA DISCUSSED IN REPORT. IMPROVEMENTS IN SOA IN AREA OF LASER AND VIBRATING ROD TECHNIQUES SINCE 1964.
106	FWD SCATTRG SPECTROMETER PROBE	THREE 1-D AND TWO 2-D PARTICLE MEASURING SYSTEM(PMS) PROBES 1-D PROBES COUNT AND SIZE PARTICLES. 2-D PROBES MAKE TWO-DIMENSIONAL SHADOWGRAPH RECORDINGS OF PARTICLE SHAPES.
115	ICE DETECTOR, MICROWAVE	MICROWAVE DE-ICING SYSTEMS HAVE INHERENT CAPABILITY FOR ICE DETECTION.
126	DYNAMIC ICE DET./ICE SEVERITY	THE STALABRASS DYNAMIC ICE DETECTOR AND SEVERITY METER. THREE LEVEL AND ANALOG SEVERITY METER TYPE DISCUSSED.
137	MORE THAN ONE TYPE	TECHNIQUES FOR MEASURING LWC AND DROPLET SIZES AND DISTRIBUTIONS ARE DESCRIBED.

ICING RESEARCH DATA FILE SEARCH FOR
REFERENCES DEALING WITH OR DISCUSSING ICING PHENOMENA

OUTPUT: Ref No., Comments Regarding Icing Phenomena

REFERENCE NUMBER	COMMENTS REGARDING ICING PHENOMENA
1	NEW RESEARCH IS REQ'D. ICE FORMATION DATA IS EMPIRICAL AND NEEDS ADDITIONAL RES. UNDER CONTROLLED CON. • SUGGEST TESTS IN ICE TUNNELS BY COMPONENT OR FULL SCALE SECTION.•
2	RESEARCH NEEDED TO EVOLVE INEXPENSIVE METHODS TO DETECT CARB ICING OR ICING CONDITIONS, WITH METHODS FOR ALERTING PILOT.BUT WITH AUTO. SYSTEMS. •ICE FORMS AT HI HUMIDITY AT TEMPS UP TO 80 DEGF.•
3	CONVENTIONAL EQUATIONS.
4	PRIMARY EFFECT IS FUEL COOLING.
5	SPHERICAL PROBE ICE ACCUMULATION IN NATURAL ICE COMPARED WITH FAR 25.
6	NO RESEARCH SUGGESTED. • STEADY STATE ICE FORMATIONS ARE QUESTIONABLE - SUGGEST RESEARCH WITH VARIABLE ICE CONDITIONS.
10	REASONS FOR PENETRATION OF THUNDERSTORM.EFFECT OF PRECIP AND ICE AND HAIL DISCUSSED. UNIQUE INSTR. AND EQPT DISCUSSED. METHOD FOR QUAL ASSESSMENT OF PRECIPITATION INTENSITY GIVEN.
11	ICE ACCRETION ON BLADES AS A FUNCTION OF TIME SHOWN.
12	PROTECTION IS ACCOMPLISHED BY A COMBINATION OF HEAT AND MASS TRANSFER. ANALYTICAL CALCULATIONS ARE DIFFICULT AND COMPLEX.
15	RELATIVE COMPARISONS OF NAT ICE VS SIMULATED ICE COND ARE DISCUSSED TO SHOW ADVANT. OF W/T ICING TESTS. WEATHER FORCASTING IS LIMITED . ICE INST. METHODS ARE DISCUSSED.

REFERENCE NUMBER	COMMENTS REGARDING ICING PHENOMENA
20	REPORT DISCUSSES RELATIONSHIPS BETWEEN FREESTREAM AND ENGINE COMPRESSOR FACE ICING CONDITIONS AND OTHER FACTORS AFFECTING ICING SIMULATION.
22	REVIEW OF OLD NACA DATA FROM 3200 ICING ENCOUNTERS OVER THE US, ATLANTIC,PACIFIC, AND ARCTIC OCEANS.
26	NEW RESEARCH IS REQUIRED IN INST FOR MEASURING LWC, DROP SIZE AND ICE CRYSTAL CONTENT TO BE USED FOR CERTIFICATION AND FOR RESEARCH.
40	ICING DUE TO IMPACT, THROTTLE ICING DUE TO CONDENSATION FROM EXPANSION COOLING,AND FUEL EVAPORATION ICING DUE TO ENTRAINED MOISTURE.
41	AIRCRAFT FLOWN IN TRACE, LIGHT, MODERATE, ICING CONDITIONS ICE-PHOBIC MATERIALS REDUCED VISIBILITY,INCREASED DISTORTION ON W/S. PILOT COMPLAINED.
44	ICE ACCRETION WAS DETERMINED BY TESTS AT NASA LEWIS FOR THE SWEPT TAIL AIRFOIL SHAPES FOR FAR 25 CONDITIONS. GLAZE AND RIME ICE SHAPES DETERMINED.
45	G 697 COMPOUND AT LWC OF 0.5GMS/CUM INCREASED SHEDDING BUT DOES NOT PROVIDE ADEQUATE PROTECTION. POOR EROSION QUALITIES. E2460 COMPOUND DID NOT AID SHEDDING AT -15 DEGC.
47	BOTH CONVENTIONAL AND NEWLY DEVELOPED HEAT AND MASS TRANSFER COEFFICIENTS ARE USED.
49	AIREPS EXTREMELY IMPORTANT IN FORMING SYNOPTIC CHARTS. ESPECIALLY SIGN. IN AREAS 30 N TO 30 S LATITUDES.
53	CONDITIONS USED WERE ACCORDING TO CERTIFICATION DEFINITIONS. ALSO HOAR FROST AND ICE.

REFERENCE NUMBER	COMMENTS REGARDING ICING PHENOMENA
58	GROUND LEVEL ICING CONDITIONS ARE DISCUSSED.
60	ADHESION RESULTS FROM SECONDARY(VAN DER WAALS) FORCES, YET EXCEEDS NORMAL COHESIVE STRENGTHS.
62	RADIOSONDE DATA ONLY GIVES PROBABILITY OF ICING OCCURENCE. NOT SEVERETY OR INTENSITY.
63	OTHER ASPECTS OF SNOW AND ICE GIVEN ADSORPTION OF RADIATION AND ELECTRICAL PROPERTIES,DIELECTRIC,CONDUCTIVITY, AND PIEZO ELECTRIC EFFECT.
66	ICING OCCURS IN THE AIR LAYER IN WHICH THE RELATIVE HUMIDITY IS GREATER THAN THE SATURATION HUMIDITY OVER ICE AT A GIVEN TEMPERATURE. POOR HUMIDITY INST. CAUSED FAILURE OF THE METH DEVELOPED.
67	BETTER SIMULATION (ARTIFICIAL ICE CLOUDS) IS REQUIRED WITH TANKER A/C TO REDUCE DROP SIZE & INTENSITY LEVELS. BETTER VISUAL REFERENCES OF ICING CLOUDS(SIMULATED).
69	RUNBACK ICE IN S-SHAPED INLET DUCT CAUSED STALL ANF FLAMEOUT CONDITIONS.
71	SAILPLANE HAS ADVANTAGE THAT NO NUCLEATING AGENTS ARE INTRO-DUCED FROM THE ENGINE EXHAUST.
75	CLOUD PHYSICS AND METEOROLOGICAL FACTORS WHICH LEAD TO A/C ICING PROBLEMS ARE DISCUSSED IN DETAIL. PROBABILITIES AND ICING INTENSITIES ARE ALSO DISCUSSED.
80	WATER IN SOME AMOUNT IS ALWAYS PRESENT IN FUEL. EFFECTS OF WATER BELOW FREEZING TEMPERATURES ARE DISCUSSED.

REFERENCE NUMBER	COMMENTS REGARDING ICING PHENOMENA
85	EXCELLENT BIBLIOGRAPHY OF PAPERS WRITTEN ON ICING TESTS PERFORMED IN THE CANADIAN FACILITIES OF APPENDIX A.
88	LT WEIGHT SYSTEM LEFT RESIDUAL ICE. BUILDUP WAS 1/2 INCH HEAVYWT SYSTEM REMOVED ALL ICE AFTER 3/4 INCH BUILDUP.
89	TESTS WERE MADE IN LIGHT THRU MODERATE ICE FORMATIONS OF RIME MIXED, AND CLEAR ICE PRODUCED BY KC135TANKER A/C.
90	ICING PARAMETER DATA WAS OBTAINED BY FLIGHTS OVER EUROPE AND WESTERN SIBERIA (682 INSTANCES).
92	MANUAL DISCUSSES DISTRIBUTION OF ICING IN THE ATMOSPHERE, NON SNOPTIC FORECAST AIDS,SUGGESTED PROCEDURES FOR FORECASTING AND THE OPERATIONAL ASPECTS OF A/C ICING.
93	INTERNAL,EXTERNAL HEAT TRANSFER AND ICE COLLECTION, CTCH EFFICIENCY,ETC., ARE INCLUDED IN THE MODEL MATHEMATICAL SCALING RELATIONSHIPS.
94	THE MODEL ASSUMES DROP SIZE,LWC, AND AIR STREAM VELOCITY CAN BE CONTROLLED.
97	ADHESIVE PROPERTIES BETWEEN ICE/STAINLESS ST AND ICE /POLYSTYRENE, AND IC/POLYMETHYLMETHACRYLATE(LUCITE) WERE STUDIED AND THE DATA PRESENTED.
98	IN GENERAL AND INCREASE IN THICKNESS OF SUBSTRATE LOWERS THE ADHESION OF ICE.
102	NEW ICING DESIGN CRITERIA(CERTIFICATION) IS GIVEN AND DISCUSSED FOR HELICOPTERS. SOME INFO APPLICABLE TO G/A BECAUSE OF THE ALTITUDE CONSIDERATION.

REFERENCE NUMBER	COMMENTS REGARDING ICING PHENOMENA
105	SUMMARY OF MEASURED CLOUD CONDITIONS. FAA AND BRITISH CERTIFICATION CONDITIONS. ICING EXCEEDANCE PROBABILITY DATA. FREQ DISTRIBUTIONS IN ICING-TYPES OF ICE,PHYSICS OF ICE-ACCRETION.
106	FOUR SAMPLE DISTANCES - 100&200&300&400 FT.
107	THE MATERIALS THAT SHOWED GREATEST ICEPHOBIC POTENTIAL BUT FAILED RAIN EROSION (1) CATIONIC SILICONE E-2460, (2)SILICONE GREASE G6350 (3) HMOD4, AND (4) REPCON.
108	ATMOS ENV DESIGN POINTS; ENGINE WATER INGESTION RATES; WATER DROPLET IMPINGEMENT ON ENGINE SURFACES; A/I NEED/NON-NEED; ICE ACCUMULATION AND LIMITS; DESIGN AND TEST VERIFICATION.
112	ANTI-ICING CYCLING BETWEEN WING AND TAIL IS HIGHLY DEPENDENT ON THE RESPONSE TIME OF THE SYSTEM.
113	3-DIM FLOW ABOUT WING AND WING TIP WERE COMPUTED VIA COMPUTER AND TRAJECTORIES OF WATER DROPS RANGING IN DIA. FROM 10 TO 7000 MICRONS WERE COMPUTED FOR FOUR TO SITE LOCATIONS.
115	CONSIDERATIONS FOR ROTOR ICE INCLUDE UNFROZEN WATER CONTENT, AIR CONTENT,WATER IMPURITY RATE OF GROWTH,CRYSTAL STRUCTURE AT TEMP FROM 0 DEGC TO -40 DEGC.
116	ICE ACCRETION SHAPES FOR 44 DEGREE SWEPT HORIZ WAS DETERMINED IN SOVIET IRT. SIMULATED ICE MADE FROM TUNNEL TEST ICE WAS USED ON TAIL MODELS IN SWEDISH FFA TEST TUNNEL.
117	THREE DIFFERENT GRAIN SIZE SAND PAPERS WERE USED TO SIMULATE THE HOAR FROST.
119	SIMULATED HORN AND ROUND ICE SHAPES WERE USED IN THE TESTS.

REFERENCE NUMBER	COMMENTS REGARDING ICING PHENOMENA
120	TAR AND CRUSHED SLAG WAS USED TO SIMULATE RESIDUAL ICE FOR FULL SCALE ICING TUNNEL TESTS OF AIRFOIL LE AT 60 MPH.
121	PAGES 253-321 HAVE AN EXCELLENT DISCUSSION OF TECHNIQUES USED TO DETERMINE ICE SHAPES AND ICE SHEDDING CHARACTERISTICS OF UNPROTECTED SURFACES. BOEING METHOD.
123	A PARAMETRIC STUDY WAS PERFORMED TO DETERMINE THE EFFECTS OF THE TEST CELL INLET AND WATER SPRAY CONDITIONS ON THE THERMODYNAMIC AND KINETIC STATE OF FLOW IN THE TEST SECTION.
124	APPLICATION OF THE KO PARAMETER TO SCALE MODELS PROVIDES CRITERIA FOR MODEL TESTING IN AN ICING WIND TUNNEL.
125	FORECASTING RESEARCH REQUIREMENTS FOR IMPROVEMENT ARE DISCUSSED AND AF APPROACHES TO THE PROBLEM ARE GIVEN.
128	EXCELLENT ICING PARAMETERS FOR HORIZ STAB WITH SPHERICAL CORRELATING RELATIONSHIPS. *RECOMMEND FOR OTHER AIRFOILS. G/A ON SWEPT AIRFOILS, IC SHEDDING TRJ. ANAL. INCLUDED.
129	EXCELLENT EMPIRICAL METHOD FOR PREDICTING ICE SHAPES AND SIZE FOR SWEPT AIRFOILS.
130	EXCELLENT EQUATIONS FOR SIMILITUDE LAWS (AERO, THERMO, ICE DEPOSITS, WATER DROPS) IN TESTING TECHNOLOGY AND VALIDITY OF SCALE TESTING.
134	A NEW RECOMMENDED ATMOSPHERIC ICING CRITEREON IS SHOWN AND SUGGESTED.
141	FINER SCALE ICING CLIMATOLOGY IS REQUIRED TO IMPROVE ICING PREDICTION BASED ON CLIMATOLOGICAL STATISTICS.

ICING RESEARCH FILE SEARCH FOR
REFERENCES ADDRESSING CERTIFICATION REQUIREMENTS

OUTPUT: a) Ref No., Icing Condition, Reference Comment
b) Ref No., Comments Re Ice Phenomena

REFERENCES WHICH RELATE TO CERTIFICATION REQUIREMENTS

REF NO	ICING CONDITION	REFERENCE COMMENT
1	GENL AVIATION PROFILE	MAJOR PROBLEM IS GEN'L ACTIVITY OF LT TRANSPORT A/C IN ICING CONDITIONS. DATA USES FAR 25 CONT MAX CONDITIONS AS A DATA BASE. REF SUGGESTS TANKER & NAT ICE TESTS. *CONSIDERED COSTLY AND UNCONTROLLED*
2	GENL AVIATION PROFILE	NTSP RECOMMENDS PILOT EDUCATIONAL PROG.&ADVISORY CIRCULAR. THERE WERE 360 ACCIDENTS IN LAST 5 YRS INVOLVING CARB. ICING. REFERENCE STRESSES PROCEDURAL PREVENTION METHODS INCLUDING JUDICIAL USE OF HEATING.
3	GENL AVIATION PROFILE	DATA COVERAGE- CONVENTIONAL EDUCATIONAL VALUE. PROBLEM CITED- LOSS OF UTILIZATION. NO PROBLEM SOLVING RESEARCH CITED. *SUGGEST RESEARCH NEEDED TO REDUCE COST,COMPLEXITY OF ANTI-ICE METHODS.
4	GENL AVIATION PROFILE	TEFLON + FUEL ADDITIVE,ASTM ICE TOWER. THERE WERE 44 ACCIDENTS IN 66-67,29% ENG PROBLEMS,MOSTLY FUEL-CAUSED. HARD TO CONTROL, NOT READILY RECOGNIZED.
5	GENL AVIATION PROFILE	PROPOSED CERTIFICATION METHOD. RESEARCH TO DETERMINE ICEING SEVERITY. RESEARCH INVOLVED DRY AIR,TANKER,NATURAL, AND SIMULATED ICE CONDITIONS. TESTS ENCOUNTERED 1.5 TIMES FAR25 CONDITIONS.
6	CERT.DEFN.ILWC.ALT.DSDJ	FAR METHOD HAS NO STD PROCEDURES. ENCOUNTER PROBLEMS TOO SMALL BY NATL ICE TESTS. PAPER DESCRIBES LESS EXPENSIVE METHOD. TUNNEL TESTS COMPARED WITH FLT TEST - GOOD CORRELATION.
7	TRANSPORT PROFILE	STUDY FOR HI BYPASS RATIO ENGINE MAY HAVE VALUE TO HI BYPASS ENGINE LIGHT TRANSPORT A/C.
9	TRANSPORT PROFILE	COVERS COMPLETE METHOD FOR CERTIFICATION FOR ALL ICE SENSITIVE COMPONENTS & SURFACES. DISCUSSES DRY AIR, SIMULATED ICE SHAPE(FLT),W/T,NATL ICE(FLT),GROUND SLUSH SPRAY. GOOD OVERALL OUTLINE.
11	CERT.DEFN.ILWC.ALT.DSDJ	EXCELLENT REPORT - NEW CONCEPTS FOR DEFINING ICING INTENSITIES FOR GA/LT AIRCRAFT. SUGGESTS NEW FORECASTING TO GO ALONG WITH ICING DEF. DEF. BASED ON ICE ACCUMULATION ON 1IN SPHERE.
24	GENL AVIATION PROFILE	HUMAN FACTORS PROBLEMS IN ICING NOT YET SOLVED. CONTINUING NEED FOR PILOT TRAINING IN EFFECT OF ICING. RECOGNITION OF ICING. NEED FOR ICE DETECTION RESEARCH.

REFERENCES WHICH RELATE TO CERTIFICATION REQUIREMENTS

REF NO	ICING CONDITION	REFERENCE COMMENT
31	GENL AVIATION PROFILE	DISCUSSES POSSIBILITY FO G/A OPERATION IN IFR AS REQUIREMENT IN FUTURE. PROBLEMS OF A/C ICING. NEW TECHNIQUES AND A/I SYSTEM ARE NEEDED BY G/A FOR CERTIFICATION. NEW SMALL TANKER.
35	CERT.DEFN.(LWC,ALT,DSD)	FACTORS INVOLVED IN MECHANISM OF ICING AND PRINCIPLES OF ICE DETECTION ARE DISCUSSED. DESCRIPTION OF SIMPLE HOT ROD AND OF THE TEDDINGTON INFERENTIAL ICING RATE METER ARE GIVEN.
43	CERT.DEFN.(LWC,ALT,DSD)	NAVAL TEST FACILITY(NAPTC) DESCRIPTION. ICE TUNNEL TESTING METHODS, SYSTEMS, AND INSTRUMENTATION. TURBOFAN. TURBOPROP. TURBOJET ENG. SIMULATES ALT.TEMP.SPEED. ICE . HUMIDITY. ETC.
53	CERT.DEFN.(LWC,ALT,DSD)	METHODS FOR PREDICTING ICE SHAPES AND EFFECTS OF ICE SHAPES ARE DISCUSSED. W/T TESTS ARE USED FOR BOTH. 2-DIM AN IS APPLIED TO 3-DIM WING. SIMULATED ICE HAPES USED IN W/T. TECHNIQUE IS USED DURING DESIGN STAGE OF A/C. WINGS. HI LIFT DEVICES.
59	GENL AVIATION PROFILE	ACCIDENT REPORT. PILOT DID NOT FOLLOW PROPER PROCEDURES WHEN WARNED OF ICING CONDITIONS. A/C UNABLE TO CLIMB OVER MOUNTAIN RIDGE.
69	CERT.DEFN.(LWC,ALT,DSD)	EVALUATION OF BUFFALO ENG INLET DUCT A/I SYST. VIA TANKER TESTS. FAR 25 CONDITIONS SIMULATED AS MUCH AS POSSIBLE. TESTING WAS RESULT OF ENG STALLS DURING LIGHT ICING.
84	CERT.DEFN.(LWC,ALT,DSD)	FAA GUIDE ON ICE PROTECTION. METHODS OF ICE PROT. ARE LISTED. FAR 25 DATA IS DISCUSSED. A/C OPERATIONAL FACTORS ARE DISCUSSED. OBJECTIVES OF A/I SYSTEM DESIGN ARE GIVEN & DISCUSSED.
86	CERT.DEFN.(LWC,ALT,DSD)	USA,EUROPE,AND RUSSIAN ICING REGULATIONS AND ICING CONDITIONS ARE GIVEN AND DISCUSSED. PARAMETERS ARE LISTED AND CERTAIN ICING PARAMETER VALUES ARE TABULATED. FAR-25&JAR-25.CAR-2.AND JAR-E,ETC.
88	GENL AVIATION PROFILE	COMPARISON OF LIGHTWEIGHT(80LBS) DE-ICING SYSTEM AND HEAVYWT ANTI-ICING SYSTEM(144LBS) IS MADE UNDER THE SAME ICING CONDITIONS. ONLY THE 144 LB SYSTEM WAS SATISFACTORY.
91	CERT.DEFN.(LWC,ALT,DSD)	REPORT ON DEVELOPMENT OF THE BRITISH TKS FLUID A/I SYSTEM. BASIC A/I FLUIDS ARE GLYCOLS EXCEPT FOR W/S WHERE ALCOHOL (PRIMARILY ETHYL) IS USED. LOGISTICS PROB. WITH FLUID SYSTEMS.

REFERENCES WHICH RELATE TO CERTIFICATION REQUIREMENTS

REF NO	ICING CONDITION	REFERENCE COMMENT
104	TRANSPORT PROFILE	SPECIFICATION FOR ADVANCED LIFT FAN SYSTEM(X1).SHOWS A/I FLIGHT REQUIREMENTS ENVELOPE. GUIDE VANES ANTI-ICED WITH BLEED AIR. NON-CONTINU[illegible]S SYSTEM
108	CERT.DEFN.(LWC,ALT,DSD)	TECHNICAL REF DOCUMENT FOR A/C POWERPLANT ICE PROTECTION SYSTEM DESIGN. SEQUEL TO ADS-4 FOR AIRFRAME A/I DESIGNERS. INCLUDES UPDATED MATERIAL, WHERE AVAILABLE.
116	TRANSPORT PROFILE	A STUDY WAS MADE TO INVESTIGATE THE SENSITIVITY OF A NUMBER OF DIFFERENT TAIL DESIGNS WITH ICE ACCRETIONS. ICE SHAPES WERE DETERMINED IN W/T TESTS. THEN SIMULATED SHAPES WERE TESTED IN W/T DRY AIR.
118	COMMUTER PROFILE	METHODS FOR MAKING AND USING MOLDS FOR ICE SHAPES FROM WINGS AND PROP RUNWAYS ARE DESCRIBED. PROBLEMS WITH SILICONE RUBBER ARE DESCRIBED.
120	TRANSPORT PROFILE	MEASUREMENTS WERE MADE OF THE EFFECTS OF RESIDUAL ICE ON AN AIRFOIL CONTAINING A PNEUMATIC BOOT DE-ICING SYSTEM.
121	CERT.DEFN.(LWC,ALT,DSD)	1969 FAA SYMPOSIUM ON A/C ICE PROTECTION. SERIES OF PAPERS BY DIFFERENT AUTHORS ON ENGINE AND AIRFRAME ICE ACCRETION AND SHEDDING AND ICE PROTECTION SYSTEMS.
122	CERT.DEFN.(LWC,ALT,DSD)	FAA HELICOPTER OPERATIONS R&D PLAN INCLUDING ICING STANDARDS SECTION. DISCUSSION INCLUDES SHORT TERM AND LONG TERM OBJECTIVES OF THE PROGRAM.
123	CERT.DEFN.(LWC,ALT,DSD)	ANAL STUDY OF ICING SIMULATION FOR TURBINE ENGINES IN ALT. TEST CELLS. DEVELOPMENTS OF MATHEMATICAL MODEL STUDY LENDS SUPPORT TO CONCEPT THAT GROUND TEST FACILITIES PROVIDE THE BEST CAPABILITY FOR CONDUCTING TURBINE ENG. ICE TESTS.
128	TRANSPORT PROFILE	NASA LEWIS ICING TUNNEL WAS USED. ICE SHAPES TEST TUNNEL. NATL ICE TEST.APU INLET,NO PROBLEM.FLOW DISTORTION TEST FOR INLETS.
131	CERT.DEFN.(LWC,ALT,DSD)	GENERAL SUMMARY AND HISTORICAL PERSPECTIVE OF ICING AND ICING RESEARCH NEEDS. OVERVIEW OF ICING EFFECTS ON A/C DESIGN,ICING ENVIRONMENTS,CERTIFICATION CRITERIA,NASA ROLE. FACILITIES,ETC

REFERENCES WHICH RELATE TO CERTIFICATION REQUIREMENTS

REF NO	ICING CONDITION	REFERENCE COMMENT
133	CERT,DEFN,LWC,ALT,DSD	A REVIEW OF ICING SITUATION FROM G/A STANDPOINT. EXCELLENT SECTION ON PROBLEMS WITH FAA RULES AND REGULATIONS AND DEFINITIONS ON ICING CONDITIONS. NEED FOR WORK ON G/A REGS & CERTIFICATION.
137	CERT,DEFN,LWC,ALT,DSD	ICING MEASUREMENT CAPABILITIES OF AEDC ENGINE ICING TEST FACILITIES ARE DESCRIBED. SPRAY CAPABILITIES AND MANIFOLDS CONTAINING NOZZLES ARE DESCRIBED.
140	CERT,DEFN,LWC,ALT,DSD	NGTE ENGINE TEST FACILITY. TEST IN CELL 3WEST OF OLYMPUS 593 INLET ANTI-ICING SYSTEM. ELEC CYCLIC AND HOT AIR CONT FOR INTAKE SUPPORT STRUTS.
141	CERT,DEFN,LWC,ALT,DSD	THE NEW ROLE OF THE METEOROLOGIST IN THE ICING CLIMATOLOGY AND ICE PROT CERTIFICATION PROGRAMS IS GIVEN. CERTIFICATION, CLOUD PHYSICS, ICE FORMATION, ETC., ARE DISCUSSED.

REFERENCES PERTAINING TO CERTIFICATION REQUIREMENTS

REF NO	COMMENTS RE ICE PHENOMENA
1	NEW RESEARCH IS REQ'D. ICE FORMATION DATA IS EMPIRICAL AND NEEDS ADDITIONAL RES. UNDER CONTROLLED CON. * SUGGEST TESTS IN ICE TUNNELS BY COMPONENT OR FULL SCALE SECTION.*
2	RESEARCH NEEDED TO EVOLVE INEXPENSIVE METHODS TO DETECT CARB ICING OR ICING CONDITIONS, WITH METHODS FOR ALERTING PILOT, BUT WITH AUTO. SYSTEMS. *ICE FORMS AT HI HUMIDITY AT TEMPS UP TO 80 DEGF.*
3	CONVENTIONAL EQUATIONS.
4	PRIMARY EFFECT IS FUEL COOLING.
5	SPHERICAL PROBE ICE ACCUMULATION IN NATURAL ICE COMPARED WITH FAR 25.
6	NO RESEARCH SUGGESTED. * STEADY STATE ICE FORMATIONS ARE QUESTIONABLE - SUGGEST RESEARCH WITH VARIABLE ICE CONDITIONS.
53	CONDITIONS USED WERE ACCORDING TO CERTIFICATION DEFINITIONS. ALSO HOAR FROST AND ICE.
69	RUNBACK ICE IN S-SHAPED INLET DUCT CAUSED STALL ANF FLAMEOUT CONDITIONS.
80	LT WEIGHT SYSTEM LEFT RESIDUAL ICE. BUILDUP WAS 1/2 INCH HEAVYWT SYSTEM REMOVED ALL ICE AFTER 3/4 INCH BUILDUP.
108	ATMOS ENV DESIGN POINTS; ENGINE WATER INGESTION RATES; WATER DROPLET IMPINGEMENT ON ENGINE SURFACES; A/I NEED/NON-NEED; ICE ACCUMULATION AND LIMITS; DESIGN AND TEST VERIFICATION.

REFERENCES PERTAINING TO CERTIFICATION REQUIREMENTS

REF NO	COMMENTS RE ICE PHENOMENA
116	ICE ACCRETION SHAPES FOR 44 DEGREE SWEPT HORIZ WAS DETERMINED IN SOVIET INT. SIMULATED ICE MADE FROM TUNNEL TEST ICE WAS USED ON TAIL MODELS IN SWEDISH FFA TEST TUNNEL.
120	TAR AND CRUSHED SLAG WAS USED TO SIMULATE RESIDUAL ICE FOR FULL SCALE ICING TUNNEL TESTS OF AIRFOIL LE AT 60 MPH.
121	PAGES 253-321 HAVE AN EXCELLENT DISCUSSION OF TECHNIQUES USED TO DETERMINE ICE SHAPES AND ICE SHEDDING CHARACTERISTICS OF UNPROTECTED SURFACES. BOEING METHOD.
123	A PARAMETRIC STUDY WAS PERFORMED TO DETERMINE THE EFFECTS OF THE TEST CELL INLET AND WATER SPRAY CONDITIONS ON THE THERMODYNAMIC AND KINETIC STATE OF FLOW IN THE TEST SECTION.
128	EXCELLENT ICING PARAMETERS FOR HORIZ STAB WITH SPHERICAL CORRELATING RELATIONSHIPS. *RECOMMEND FOR OTHER AIRFOILS. G/A UNSWEPT AIRFOILS, IC SHEDDING TRJ. ANAL. INCLUDED.
141	FINER SCALE ICING CLIMATOLOGY IS REQUIRED TO IMPROVE ICING PREDICTION BASED ON CLIMATOLOGICAL STATISTICS.

APPENDIX D

SUMMARY OF INDUSTRY/GOVERNMENT SURVEY QUESTIONNAIRE

BACKGROUND AND RECOMMENDATIONS

A survey/questionnaire was sent to 60 members of industry, Government, and universities who are involved in icing related activity in the field of general aviation and light transport aircraft. Only 23 responses were returned. This response rate appears typical, based on comments found in the literature regarding similar surveys.

A number of those on the mailing list were contacted almost eight weeks after transmittal of the questionnaire to inform them that we would still accept submittals if they had any. This was done because the original transmittal letters had requested that the questionnaire be returned within two weeks after receipt. Several phone calls had been received requesting extensions to this two week period, so it was assumed that there might be others who were unable to meet the two week turnaround and so did not submit a reply.

The followup telephone calls verified this suspicion. It was quite difficult to make contact with most of the individuals, since many were out of town on business, in conference at the time of the call, etc. Obviously, these are very busy people, and if the two week deadline were to expire, they would most likely not be able to take the time to pursue the questionnaire, especially if they felt that it wouldn't be used in the survey. It is recommended that in future surveys, a time limit be suggested, but encouragement should be given for submittal within a reasonable period to accommodate the work schedules of the respondents.

Some companies or Government agencies were represented by more than one individual (one had 5), usually at different divisions of the same company. In one instance, a member of one division had indicated to us that he would be returning a questionnaire. When contacted about eight weeks later, he noted that subsequently he had found out that a member of a sister division had already submitted a reply, and since he thought we needed only one reply per company, he did not bother to submit his. In the future, when polling multiple members of the same company or agency, instructions should be explicit as to whether individual or coordinated replies are desired.

It was found that a number of those who did not respond felt that they had nothing of value to contribute to the survey. Several wrote us and told us this, as did two others who were contacted later. It would be of great value in future surveys to get an immediate feedback on what kind of response can be expected. Possibly a postcard should be enclosed for immediate return which would indicate whether or not a response will be forthcoming. This step would aid tremendously in planning the compilation of the survey results and in establishing a cutoff date for incorporating the results in the main effort.

This appendix is divided into two parts. Part 1 presents the survey/questionnaire, including the cover letter, as it was mailed out to the various individuals.

In part 2 is the summary of the questionnaire responses received from industry and Government. The replies are summarized quantitatively, where possible, and all comments of interest have been included. The results in part 2 have been used to support the assessments, conclusions, and recommendations presented in the body of this report.

APPENDIX D-1

LETTER OF TRANSMITTAL AND SURVEY/QUESTIONNAIRE

NASA

Dear

NASA has recently started a new program in aircraft icing research at the Lewis Research Center, Cleveland, Ohio. The program will include in-house research, university grants, and industry contracts. Since you are a member of the general aviation or small transport aircraft industry (manufacturer or operator), your recommendations for our icing program are important.

Therefore, we have included with this letter a QUESTIONNAIRE on aircraft icing. Your responses to this QUESTIONNAIRE will help NASA determine what advances in aircraft ice protection technology will most benefit your industry. We hope you will consider this an opportunity to voice your concerns about aircraft icing, and to influence future NASA research.

Rather than send this QUESTIONNAIRE directly to the person responsible for ice protection in your organization, we are sending it to you to insure that the responses represent corporate technical policy. Since the QUESTIONNAIRE is rather long, please respond only to those questions that your organization regards as important.

Please understand that the enclosed QUESTIONNAIRE is intended to aid you in communicating your thoughts to NASA. It should be considered as a guide. Please feel free to omit answers to questions or address your concerns in letter form if you deem it appropriate to do so. NASA is interested in your ideas, not the form in which they may be submitted. You are under no obligation to respond to this request, but all replies will be given careful consideration.

If you choose to respond, please do so within two weeks of the date of this letter. Please send your replies and address any inquiries to:

Mr. Robert Breeze, MA-14
Rockwell International
North American Aircraft Division
815 Lapham Street
El Sugundo, CA 90009

Telephone: (213) 647-3995

Sincerely,

Allan R. Tobiason
Manager, Aviation Safety Technology

Enclosure

INTRODUCTION

The NASA Lewis Research Center, Cleveland, Ohio, has contracted with the North American Aircraft Division of Rockwell International to conduct a study for small transport and general aviation aircraft icing research requirements. The objectives of the study are to define for NASA both a long-term and a short-term icing research and technology program that is responsive to the needs and desires of members of the small transport and general aviation industry.

For the purposes of the study and this survey, small transport is defined as fixed wing aircraft of up to 30 passengers, having an annual utilization of about 2500 hours in scheduled operations, and operating primarily at altitudes at or below 10,000 feet. General aviation refers to fixed wing aircraft utilized in non-military and unscheduled airline operations. Aircraft with the following types of engines are being considered: jet and fan engines, turboprops, and piston engines.

OBJECTIVES OF THE QUESTIONNAIRE

The objectives of this survey are to solicit from selected general aviation and small transport manufacturers and government agencies technical data, where available, but more importantly, their views, comments, and recommendations concerning icing research subjects. This should be considered by the respondents as an opportunity to voice their concerns relating to icing and icing protection, and to influence the direction of future NASA research. Your inputs will allow the reflection of the broader view of the general aviation industry in the recommendations given to NASA for short- and long-term research plans.

QUESTIONNAIRE SURVEY QUESTIONS

The questions in this survey have been grouped into six basic sections dealing with: (1) ice protection systems, (2) ice protection penalties, (3) propulsion system icing, (4) airframe icing, (5) testing techniques, (6) calculational techniques, (7) weather data, (8) final recommendations.

I. ICE PROTECTION SYSTEMS

1. Established ice protection systems include (1) hot air from compressor bleed, (2) electrothermal, (3) pneumatic boots, (4) engine waste heat, and (5) anti-freeze fluids. The USSR has developed an electromagnetic-impulse ice protection system for which they are offering licensing agreements. What additional development, research data, design data, or performance data are required for the systems mentioned above?

2. Icephobics (materials that reduce ice adhesion) development is a high risk, high payoff venture. What priority should NASA place on developing an ice phobic?

3. What are the most important features that any new ice protection system should provide?

4. If new ice protection systems could be developed or existing ones improved, which ones would provide the greatest payoff?

II. ICE PROTECTION PENALTIES

Information is needed on <u>penalties</u> to the aircraft or to individual components <u>due to the effects of icing</u>. It is requested that Table I be filled out for the various aircraft or components manufactured or tested by your company for which icing penalties are available. Note that penalties may be given as actual values, if known, or relative rankings of the penalties involved.

In addition, penalties on aircraft due to the use of ice protection systems are also needed. It is requested that Table II be filled out for the various aircraft, engines, or components manufactured or tested by your company. Again penalties may be given as actual values or in the form of relative rankings. If the penalties can be broken down for each component, please do so (see example on table).

III. PROPULSION SYSTEM ICING

1. What icing research is required in support of the following propulsion components?

   - Carburetors
   - Cowlings for IC engines
   - Propellers
   - Inlet guide vanes (fixed and variable)
   - Core inlets
   - Engine or fan inlets
   - Fan blades
   - Stator blades

2. What analytical and experimental research is required on shed ice control and transient heat transfer for engine de-ice systems?

3. What research is required to make ice protection systems compatible with engine components made of composite materials?

TABLE I

PENALTIES OF ICING EFFECTS ON AIRCRAFT OR COMPONENTS

- List Component or Aircraft and Associated Actual or Relative Penalties Due to Icing

AIRCRAFT OR COMPONENT	PENALTIES DUE TO ICING (Use Actual Values or Relative Penalties: 1=Severe Penalty; 2=Moderate; 3=Small)						
	WEIGHT	Δ MAX SPEED	Δ LIFT	Δ DRAG	Δ STALL SPEED	Δ RANGE	SAFETY

TABLE II

PENALTY ASSESSMENT OF THE PROTECTION SYSTEMS

- List Aircraft and Check Components Protected From Icing
- Note Actual or Relative Penalties of Individual Components or for Total Aircraft

AIRCRAFT TYPE, NAME, OR MODEL	CHECK COMPONENTS THAT ARE ANTI ICED/DEICED										ANTI ICING SYSTEM PENALTIES OF INDIVIDUAL COMPONENTS FOR TOTAL AIRCRAFT • Use Actual Values or Relative Ranking: 1=Severe Penalty to Aircraft; 2=Moderate; 3=Small						
	WINDSHIELD	WING LEADING EDGE	TAIL LEADING EDGE	PROPELLER	ENGINE INLET	NACELLE	PITOT	ICE DETECTOR	BALANCE HORN	OTHER	POWER REQD BY SYSTEM	INITIAL COST	WEIGHT	RANGE REDUCTION IMPACT	CRUISE SPEED IMPACT	MAX SPEED IMPACT	RELIABILITY IMPACT
Example: Sabreliner 65	x	x		x	x	x	x				(3) ~3100 watts	(2)	(4)	(3)	(3)	(3)	(3)
Example: Sabreliner by Component	x	x				x					1% eng bleed 2% eng bleed	(4)	(3)				

IV. AIRFRAME ICING

1. Airfoil lift, drag, pitch moment, and stall speed increments due to ice accretion have been obtained in the past in the NASA Lewis Icing Research Tunnel (IRT). Do you want such icing sensitivity data from the IRT for the following:

YES	NO	
___	___	Airfoils on your current aircraft
___	___	Your future airfoils
___	___	New computer designed airfoils (Low Speed, Laminar Flow, Supercritical)

2. Do you want NASA IRT data on airfoil ice shapes from which artificial ice shapes could be made for use in dry wind tunnel and flight testing?

3. Are there any aircraft components, especially vulnerable to icing, for which the airframer needs special design guidelines. (e.g. tail balance horns)?

4. What research needs to be done to make ice protection systems compatible with airframe components made of composite materials?

5. In Table I please identify the ice sensitive components which require additional research, and list, in order of importance, the required research in the areas of (1) ice accretion or water collection efficiency, (2) ice shedding, (3) ice protection system, (4) performance penalties.

V. TESTING TECHNIQUES

1. The methods listed below are used for determining (1) the nature and extent of icing of a component, (2) ice protection system performance, and (3) aircraft performance penalties due to either ice accretion or ice protection system operation. Based on your experience, please comment on such factors as the accuracy, practicalness, availability, and costs of these methods.

   - o Full-scale icing wind tunnel tests
   - o Sub-scale icing wind tunnel tests
   - o In-flight tanker spray cloud tests
   - o Ground spray cloud tests
   - o Flight tests in natural clouds
   - o Analytical techniques and computer codes
   - o Other

2. What improvements should NASA make to their icing facilities? Please discuss such improvements as test section size, air speed, range of icing parameters, instrumentation (e.g., force balance, cloud parameters).

3. Should the NASA Lewis Altitude Wind Tunnel be rehabilitated to provide expanded icing facilities which include a 20-ft diameter high speed test section (up to M=1) and a low speed 45-ft diameter test section with speeds to 200 knots?

   _____ YES. Would be willing to use on a cost basis.

   _____ YES. But do not foresee any immediate application for us.

   _____ NO. Our facilities or test procedures are adequate.

   _____ NO. No need.

   _____ OTHER: ______________________________

4. Should spray systems be standardized for the existing icing spray tankers, and should instruments for measuring the spray cloud properties be standardized?

VI. CALCULATIONAL TECHNIQUES

1. There are a number of handbooks available which provide technical icing data. Which of the following do you use?

   _____ FAA ADS-4, Engineering Summary of Airframe Icing Technical Data

   _____ FAA RD-77-76, Engineering Summary of Powerplant Icing Technical Data

   _____ OTHER: ______________________________

   ____

2. Are the design procedures and icing data in ADS-4 sufficient enough to be worked up into computer codes for preliminary design trade-off studies and for inputs to mission analyses?

3. What new ice protection problem areas do you feel need to be addressed by these or new technical handbooks?

4. Which existing areas covered by these handbooks most need improvement?

5. Please list and briefly explain any computer codes you use to design ice protection systems and to determine icing penalties. Indicate whether they are proprietary or available in the open literature.

6. Listed below are several computer codes that NASA is either procuring or planning to procure.

   o Water droplet trajectories for water catch rates and impingement limits on:

     2-D lifting bodies (wings, tails)

     3-D lifting bodies (wings, tails, fuselage)

     3-D non-lifting bodies (fuselages)

     Axisymmetric engine inlets at angle of attack

   o Steady-state heat transfer for anti-icing analysis.

   o Ice accretion modeling on wings, inlets, and rotors.

   o Prediction of aerodynamic penalties due to ice accretion.

   o Transient heat transfer codes for de-icer analysis.

   o Prediction of shed ice trajectories.

   Will these computer codes be of use to you in addressing your icing requirements?

   _____ *YES. Would supplement or replace codes currently used

   _____ *YES. Currently do not use computer codes

   _____ NO. Would not use any computer codes

   _____ OTHER: ____

   ____

   * What additional codes or special features would you want in these codes?

7. Since these codes will require extensive in-house expertise in programming and analysis, some companies may prefer to buy such services. When these codes become operational should NASA create an Ice Protection Analysis Center similar to the Airfoil Design Analysis Center created by NASA at Ohio State University?

VII. WEATHER DATA

1. Are you satisfied with the FAR 25, Appendix C icing envelopes for certifying general aviation and small transports? Please explain.

2. What changes would you like to see in the operational constraints (certification requirements) relative to icing, in order to improve utilization of the existing and growing body of general aviation and small transport aircraft? How would you justify the change?

3. What advancements are needed to help justify the desired changes of question 2 (e.g., instrumentation, ice protection capabilities, and weather forecasting)?

4. What improvements in weather forecasting would most directly help icing forecasts?

5. Are you satisfied with the present method of categorizing the icing condition (e.g., trace, light, moderate, severe)? Please explain.

6. Do you want an on-board instrument that measures cloud properties and that could be used to evaluate the aircraft's capability to operate in that local cloud environment?

VIII. GENERAL

1. Do you think a pilot training movie should be made that addresses the problems of flight into icing conditions—how to avoid it, how it affects aircraft performance, how to cope with it, and how to get out of it?

IX. FINAL RECOMMENDATIONS

1. What aspects of the icing problem most need attention? In the short term? In the long term?

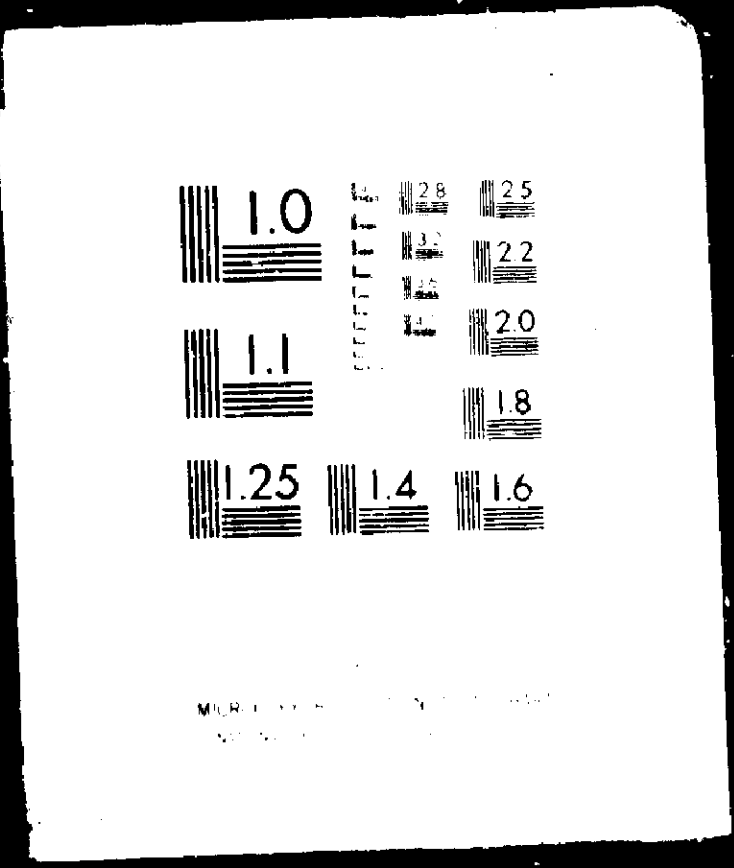
2. In what areas of the icing problem could NASA make the greatest contribution? In the short term? In the long term?

APPENDIX D-2

SUMMARY OF QUESTIONNAIRE RESPONSES

4 OF 4

81-19079



Section I

ICE PROTECTION SYSTEMS

I.1 ADDITIONAL DEVELOPMENT, RESEARCH, DESIGN, OR PERFORMANCE DATA NEEDED FOR ICE PROTECTION SYSTEMS

1. Updating of icing information in ADS-4 and NACA reports for new airfoil series.

2. Regeneration of FAR 25 envelopes.

3. Carburetor anti-icing techniques, including icephobics/fuel additives.

4. Trade studies of cost, weight, and effectiveness of all systems.

5. Standardized design methods to reduce engineering and certification costs.

6. Generalized computer programs to determine heat requirements.

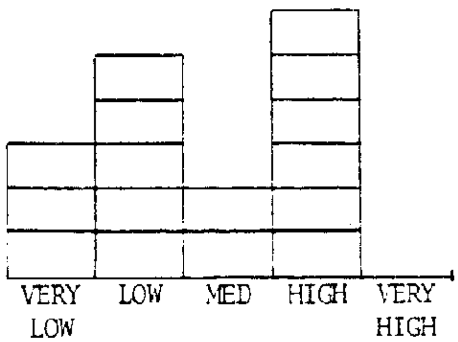
7. Electromagnetic impulse:

   -- Would like to see further development.

   -- Need relative effectiveness, power requirements, fatigue, design impact.

   -- Testing would be advantageous to prove the performance of the system and to provide enough information to accurately assess system advantages.

I.2 WHAT PRIORITY SHOULD NASA PLACE ON DEVELOPING AN ICEPHOBIC?



"PRO" COMMENTS

1. Ideal to develop one which would also shed bugs and maintain laminar flow.

2. Aim towards objective of being easily applied, noneroding, and highly efficient.

3. Breakthrough is very close - further R&D is not high risk.

4. Inherent low cost, low weight, and fail safe simplicity are extremely attractive.

5. NASA should continue to investigate the icephobic properties of new materials and coatings. Also, some testing may be done in conjunction with other deicing systems, such as microwave, electroimpulse, etc.

"CON" COMMENTS

1. Not much potential in pursuing.

2. Very low unless one could eliminate a system or protect difficult to deice areas that might shed ice.

3. Low to middle priority until a promising material family is discovered.

4. Risk/payoff seems too high.

I.3 WHAT ARE THE MOST IMPORTANT FEATURES OF ANY NEW ICE PROTECTION SYSTEM?

Feature	No. of Times Cited
Low Cost	9
Low Weight	8
Low Power Loss Requirement	8
High Reliability	6
Simplicity of Operation	4
Minimum Effect on Performance	3
Good Capability	3
Low Drag	1
Low Maintenance	1
Quick Response	1
Minimizes Pilot Work Load	1
Predictable so as to Simplify Certification	1

I.4 WHICH NEW OR IMPROVED ICE PROTECTION SYSTEMS WOULD PROVIDE THE GREATEST PAYOFF?

System	No. Times Cited
Icephobics	4
Engine Waste Heat	3
Microwave	2
Antifreeze Fluids	2
Leading Edge Anti-icing	2
Acoustic	1
Ice Detector	1
Windshield Anti-icing	1
Passive, Low Weight and Power	1
Improved Deicing	1
Those Easiest to Retrofit	1
Supercooled Droplet Transformer	1
Electroimpulse	1

Section II

ICE PROTECTION PENALTIES

II.1 ADDITIONAL COMMENTS REGARDING ICE PROTECTION PENALTIES

1. We have been involved with three aircraft icing programs where freezeup of the movable surface to the fixed surface occurred due to the configuration of the balance horn. One aircraft experienced loss of rudder control. Two aircraft configurations involved loss of elevator control. In all cases, design changes were necessary. One aircraft configuration encountered strut buffet during our natural icing flight tests. The buffet was subsequently reproduced with ice shapes attached to the struts and the buffet traced to vortex shedding from the glaze ice horns. Redesign was necessary. The above deficiencies all involve flight safety, structural loss of a wing strut would have been catastrophic. Loss of pitch control could be overcome by pilot skill if the situation were properly assessed by the crew. Singly, loss of yaw control on a multiengined aircraft is a small matter.

2. The largest penalty which could be ameliorated through NASA sponsored R&D efforts is the design time and development program cost associated with assuring safe and reliable anti icing systems. The weight, performance, and cost penalties to the overall aircraft can best be quantified by the airframe company since, in virtually all cases for the class of applications served by AiResearch engines (APU's, business aircraft, and flight transports), we are able to design our engines so that they do not require active anti-icing in the engine, and our requirement is only to supply a source of bleed air to the airframe for inlet anti-icing.

Section III

PROPULSION SYSTEM ICING

III.1 ICING RESEARCH NEEDED IN SUPPORT OF FOLLOWING PROPULSION COMPONENTS

CARBURETORS

Needs further research.

No need. (2)

Needs more study - using advanced ice detectors, icephobics, fuel additives.

Research on icephobics would be of benefit.

Tests of fuel additives to prevent carburetor icing.

Tests of throttle plate coating to prevent ice formation.

COWLINGS

Needs further research.

None needed. (2)

Alternate air inlets.

More research for IC engines, especially inlet deicing.

Look at use of engine oil for ice protection.

Research on icephobics would be of benefit.

Design for decreased ice accumulation on leading edges of cowling.

PROPELLERS

Needs further research.

None needed. (2)

Need reliable alternate to electrical anti-icing.

Research on icephobics would be of benefit.

STATOR BLADES

None needed. (2)

Need ice particle trajectory analysis, icing heat transfer, etc.

Research on icephobics would be of benefit.

Look at use of engine oil for ice protection.

III.1 (continued)

INLET GUIDE VANES

None needed. (1)

Need ice particle trajectory analysis, icing H.T., standardized tech., etc.

Look at jamming tendency after delayed actuation.

Consider use of engine oil for ice protection.

Research on icephobics would be of interest.

CORE INLETS

Needs further research.

None needed. (1)

Need ice particle trajectory anal., icing heat transfer, etc.

Look at use of engine oil for ice protection.

Research on icephobics would be of interest.

ENGINE/FAN INLETS

Cowl and lip shape collection efficiency as function (inlet vel., angle-of-attack, droplet size).

Desire performance and effect of runback ice due to shorter heated surface lengths with acoustical treatment aft of inlet lip.

Need ice particle trajectory analysis, icing heat transfer, etc.

Research on icephobics would be of benefit.

FAN BLADES

None needed. (1)

Need ice particle trajectory analysis, icing heat transfer, etc.

Research on icephobics would be of benefit.

OTHERS

Design guidelines on fuel system components susceptible to ice blockage and long term stability of fuel icing inhibitors.

Spinners - Effect of spinner shape on ice buildup. More adequate testing on conical shapes now used unheated on several engines.

III.2 ANALYTICAL AND EXPERIMENTAL RESEARCH REQUIRED ON SHED ICE CONTROL AND ENGINE DEICE HEAT TRANSFER

1. Doubtful trajectory analysis could be applied with confidence. Look at deicing radomes to control mass and form factor of shed ice.

2. Would like to see flight or wind tunnel ice shedding tests.

3. Look at inertial separator used for typical turboprops - low weight, low drag, simple, and low momemtum losses.

4. No additional research needed from airframe manufacturer's viewpoint.

5. Water catch research on rotating spinner shapes needed.

6. Improvement in methodology of shedding ice required.

7. Need research in what causes shedding.

8. Design guides for inertial separators needed.

9. Look at use of exhaust heat to deice engine inlet lips.

10. Aim for low cost engine deice system - no research needed for shed ice control.

III.3 <u>RESEARCH REQUIRED TO MAKE ICE PROTECTION SYSTEMS COMPATIBLE WITH ENGINE COMPONENTS MADE OF COMPOSITE MATERIALS</u>

1. None, but need basic data on aircraft components of composite materials.

2. Impact properties on engine composite materials.

3. Thermal characteristics of composite materials for inlets and nacelles.

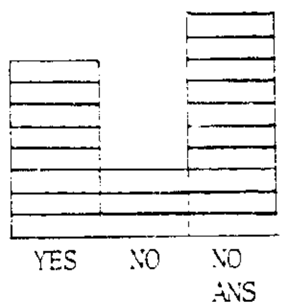
4. Testing to develop thinnest possible skins and verify heat transfer to surface.

Section IV

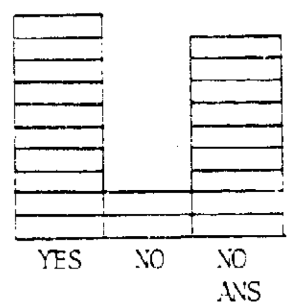
AIRFRAME ICING

IV.1 <u>WOULD YOU LIKE NASA IRT DATA ON AIRFOIL LIFT, DRAG, PITCH MOMENT AND DELTA STALL SPEED?</u>

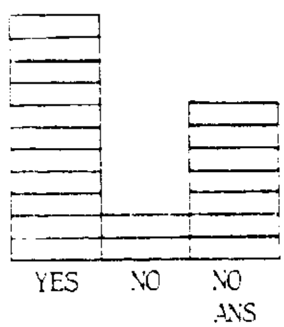
AIRFOILS ON YOUR CURRENT A/C?



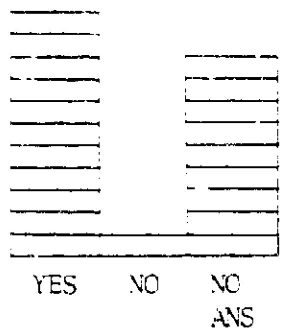
YOUR FUTURE AIRFOILS?



NEW COMPUTER-DESIGNED AIRFOILS?



IV.2 WOULD YOU LIKE NASA IRT DATA ON ICE SHAPES FROM WHICH ARTIFICIAL ICE SHAPES COULD BE MADE FOR DRY WIND TUNNEL TESTS?



IV.3 AIRCRAFT COMPONENTS VULNERABLE TO ICING NEEDING SPECIAL DESIGN GUIDELINES

COMPONENT	NO. OF TIMES CITED
Balance Horns	5
Antennas	5
Struts	2
Control Surfaces	2
Nose Shapes	1
External Inlet Scoops	1
Engine Inlets	1
Props	1
Stall Warning Devices	1
Windshields	1
Exposed Wheelwells	1
None Needed	2
No Answer	10

IV.4 WHAT RESEARCH IS NEEDED TO MAKE ICE PROTECTION SYSTEMS COMPATIBLE WITH COMPOSITES?

1. Applicability of thermal devices - other systems?

2. Investigate peculiar problems associated with various systems. Study ice protection systems for carbon fiber composite leading edges.

3. Analytical investigations should be made to determine type of system most compatible, followed by icing wind tunnel testing to verify its adequacy and establish design parameters.

4. Heat tolerance of composites.

5. Long term fatigue of composites when using pulse or vibratory methods. Also, effects of antifreeze fluids on composites.

6. Testing to develop thinnest possible skins and verify heat transfer to surface.

Section V

TESTING TECHNIQUES

V.1 RATING OF METHODS FOR ASSESSING ICING PROBLEMS

RATING AS TO METHOD OF ACCURACY

- Full Scale Wind Tunnel Tests
- Flight Tests in Natural Clouds
- In-flight Tanker Spray Cloud Tests
- Analytical Techniques
- Subscale Icing Wind Tunnel Tests
- Ground Spray Cloud Tests

MOST-TO-LEAST PRACTICAL METHODS

- In-flight Tanker Spray Cloud Tests
- Analytical Techniques
- Full Scale Wind Tunnel Tests
- Flight tests in Natural Clouds
- Ground Spray Cloud Tests
- Subscale Icing Wind Tunnel Tests

AVAILABILITY OF METHODS

- In-flight Tanker Spray Cloud Tests
- Subscale Icing Wind Tunnel Tests
- Full Scale Icing Wind Tunnel Tests
- Flight Tests in Natural Clouds
- Analytical Techniques
- Ground Spray Cloud Tests

V.1 (continued)

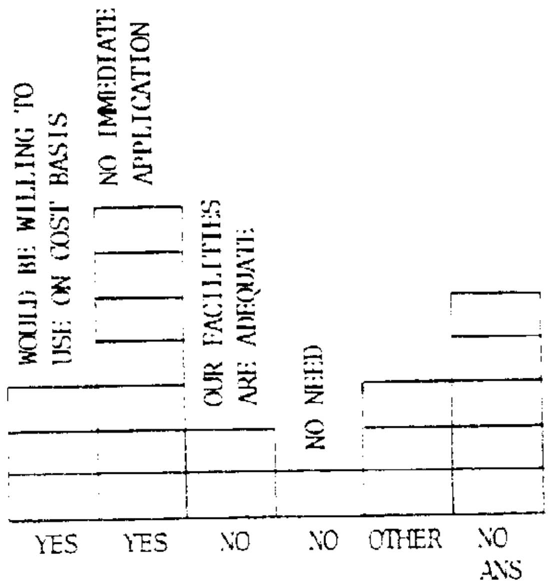
LEAST-TO-MOST COSTLY METHODS

- Analytical Techniques
- Subscale Icing Wind Tunnel
- Ground Spray Cloud Tests
- In-flight Tanker Spray Cloud Tests
- Full Scale Icing Wind Tunnel Tests
- Flight Tests in Natural Clouds

V.2 IMPROVEMENTS NASA SHOULD MAKE TO THEIR ICING FACILITIES

1. Increased range of liquid water content (LWC).
2. Improved force balance systems to obtain lift, drag, pitching moment data.
3. Improved instruments.
4. Higher speed capability (to 400 mph).
5. Lower temperature.
6. Improved wake drag system.
7. Refurbish vanes, blades, etc.
8. Droplet size and LWC calibration.
9. Blowing/falling snow and ground fog capability for engine inlet tests.
10. More tunnels to reduce lead times.
11. Instrument tunnel for "frost" testing.
12. Altitudes to 20,000 feet.
13. Automated control system to assist in faster stabilization of tunnel conditions to save time and energy.
14. Uniform cloud at test section.
15. Measurement of droplet size and LWC during testing.
16. Computer-linked data recording and processing.

V.3 SHOULD NASA-LRC ALTITUDE WIND TUNNEL BE REHABILITATED TO PROVIDE EXPANDED ICING FACILITIES?



COMMENTS

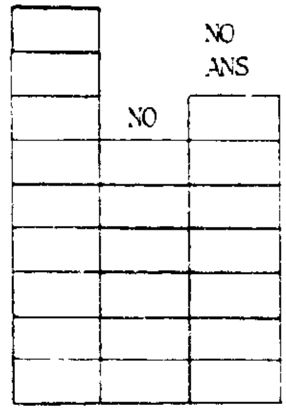
1. Increase range of icing parameters.

2. Do not associate M = 1 requirement with icing as a problem. 200 knots adequate.

3. First priority should be climatic research.

4. Need flow provisions to test engine inlets. Also, alternate rain spray rigs.

V.4 SHOULD SPRAY SYSTEMS BE STANDARDIZED FOR THE EXISTING ICING SPRAY TANKERS, AND SHOULD SPRAY CLOUD PROPERTY MEASUREMENT INSTRUMENTS BE STANDARDIZED?



*The "No's" were inferred from the following comments:

1. Doubtful standardized system could be developed. Real need for real time, affordable, water droplet diameter system.

2. No need to standardize, but design guidelines would be useful. Need development of inexpensive, reliable, immediate readout of LWC and droplet size instruments.

3. Prefer not to fly behind a tanker due to problems with controlling droplet size in 10-40μ range and difficulty in controlling spray pattern. Develop new equipment/techniques to control and measure LWC and droplet size more accurately.

4. Standardization second in importance to accurate measurement and prediction of droplet size and distribution. Standardization may prove too limiting because conditions differ with aircraft type, altitude, operations, etc.

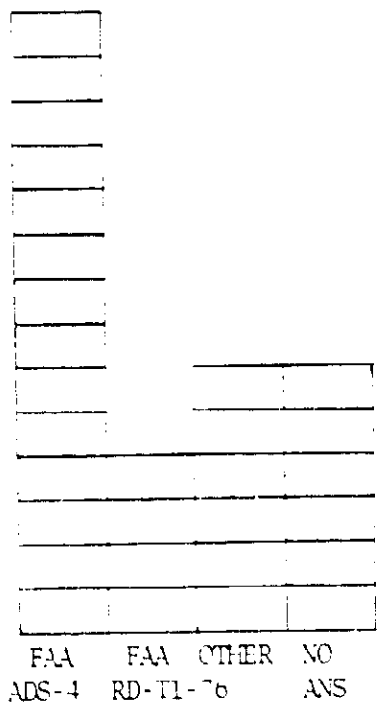
5. Do not consider necessary. Satisfactory results now. Standardization could increase requirements resulting in complication and expense without improvement in results.

6. This would be an unneeded added expense to certification, with little or no benefits. Satisfactory results are being obtained without this.

Section VI

CALCULATIONAL TECHNIQUES

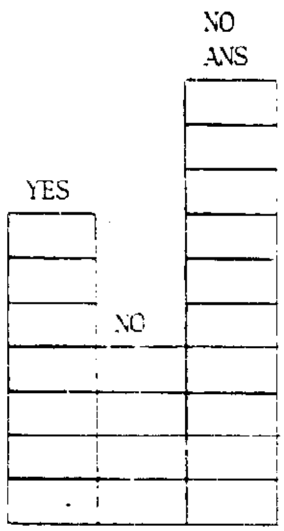
VI.1 THERE ARE A NUMBER OF HANDBOOKS AVAILABLE WHICH PROVIDE TECHNICAL ICING DATA. WHICH OF THE FOLLOWING DO YOU USE?



OTHERS NOTED:

1. WADC-TR-54-313, A Design Manual for Thermal A/I Systems.
2. "Analytical Investigation of Aircraft Windshield Anti-ice Systems."
3. SAE Applied Thermodynamics Manual.
4. FAA Advisory Circular 20-73, "Aircraft Ice Protection."
5. FAR 25 Appendix C. (Not a handbook as such, Author.)
6. Douglas Aircraft Rpt. SM-23978, "Manual for Aircraft Ice Protection."
7. Various NACA reports.

VI.2 <u>ARE THE DESIGN PROCEDURES AND ICING DATA IN ADS-4 SUFFICIENT ENOUGH TO BE WORKED UP INTO COMPUTER CODES FOR PRELIMINARY DESIGN TRADEOFF STUDIES AND FOR INPUTS INTO MISSION ANALYSES?</u>



COMMENTS

1. Must be aware of inaccuracy of data due to measurement techniques of the day.

2. Limited application.

3. It may be better to use it in the manner it is presented and then write a simple computer code to handle a specific problem. An all encompassing program tends to not be general enough to handle all specific problems.

VI.3 WHAT NEW ICE PROTECTION PROBLEM AREAS DO YOU FEEL NEED TO BE ADDRESSED BY THESE OR NEW TECHNICAL HANDBOOKS?

1. Protection of leading edge devices.

2. All new generation materials.

3. Neither handbook has sufficient water catch/shape data and both lack information on rotating systems and ice surface adhesion. Additional information is also needed on convection and evaporation for the various shapes of interest.

4. Rotors. No good system exists yet.

5. Reevaluate icing criteria parameters, airfoil icing shapes data.

6. Parasite ice on surfaces parallel to airstream.

7. Shadow-zone and high concentration zone of droplets in the near vicinity of a fuselage. Also, effect of engine mass flow on nose cowl ice collection, and impingement and aerodynamic effects data on new type airfoils, such as supercritical, both with and without high lift devices.

8. Icing of non-airfoil surfaces.

VI.4 WHICH EXISTING AREAS COVERED BY THESE HANDBOOKS NEED MOST IMPROVEMENT?

1. More accurate methods to predict ice shapes which could be simulated in dry air tests.

2. A good primer for certifying to FAR 25.1093 and 25.1419 would be helpful. AC-20-73 is very incomplete.

3. Design methodology, design parameters for optimization.

4. More exact ice shape prediction would be beneficial. Also, the thermal analysis given in the SAE manual should be expanded to cover the exact airfoil being analyzed.

5. Use of antifreeze fluids.

6. Reevaluate icing criteria parameter, airfoil ice shape data.

7. Precise methods for determination of ice shapes. Ice shapes on a 10 cm ball could be precisely determined under various test conditions and used as an impingement shape.

VI.5 PLEASE LIST AND BRIEFLY EXPLAIN ANY COMPUTER CODES YOU USE TO DESIGN ICE PROTECTION SYSTEMS AND TO DETERMINE ICING PENALTIES. INDICATE WHETHER THEY ARE PROPRIETARY OR AVAILABLE IN THE OPEN LITERATURE.

1. *Windshield and engine inlet anti-icing - company programs published in FAA certification reports.

2a. "POT" - potential flow program - two-dimensional or axisymmetric flow field. Can accept models with one or more surfaces, such as an engine inlet with centerbody. Can account for engine air appetite. Includes subroutine to rotate the model to any desired angle of attack. Accepted by FAA.

2b. "DROP" = droplet trajectory program. Uses POT to compute model impingement limits and water loading. Imposes Langmuir A or D droplet distributions as coded by FAA.

2c. "HOT" = thermal program. We have developed a handbook of methods and techniques for steady state and transient. Unpublished.

2d. *Handbook for glaze ice shape prediction using analytical/graphical methods, using output of DROP. Water loadings within the stated population form the basis for shape prediction. Method accepted by FAA.

3. Computer programs based on handbooks of VI.1.

4. Icing collection analysis programs.

5. *AEROICE, described in AFFDL-TM-79-91-WE, and is available on request if approved by higher headquarters.

6. *Company thermal analyzer program, impingement and heat requirements program.

7. Several heat transfer and droplet trajectory programs.

8. Ice shape program.

9a. Aerodynamic flow field definition code.

9b. Code for calculation of water droplet trajectories to compute ice collection efficiency and limits of impingement.

9c. Heat transfer analysis code to determine evaporation rates and runback ice amounts.

* All but these were identified as proprietary.

VI.6 WHICH OF THE FOLLOWING COMPUTER CODES THAT NASA IS EITHER PROCURING OR PLANNING TO PROCURE WOULD BE OF USE TO YOU IN ADDRESSING YOUR ICING REQUIREMENTS?

Code	No. Times Cited
Water Droplet Trajectories for Water Catch Rates and Impingement Limits on:	
2-D Lifting Bodies	10
3-D Lifting Bodies	12
3-D Non-lifting Bodies	11
Axisymmetric Engine Inlets at Angle of Attack	9
Steady-State Heat Transfer for Anti-ice Analysis	11
Ice Accretion Modeling on Wings, Inlets, and Rotors	11
Prediction of Aerodynamic Penalties Due to Icing	13
Transient Heat Transfer Codes for Deicing Analysis	10
Prediction of Shed Ice Trajectories	11
No Answer	8

WHAT ADDITIONAL CODES OR SPECIAL FEATURES WOULD YOU WANT IN THESE CODES?

1. Liquid water content and droplet size.
2. Ice collection efficiency, upper and lower surface impingement limits, etc.
3. Ice shed trajectories from wings to rear mounted engines.
4. Prediction of ice adherence characteristics toward outboard sections (3-D effects).
5. Nonaxisymmetric engine inlet applications.

VI.7 <u>SINCE THESE CODES WILL REQUIRE EXTENSIVE IN-HOUSE EXPERTISE IN PROGRAMMING AND ANALYSIS, SOME COMPANIES MAY PREFER TO BUY SUCH SERVICES. WHEN THESE CODES BECOME OPERATIONAL, SHOULD NASA CREATE AN ICE PROTECTION ANALYSIS CENTER SIMILAR TO THE AIRFOIL DESIGN ANALYSIS CENTER CREATED BY NASA AT OHIO STATE UNIVERISTY?</u>

YES	NO	PROBABLY NO	OTHER	NO ANS

COMMENTS FROM "NO" OR "PROBABLY NO" RESPONDENTS

1. Would run ourselves.

2. Would prefer in-house analyses. However, would consider outside source if turnaround time were attractive. Only water loading and surface pressure coefficients would be required from the outside source. Thermal analysis would occur in-house.

3. We do not see the necessity in establishing an ice protection analysis center. It is difficult to see how such a center would be cost effective. In addition, considerable product liability difficulties could be developed.

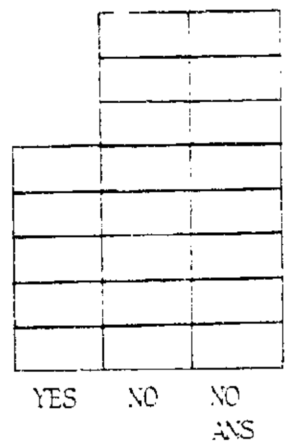
4. Not sure. My first impression is that the codes could be used by the companies themselves. I've heard that the Ohio State facility is not being well utilized. It's too early to make a judgement.

5. Not recommended. We would rather have the codes available for our own adaptation.

Section VII

WEATHER DATA

VII.1 ARE YOU SATIFIED WITH THE FAR 25, APPENDIX C ICING ENVELOPES FOR CERTIFYING GENERAL AVIATION AND SMALL TRANSPORTS? PLEASE EXPLAIN.



"YES" COMMENTS

1. FAR 25 envelopes were developed using questionable instrumentation but have been applied with good results. Indications are that envelopes are very conservative but hard to argue versus safety. Doubt FAA would want to change criteria.

2. Have been used satisfactorily in past. Need updating with more cloud data on LWC and probabilities to facilitate more meaningful mission analyses.

"NO" COMMENTS

1. Better definition at low altitudes.

2. Horizontal cloud extent is in error for maximum intermittent (too short). FAA Region would not allow time/distance factoring specified in Appendix C for approval. One position must change - either FAA or FAR 25.

3. None of the data available on icing encounters supports the FAR Part 25, Appendix C, requirements for ice protection at low altitudes when the ambient temperature is -22°F continuous maximum icing conditions). This corner of the icing envelope is difficult to meet for thermal ice protection systems. More energy is required which results in inefficiency for all operation in icing conditions. We suggest that the military requirements which eliminate ice protection below a line through 8,000 ft altitude at -22°F and sea level of 0°F are more realistic. Actually, more research is needed for better definition of limitations closer to experience with actual encounters.

VII.1 (continued)

4. Altitude limit - too low, validity of low temperature icing point - questionable.

5. The -22°F at sea level is unrealistic. Should emphasize the operational +10 to +32°F at sea level to 15,000 ft. Design philosophy behind Appendix C is to have an envelope that will include 99.9 percent of all icing encounters and allow the aircraft to remain in these conditions for an indefinite period of time. This not needed for G/A aircraft or helicopters used in non-air carrier operations. Also, FAR 25 envelope appears to be inaccurate at lower altitudes <5,000 ft. May also be too representative of maritime climates.

6. Current icing design envelopes are based on extensive NACA multicylinder data. This data should be confirmed with the more accurate scattering spectrometer instruments currently available. If confirmation cannot be obtained, new design envelope maps should be defined.

7. Large drop sizes are very difficult to obtain in a natural environment - not representative of actual conditions. Also, the high liquid water content specified for the 15 micron drops in intermittent maximum conditions is difficult to obtain in natural icing conditions and probably not very representative of actual conditions.

VII.2 WHAT CHANGES WOULD YOU LIKE TO SEE IN THE OPERATIONAL CONSTRAINTS (CERTIFICATION REQUIREMENTS) RELATIVE TO ICING, IN ORDER TO IMPROVE UTILIZATION OF THE EXISTING AND GROWING BODY OF GENERAL AVIATION AND SMALL TRANSPORT AIRCRAFT? HOW WOULD YOU JUSTIFY THE CHANGE?

1. No changes until the validity of current data are verified.

2. Criteria for rotorcraft are lacking and FAA is taking steps to formulate appropriate requirements. This need emerged as the next logical step after helicopter IFR approvals. Also, a definition of "falling and blowing snow" per FAR 25.1093 is needed.

3. Raise temperature from -22°F to +10°F, delete requirement for analysis so certification could be obtained by test only, delete ability to certify by analysis only. With inappropriate FAR 25 envelope, present operational rules are intolerable. A forecast of "occasional light icing" would completely ban all nonequipped aircraft certificated in last few years, even though such exposure would probably be without significant hazard.

4. Limitation of flight into known icing conditions should not be required when length of time in and degree of icing is known by the pilot to be very small, e.g., climg to on-top through shallow cloud layer. This could be justified by pilot judgment.

5. Icing certification should consist of selection of the most severe points for a given application and subsequent test of these points or their equivalent. Fixed certification points should not be employed. The fixed ground fog certification point needs to be confirmed with test data or modified to reflect proper exposure to ground fog.

   We would like to have the option to certify by tests for not more than three flights into icing conditions and analysis to cover the remainder of the envelope. In some cases, simulated ice shapes would be used to cover unprotected areas. We are not confident that flying behind a tanker gives representative results. Therefore, the number of flights required to cover the icing envelope would be astronomical and totally unacceptable.

7. Limited aircraft icing certification for limited icing conditions.

8. All FAA regions must abide by same regulations.

9. We would like to see uniform interpretation of FAR's by all FAA regions. Some regions are very arbitrary in their interpretation and try to apply FAR Part 25 interpretations to FAR Part 23 regulation and aircraft. This is particularly true of performance criteria.

VII.3 WHAT ADVANCEMENTS ARE NEEDED TO HELP JUSTIFY THE DESIRED CHANGES OF QUESTION 2 (E.G., INSTRUMENTATION, ICE PROTECTION CAPABILITIES, AND WEATHER FORECASTING)?

1. Instrumentation for real-time determination of water droplet diameter is perhaps the biggest need.

2. Of course, part of the problem is a lack of adequate forecasting techniques in the civil arena. It is worth noting that the military allows partial icing operations (i.e., in light icing), provides better operational forecasts, and does not appear to have airplanes falling out of the sky in the winter.

   A slight digression. Carburetor ice forecasts are now well within the state-of-the-art. With forecast relative humidity and temperature at altitude, the forecaster could use the NASA or Canadian derived charts and predict the severity of carburetor ice.

3. Actually, the desired changes of question 2 can be justified with present capabilities. It is the pilot's judgement that is the key. However, any increase in the ability to forecast icing conditions accurately would help the pilot make his decision.

4. Desirable to develop new equipment or techniques which could be used to control and measure liquid water content and droplet size more accurately.

5. Better forecasting - particularly at specific altitudes.

6. FAA/Industry MEOT meeting on ice regulations.

7. Familiarization of Part 25 FAA people with FAR Part 23 aircraft and their operating characteristics.

VII.4 WHAT IMPROVEMENTS IN WEATHER FORECASTING WOULD MOST DIRECTLY HELP ICING FORECASTS?

1. More use of satellite photos. Improved ice forecasting relative to probability and severity.

2. Some needed. Carburetor icing forecasts are now well within the state-of-the-art. With forecast relative humidity and temperature at altitude, forecaster could use NASA or Canadian derived charts and predict the severity of carburetor ice.

3. Icing forecasts would be helped most directly by better forecasting of temperature changes with altitude and cloud tops.

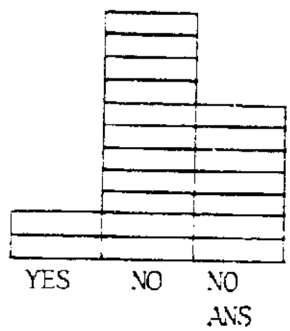
4. Liquid water content real-time data are the weak part of forecasting icing. Create a liquid water content data base and most of the forecast problem would be solved.

5. Aircraft feedback to central forecasting unit.

6. Determination of drop size presently in cloud.

7. Determination of liquid water content in clouds.

VII.5 <u>ARE YOU SATISFIED WITH THE PRESENT METHOD OF CATEGORIZING THE ICING CONDITION (E.G., TRACE, LIGHT, MODERATE, SEVERE)? PLEASE EXPLAIN.</u>



EXPLANATIONS:

1. I am not satisfied with the present categories of icing severities. They are quite ambiguous and require knowledge of the airplane that the forecaster had in mind. As a pilot reporting scheme, they are marginally acceptable. I would prefer a numerical scale (one to ten or one to one hundred) listing the icing severities with an airplane specific calibration (i.e., eight on airplane XX is moderate).

2. The categorizing of the icing condition (e.g., trace, light, moderate, severe) should be tied somehow to the size airframe and the potential effect on performance.

3. The present methods of categorizing ice accumulations (trace, light, moderate, severe, rime, glaze, etc.), are inadequate and mean different things to different people. A quantitative definition scheme is needed such as might be obtained with an ice detector. An onboard ice detector would be useful if it were reliable and inexpensive.

4. The characterization of the severity of icing should be addressed in relation to specific aircraft.

   Classification of icing severity in the meteorology reports in more specific terms, e.g., inches of rime ice per minute of exposure.

5. New definition and terminology are needed. The current definitions are not meaningful to a pilot faced with an operational problem. For example, the definition of severe icing describes the condition as "a rate of accumulation ... that deicing/anti-icing equipment fails to reduce or control the hazard." At the time this can be recognized, it may be too late. New definitions and terminology in weather reporting to pilots needs to be more quantitative and related to what the pilot can observe and use for operational decisions. For example, a scale could be

used based on the degree of hazard associated with atmospheric icing conditions. Specific airplanes could be certificated to fly up to a given scale. Weather conditions could be classified according to this scale in weather reports. A pilot could be guided in his operational decision on how his airplane capability compared to the reported weather.

6. It is a subjective method and not objective.

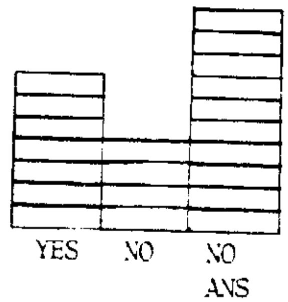
7. All agencies must use compatible terms, FAA vs. Weather Service, etc.

8. Conditions need to be more specific as to icing parameters. FDL Staff Meteorology is beginning a report tentatively titled Categorization of Aircraft Icing Response, which will use icing sensitivity data.

9. FAA doesn't permit limited icing flight approvals as in the case with several foreign agencies. Perhaps accepted definitions of light and moderate icing, coupled with service experience and improved forecasting could overcome FAA position of full approval or no approval.

10. All agencies should use the same terminology for icing conditions.

VII.6 DO YOU WANT AN ONBOARD INSTRUMENT THAT MEASURES CLOUD PROPERTIES AND THAT COULD BE USED TO EVALUATE THE AIRCRAFT'S CAPABILITY TO OPERATE IN THAT LOCAL CLOUD ENVIRONMENT?



"YES" COMMENTS

1. Yes, but look-ahead capability would be required.

2. If limited icing flight were permitted, a system such as the Rosemount Ice Severity Indicator would be mandatory to appraise the crew of actual conditions.

3. We certainly do want onboard instrumentation to measure cloud properties for testing. It would also be desirable to have equipment which could detect within, say, ten miles, where actual icing conditions exist. Sometimes an airplane flying at one altitude experiences no icing where another airplane flying 1,000 feet above does have an icing encounter.

4. Yes, if cost/reliability factor is good.

5. Sounds like a good idea if it could be developed with high reliability and accuracy.

"NO" COMMENTS

1. Such an instrument should not be required on board.

2. No, unless the cost was very low or incorporated in already existing equipment like weather radar.

3. An onboard instrument to measure cloud properties is an indirect method of assessment. An instrument would be better to measure the actual ice accretion on the airplane but only in those configurations where the lifting surfaces may not be adequately visible to the pilot. The visual assessment of ice is still the best way to go.

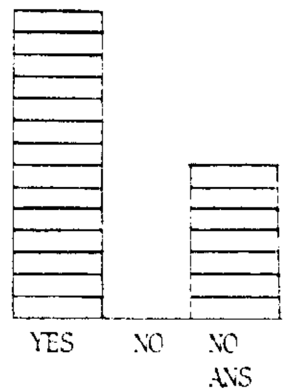
VII.6 (continued)

4. Additional required instrumentation on aircraft would constitute a safety hazard due to (a) increased pilot work load in an already hazardous environment, (b) additional electrical power requirements at a time when it could not be tolerated, and (c) such a device would require a probe in the airstream, creating additional drag, and malfunctions (e.g., not deice) it could create extremely hazardous situation in an icing environment.

Section VIII

GENERAL

VIII.1 DO YOU THINK A PILOT TRAINING MOVIE SHOULD BE MADE THAT ADDRESSES THE PROBLEMS OF FLIGHT INTO ICING CONDITIONS - HOW TO AVOID IT, HOW IT AFFECTS AIRCRAFT PERFORMANCE, HOW TO COPE WITH IT, AND HOW TO GET OUT OF IT?



COMMENTS

1. In addition to basic film, pilots should be schooled in the peculiarities of the individual aircraft type.

2. Yes, I think that pilot training is important. Most G/A pilots are afraid of ice at first. Then with their first couple of exposures (usually trace or light icing) they become brave. Their bravery continues until the first serious encounter. All too often the forecasting philosophy of overforecasting ice (i.e., call for severe when it's really moderate) helps continue the bravado until the final, often fatal, serious icing encounter. The instrument rating exam should have realistic questions concerning ice.

3. Pilot training movie on icing would be valuable as an educational aid.

4. Publications and films which promote an awareness of icing problems would be useful.

5. A pilot training movie which addresses flight into known icing conditions would be very worthwhile. It is not possible to build a general aviation airplane that is capable of handling or coping with all possible icing conditions. Pilots must continue to be impressed that skill, training, and most of all, judgment must be used in coping with icing conditions.

6. In some way the message needs to be disseminated to aircraft owners on the value of anti-icing and deicing systems and how to recognize their need.

Section IX

FINAL RECOMMENDATIONS

IX.1 WHAT ASPECTS OF THE ICING PROBLEM MOST NEED ATTENTION?

IN THE SHORT TERM?

1. Ice accretion and shapes for a combination of water droplets and ice crystals.

2. Development of fluid anti-icing/deicing systems.

3. Development of airframe and engine ice detectors.

4. Modification of operating rules.

5. Pilot/owner education on icing.

6. Pilot training movie plus the FAA safety clinic subjects.

7. Icing forecasting.

IN THE LONG TERM?

1. Refinement of current FAR 25 envelopes and establishment of limited icing flight requirements.

2. Climatological studies of the icing probabilities in the lower airspace (below 5,000 ft) and in the inland sections of the country.

3. Development of good flight test spray rigs and instrumentation.

4. Development of an ice phobic.

5. Research in a more comprehensive and accurate definition of climatic icing conditions.

6. Pilot training.

NOT IDENTIFIED AS SHORT OR LONG TERM

1. Low altitude icing in holding pattern.

2. Performance decrements of ice on unprotected areas.

3. Researching alternatives to pneumatic boots.

4. Uniform interpretation of FAR's by all FAA reigons, and standardization of certification procedures.

5. Training of pilots on how to avoid ice, cope with it, etc.

6. Generation of experimental impingement data for latest airfoils.

7. Development of efficient anti-icing for composites.

8. Improved methods to determine ice accretion shapes on unheated surfaces.

9. Definition of updated icing envelopes.

10. Reduction in engineering and certification costs to manufacturers.

11. Standardization of in-flight icing terms, icing reports, and certification procedures and regulations.

12. Development of new, low cost ice protection systems such as electro-impulse, microwave, etc.

13. In formulating the NASA Icing Program, high priority should be placed on the generic and basic research aspects of aircraft icing. For example, to comprehend the basic phenomenon of ice adhesion and to understand the complete physical process which causes ice to adhere to other materials would represent a major advancement in the attempts to define ice phobic materials and systems which mitigate against or inhibit the accretion of ice. The achievement of such a goal would not only have far reaching impact on aircraft safety but also would be significant benefit to ground-based systems (for example, antennas for navigation aids).

14. Another major program area for NASA emphasis is icing environmental definition and forecasting. It is common knowledge among the pilot population that all too often forecast icing is not encountered and icing encountered is not forecast. Also, forecasters tend to be conservative which inhibits operations in aircraft without ice protection. A basic understanding of the icing environment and how it changes with time would not only afford more accurate and reliable forecasts and hence greater operational capability, but also provide knowledge which could be used while airborne to minimize the effects of ice by a change of altitude or direction. This could be done through analysis or airborne weather sensors on the aircraft or by similar data from a ground station.

15. The aspects of the icing problem which need the most attention are the design envelopes, water catch characteristics as a function of shape, improved spectrometers, drop supercooling characteristics and icephobic coatings. NASA could make significant contributions in all of these areas.

IX.2 IN WHAT AREAS OF THE ICING PROBLEM COULD NASA MAKE THE GREATEST CONTRIBUTION?

IN THE SHORT TERM?

1. Additional ice collection efficiencies and impingement studies on current airfoils.

2. Correlate studies by a number of companies in cloud physics to validate current icing envelopes.

3. Standardize icing tests, facilities, and instrumentation.

IN THE LONG TERM?

None

NOT IDENTIFIED AS SHORT OR LONG TERM

1. On going programs in ice phobics, instrumentation, and analysis techniques. All areas would involve industry with NASA acting as clearing house for exchange of information and the test facility for correlation or proving tests.

2. Data collection from G/A operators (not "FAR" 121 operations) to substantiate changes to FAR 25 Appendix C requirement. Firmly believe that FAR 25 Appendix C is worst case for FAR 121 operations rather than practical G/A operations with their ability to delay flights, cancel flights, deviate to other airports, use alternate R-NAV routes, etc.

3. NASA could make the greatest contribution in the long term in development of an ice phobic or a system which disturbs the supercooled moisture in front of the airplane causing it to freeze before it contacts the surface of the airplane.

4. The research suggested and described in this questionnaire would probably involve several different research agencies, including the FAA, the National Weather Service and NASA. NASA's best role would be as the initiating and coordinating agency as well as the responsible agency for parts of the research needed.

5. Developing through theoretical analysis of the subject, testing of all available systems, then publishing design guides for manufacturers to insure adequate designs for icing protection.

6. Reevaluate icing parameters as related to fixed wing and rotary wing aircraft. Also, better and more icing test facilities.

7. The NASA contribution should be on improving the technology base for icing prediction, measurement, and correlation with flight experience. Applications of the analysis and techniques should be the responsibility of the user (e.g., the Air Force).

8. Standardization of testing and computer techniques to allow reduced certification costs. Coordinate the information and direction with the regulatory agencies such as FAA, DOT, etc.

   - Airfoil or component shape - design to reduce ice collection

   - NASA could form a bank of computer programs for all shapes of hardware and facilitate industry use of this information

9. Sponsor icing tunnel tests of new ice protection systems to determine performance and feasiblity.

APPENDIX E

SURVEY OF AIRCRAFT ICING SIMULATION FACILITIES IN NORTH AMERICA AND EUROPE

SURVEY OF AIRCRAFT ICING SIMULATION FACILITIES IN NORTH AMERICA

WILLIAM OLSEN
ICING RESEARCH SECTION
NASA LEWIS RESEARCH CENTER

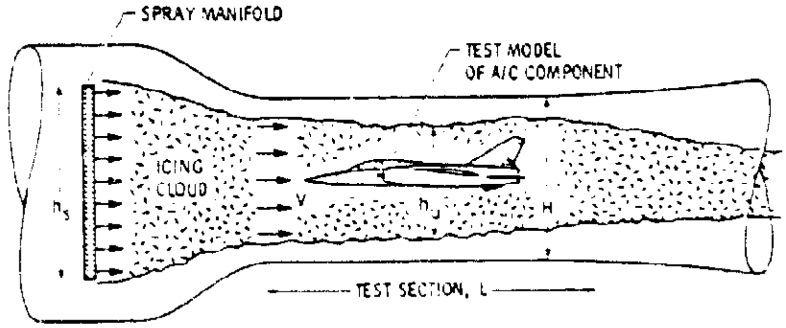
NASA was requested to survey the capabilities of the facilities in North America that can do aircraft icing simulation tests. The survey was requested by the Standing Committee on Icing, which is jointly sponsored by NASA, FAA and NOAA; the military services have also expressed a need for this survey. European icing facilities have already been surveyed and reported in AGARD Advisory Report 127.

The reasons for the survey are to: (1) inform the icing research community of the capabilities of existing icing facilities, (2) make it easier for a potential facility user to select and contact the icing facility that is appropriate for his test requirements, and (3) help facility managers evaluate and improve their facility.

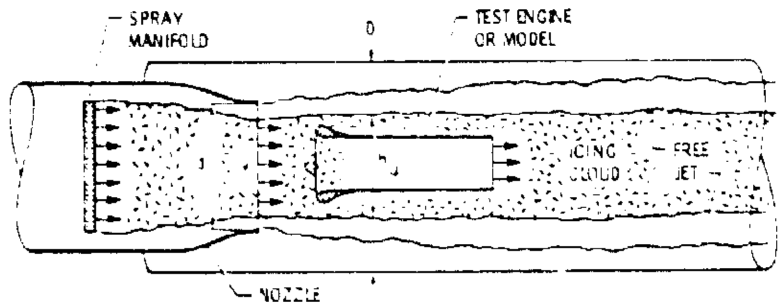
The survey determined the location and size of each facility, its airspeed and temperature range, icing cloud parameter ranges, and the technical person to contact. The facilities surveyed and their capabilities are listed in tables A to D, one for each of the four types of simulation facilities that are described on figures A to D. The capabilities of each facility were estimated by the engineers working with that facility. The numbers in the tables are single point approximations by them of the complex operating curves of their facility. Many of the facilities have capabilities beyond that required for icing testing and these excess capabilities were not included in the tables.

TYPES OF ICING SIMULATION FACILITIES

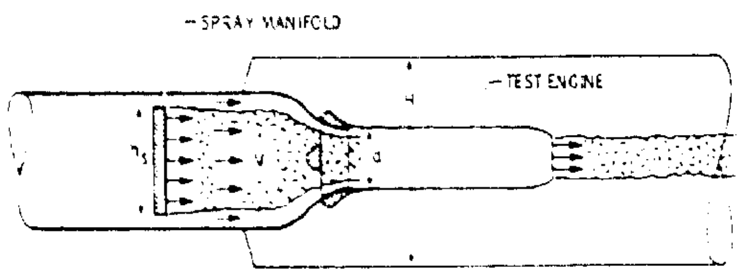
SCHEMATIC SKETCHES FROM SIDEVIEW



A. WIND TUNNELS



(a) FREE JET.



(b) DIRECT CONNECT.

B. ENGINE TEST FACILITIES

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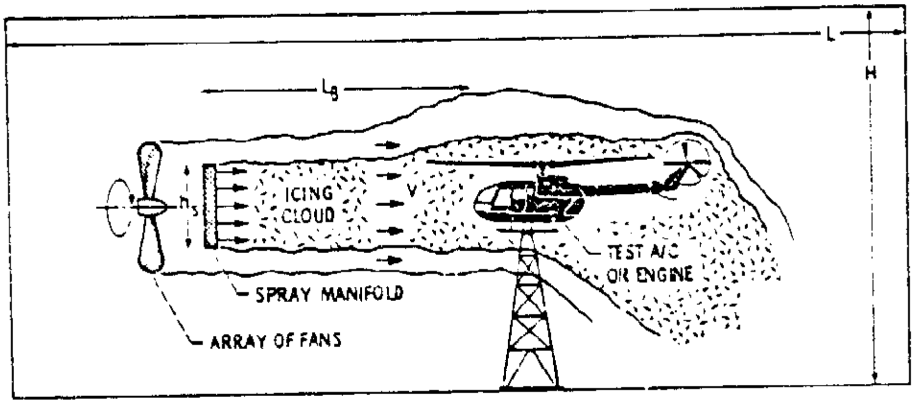
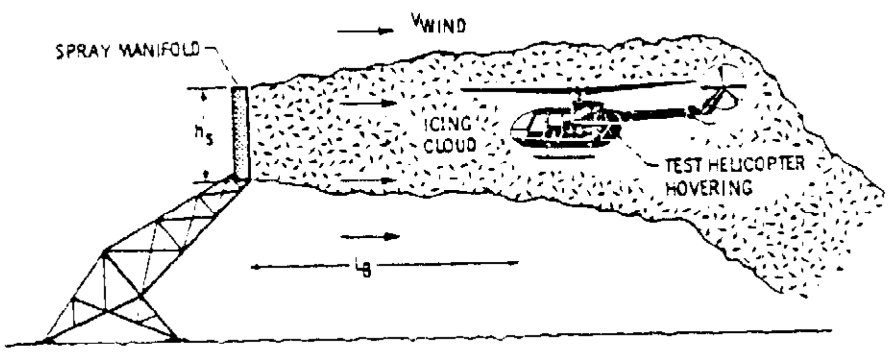
TYPES OF ICING SIMULATION FACILITIES

(CONTINUED)

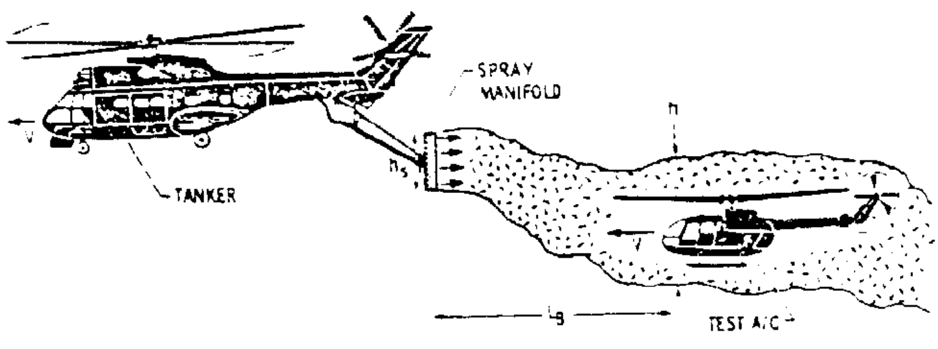


(a) FAN BLOWN SPRAY IN A LARGE ROOM OR OUTDOORS.



(b) WIND BLOWN SPRAY OUTDOORS.

C. LOW VELOCITY FACILITIES



D. FLIGHT TESTS WITH TANKER

CAPABILITIES OF ICING SIMULATION TEST FACILITIES IN NORTH AMERICA

(Capabilities estimated by technical contact person for each facility)

A. WIND TUNNELS

Facility no.	Facility name, location	Types of icing tests[a]	Weather simulated[b]	Type of facility	Size (see sketches): Test chamber	Size (see sketches): Uniform icing cloud	Range of parameters used in icing tests[c]: Air speed	Min total air temperature, °F	Altitude, ft	LWC, g/m³	Vol med drop size, μm	Instruments used for local drop size and LWC	Technical person to contact	Test season	Comment
A 1	NASA Lewis Research Center (Cleveland, OH) (a) IRT	FSC, I, MS, P[d], IA[b], P[d]	R E	Wind tunnel	H - 6 ft, W - 9 ft, L - 20 ft	h_u - 3 ft, w_u - 5 ft	5 to 250 knots	-15	0	[e]0.5 to 3.0	[e]11 to 25	Being modernized	J. Reinmann (216)433-4000	All year	Being modernized
	(b) AWT Rehabilitation	FSC, I, MS, H, CFC, P	R E, FR, SI	Wind tunnel	D - 20 ft, D - 18 ft	d_u - 15 ft, d_u - 30 ft	5 knots to M 0.9, Up to 100 knots	-15	0 to 50 000	0.2 to 3	10 to 50 (nozzles changed)	Various modern instruments	J. Reinmann (216)433-4000	All year	Proposed for 1985
A 2	Lockheed (Burbank, CA)	MS, FSC	R E	Wind tunnel	H - 4 ft, W - 2.5 ft		50 to 185 knots	-5	0	1.0 to 2.0	25 to 38	Rot cyls, oil slide (rot cyl)	F. Brown (213)847-5837	All year	[redacted]
A 3	Boeing (Seattle, WA)	MS, FSC, I	R E	Wind tunnel	H - 20 in, W - 15 in, L - 38 in	h_u - 15 in, w_u - 12 in	100 to 200 knots	15	0	0.3 to 5.0	10 to 50 (nozzles changed)	Rot cycle, oil slide (am cyl)	W. Wilder (206)342-5864	All year	
A 4	NRC (Ottawa, Canada) (a) Large Tunnel	FSC, MS, I, I	R E, FR	Wind tunnel	H - W - 4.5 ft	h_u - w_u - 3.5 ft	60 to 250 knots, 15 to 60 knots	-5	0		15 to 30 (nozzles changed)	Rot cycle, oil slide (rot cyl)	J. Stallabrass (613)993-2371	All year	Dismantled in 1979
	(b) High Speed	MS, FSC	R E	Wind tunnel	H - W - 1 ft	h_u - w_u - 10 in	50 knots to M 0.6	-20	0 to 30 000	0.2 to 2	15 to 25	Oil slide (rot cyl)	J. Stallabrass (613)993-2371	All year	
A 5	AEDC Research Cell (Arnold AFS, TN)	FSC, MS	R E	Free jet d - 1 ft	D - 3 ft	d_u - 1 ft	60 knots to M_{jet} - 0.7	-20	0 to 50 000	0.2 to 3	15 to 30	Various modern instruments (rot cyl)	J. Hunt (615)455-2611	All year	
A 6	Rosemount (Minneapolis, MN) (a) Low Speed	MS	R E	Wind tunnel	H - 6 in, W - 4 in, L - 12 in	h_u - 4.5 in, w_u - 3 in	50 to 90 knots	-20	0	0.2 to 1.5	20 to 40	Oil slide (rot cyl)	R. DeLeo (612)941-5560	All year	Rosemount use only
	(b) High Speed	MS	R E	Wind tunnel	H - 8 in, W - 11 in, L - 31 in	h_u - w_u - 4 in	50 to 490 knots	-20	0 to 10 000	0.1 to 3.0	10 to 40	Oil slide (rot cyl)	R. DeLeo (612)941-5560	All year	Rosemount use only
A 7	Frost Tunnel (Univ. of Alberta, Canada)	MS, IA	R E	Wind tunnel	D - 18 in (Octagonal), L - 3 ft	d_u - 12 in	5 to 130 knots	-20	0	4	50	Oil slide (rot cyl)	E. Gates (403)432-5180	All year	
A 8	UCLA Cloud Tunnel	MS, CP	R E, R	Vertical wind tunnel	H - W - 6 in, L - 20 in	h_u - w_u - 5 in	0 to 30 knots	-20	0	0.1 to 3	2 to 50	Various modern instruments	H. Pruppacher (213)825-1038	All year	Free particle suspension

B. ENGINE TEST FACILITIES

[Note that most free jets can do wind tunnel types of tests.]

Facility no.	Facility name (location)	Types of icing tests run (a)	Weather simulated (b)	Type of facility	Size (see sketches): Test chamber	Size (see sketches): Uniform icing cloud	Range of parameters used in icing tests[c]: Air speed	Min total air temperature, °F	Altitude, ft	LWC, g/m³	Vol med drop size, µm	Instruments used for local drop size and (LWC)	Technical person to contact	Test season	Comment
B-1	AEDC (Arnold AFS, TN) (a) ETF	EDC	R E	Direct connect d - 5 ft	D - 12 or 15 ft L - 37 ft	Spray bars sized to engine	0 to M - 0.7+	-20 and lower	0 to 50 000	0.2 to 3.+	15 to 30	Various modern instruments	J. Hunt (615)455-2611	All year	----------
	(b) Free Jet	CPU, FSC, I, MS	R E	Free jet d - 5 ft	D - 12 or 15 ft L - 37 ft	Spray bars sized to engine	0 to M - 0.7+	-30 and lower	0 to 50 000	0.2 to 3.+	15 to 30	Various modern instruments	J. Hunt (615)455-2611	All year	----------
	ASTF	CPU, FSC, I	R E	Free jet d - 9 ft	D - 28 ft L - 60 ft	Spray bars sized to engine	0 to M - 0.7+	-30 and lower	0 to 50 000	0.2 to 3.+	15 to 30	Various modern instruments	W. Bates (615)455-2611	All year	Planned for 1983
B-2	Detroit Diesel Allison (Indianapolis, IN) (a) Comp. Test Facility	EDC, CPU	R E	Free jet / Direct connect d - 1.5 ft	D - 15 ft L - 30 ft	Spray bars sized to engine	0 to M - 0.7+	-30 and lower	0 / 0 to 20 000	0.2 to 3.5	15 to 40	Rotating cylinders	W. Stiefel (317)243-4060	All year	----------
	(b) Small Engine Facility	EDC	R E	Direct connect	D - 1.5 ft L - 4 ft	Spray bars sized to engine	0 to M - 0. +	-20	0 to 20 000	0.2 to 3.0	15 to 40	Rotating cylinders	W. Stiefel (317)243-4060	All year	----------
B-3	GE Cross-wind Facility (Peebles, OH)	CPU, P[d], R[d]	R E	Free jet outdoors d - 23 ft	Outdoors	d_u - 15 ft	50 knots	Ambient air to 8	0	0.4 to 3.5	15 to 50	Knollenberg spectrometer (rot. cyl.)	R. Keller (513)243-4483	Winter	----------
B-4	P&W Altitude Facilities (E. Hartford, CT) (a) Large	EDC, I	R E	Direct connect	D - 18 ft L - 35 ft	Spray bars sized to engine	0 to M - 0.5	-15	0 to 20 000	0.2 to 9.0	15 to 40	Oil slide	J. Barlock (203)565-2091	All year	----------
	(b) Smaller	EDC, CPU	R E	Direct connect	D - 12 ft	Spray bars sized to engine	0 to M - 0.5	-30 and lower	-		-----	Oil slide	J. Barlock (203)565-2091	----	----------
	(c) P&W Sea Level Facility	EDC	R E	Direct connect	Varied	Spray bars sized to engine	0 to M - 0.5	-4 (ambient)	0	0.2 to 9.0	15 to 50	Oil slide	J. Barlock (203)565-2091	Winter	----------

B. Concluded. ENGINE TEST FACILITIES

[Note that most free jets can do wind tunnel types of tests.]

Facility no.	Facility name (location)	Types of icing tests run (a)	Weather simulated (b)	Type of facility	Size (see sketches): Test chamber	Size (see sketches): Uniform icing cloud	Range of parameters used in icing tests[c]: Air speed	Min total air temperature, °F	Altitude, ft	LWC, g/m^3	Vol med drop size, µm	Instruments used for local drop size and (LWC)	Technical person to contact	Test season	Comment
B.5	McKinley Climatic Lab Engine Test Cell (Eglin AFB, FL)	CPU, FSI	RE, SI, FR, R	Fan blown spray nozzle	H - 25 ft W - 30 ft L - 130 ft	s_u - 10 ft v_u - 20 ft	0 to 15 to 40 knots	30	0	0.1 to 3	12 to 60 (nozzles changed)	Particle interferometer (rot. cyl.)	R. Tolliver (904)882-3828	All year	
B.6	Naval Air Propulsion Facility (Trenton, NJ)														
	(a) Five small engine cells	CPU, I, FSI, MS	RE, SI, FR, R	Free jet d - 2 ft	H - W - 10 ft L - 20 ft	Spray bars sized to engine	0 to M - 0.7+	30 and lower	0 to 50 000	0.1 to 2	10 to 50 (nozzles changed)	Knollenberg spectrometer and OAP (rot. cyl.)	Resource Mgr (609)882-1414 ext. 373	All year	
	(b) Two large sea level cells	CPU, I, FSI, MS	RE, SI, FR, R	Free jet d - 4 ft	H - 14 ft W - 23 ft L - 58 ft	Spray bars sized to engine	0 to M - 0.7+	30 and lower	0	0.1 to 2	10 to 50 (nozzles changed)	Knollenberg spectrometer and OAP (rot. cyl.)	Resource Mgr (609)882-1414 ext. 373	All year	
	(c) Three large altitude cells	CPU, I, FSI, MS	RE, SI, FR, R	Free jet d - 4 ft	D - 12 ft L - 30 ft	Spray bars sized to engine	0 to M - 0.7+	30 and lower	-	0.1 to 2	10 to 50 (nozzles changed)	Knollenberg spectrometer and OAP (rot. cyl.)	Resource Mgr. (609)882-1414 ext. 373	All year	
B.7	Teledyne Altitude Cells (Toledo, OH)														
	(a) Chamber 1	CPU, EDI	RE, SI, FR, R	Free jet or direct connect, d - 0.7 ft	D - 9 ft L - 18 ft	Spray bars sized to engine	0 to M - 0.7+	30 and lower	0 to 50 000	Up to 3	15 to 25	Oil slide	R. Traub (419)470-3238	All year	
	(b) Chamber 2	CPU, EDI	RE, SI, FR, R		H - 8 ft W - 8 ft L - 13 ft	Spray bars sized to engine	0 to M - 0.7+	30 and lower	0 to 50 000	Up to 3	15 to 25	Rotating cylinders	R. Traub (419)470-3238	All year	
B.8	Avco Lycoming (Stratford, CT)														
	(a) Component Facility	EDI	RE, FR	Direct connect d - 1.3 ft	......	Spray bars sized to engine	0 to 200 knots	-30 and lower	0	0.1 to 3	15 to 40	Oil slide	J. Sherman (203)378-8215	All year	
	(b) Engine Test Facility	EDI	RE, FR	d - 1.3 ft	W - 12 ft H - 9 ft	Spray bars sized to engine	0 to 200 knots	-30 and lower	0	0.1 to 3	15 to 40	Oil slide	J. Sherman (203)378-8215	All year	
				d - 4 ft	Outdoors			4						Winter	
B.9	NRC Cell 4 (Ottawa, Canada)	EDI, CPU	RE, SI	Free jet or direct connect d - 2.5 ft	H - W - 25 ft	Spray bars sized to engine	0 to 350 knots	-4 and lower	0	0.2 to 2	15 to 40	Oil slide (rot. cyl.)	W. Grabe (613)993-2214	Winter	
		CPU, P		d - 7 ft			0 to 50 knots	Ambient							

C. LOW VELOCITY FACILITIES

Facility no.	Facility name (location)	Type of icing tests run (a)	Weather simulated (b)	Type of facility	Size (see sketches): Test chamber	Size (see sketches): Uniform icing cloud	Range of parameters used in icing tests[c]: Air speed	Min total air temperature, °F	Altitude, ft	LWC, g/m^3	Vol med drop size, μm	Instruments used for local drop size and LWC	Technical person to contact	Test season	Comment
C.1	NRC Helicopter Spray Rig (Ottawa, Canada)	FI, FT (helicopters in hover)	R, E, FR	Wind blown spray outdoors	D = ∞	Spray manifold h_e = 15 ft w_e = 75 ft	Ambient wind, 10 to 25 knots (gusty)	4 (ambient)	0	0.1 to 0.8	30 to 60	Oil slide (rot. cyl.)	T. Ringer (613)993-2439	Winter	May be mothballed
C.2	G. E. Cross Wind Facility (Peebles, OH)	CPU, P[d], R[d]	R, E, FR	Free jet outdoors	D = ∞	d_c = 15 ft	50 knots	-4 (ambient)	0	0.4 to 3.8	15 to 50	Knollenberg spectrometer (rot. cyl.)	R. Keller (513)243-4483	Winter	
C.3	McKinley Climatic Lab (Eglin AFB, FL) (a) Main Chamber	FS, R[d]	R, E, SI, FR, R	Fan blown spray indoors	H = 70 ft W = 250 ft L = 250 ft	Spray manifold h_e = 10 ft w_e = 30 ft	0 to 15 to [e]40 knots (depending on t_H)	-30 and lower	0	0.1 to 3	12 to 60 (nozzles changed)	Particle interferometer (rot. cyl.)	R. Tolliver (904)882-3626	All year	Largest cold room
	(b) Engine Test Cell	CPU, FSC	R, E, SI, FR, R	Fan blown spray indoors	H = 25 ft W = 30 ft L = 130 ft	Manifold h_e = 10 ft w_e = 20 ft	0 to 15 to 40 knots (depending on t_H)	-30 and lower	0	0.1 to 3	12 to 60 (nozzles changed)	Particle interferometer (rot. cyl.)	R. Tolliver (904)882-3626	All year	
	(c) All Weather Room	FSC	R, E, SI, FR, R	Fan blown spray indoors	H = 15 ft W = 22 ft L = 40 ft	Manifold h_e = 10 ft w_e = 10 ft	0 to 15 to 40 knots (depending on t_H)	-30 and lower	0	0.1 to 3	12 to 60 (nozzles changed)	Particle interferometer (rot. cyl.)	R. Tolliver (904)882-3626	All year	
C.4	U.S. Army CRREL Cold Room (Hanover, NH)	FM, MS, R, IA	R, E, SI, FR, R	Fan blown spray indoors	H = 3.5 ft W = 2.3 ft L = 5 ft		0 to 1[illegible] knots	-30 and lower	0	1 to 2.5	10 to 80	Cascade impactor	G. Ashton (603)643-3200	All year	
C.5	Mt. Washington Observatory (Gorham, NH)	FS, CP, MS	Natural icing of tied down equipment on top of mountain				0 to 100 knots (gusty)	-20 and lower	6000	Generally severe natural conditions		Rotating cylinders	J. Howe (603)466-3388	Fall to spring	

D. TANKERS FOR FLIGHT TESTS

[In addition, most airframe companies can test aircraft in natural icing.]

Fa-cility no.	Facility name (Location)	Types of icing tests run (a)	Weather simulated (b)	Time in icing at high LWC, min	Size of spray: At nominal distance L_B	Size of spray: Manifold	Range of parameters used in icing tests[c]: Air speed	Min total air temperature	Altitude, ft	LWC, g/m^3	Vol med drop size, μm	Instruments used for local drop size and (LWC)	Technical person to contact	Test season (find temp at altitude)	Comment
D.1	Air Force (Edwards AFB, CA) (a) KC-135 Tanker	FLT	ICE, N R, FR	60	At L_B = 200 ft d = 10 ft	d_s = 3.7 ft	165 to 350 knots (200 m.p.h.)	4 (ambient)	4000 to 26 000	0.05 to 4 0.5 to 32	10 to 20	Knollenberg spectrometer (")	W. Tracy (805)277-3068	All year	Drop size recently reduced
	(b) C-130 Tanker	FLT	ICE, N R, FR	60	At L_B = 200 ft d = 18 ft	d_s = 1 ft	100 to 210 knots (150 m.p.h.)	-4 (ambient)	4000 to 26 000	0.05 to 2 0.05 to 32	20 to 50 desired	Knollenberg spectrometer (")	W. Tracy (805)277-3068	All year	Planned for 1981
D.2	Army [illegible] Helicopter Tanker (Edwards AFB, CA)	FLT	ICE, R, N, FR	20	At L_B = 200 ft h = 18 ft w = 60 ft	h_s = 5.2 ft w_s = 60 ft	60 to 140 knots (90 m.p.h.)	-4 (ambient)	2000 to 12 000	0.1 to 1.0	20 to 50 desired	Knollenberg spectrometer (Leigh)	A. Todd (805)277-2271	Normally winter	Tests in progress to reduce drop size
D.3	Cessna 401 Tanker (Wichita, KA)	FLT	ICE, R, FR, N	60	At L_B = 500 ft d = 20 ft	d_s = 2 ft (V bar)	90 to 180 knots (140 m.p.h.)	4 (ambient)	1000 to 26 000	0.1 to 3.0	35 (water fog nozzles)	Gelatin slide (J&W)	D. Hazelwood (316)946-6606	All year	....
D.4	Piper Cheyenne Tanker (Lock Haven, PA)	FLT	ICE, FR, R, N	14	At L_B = 100 ft h = 10 ft w = 15 ft	h_s = 4 ft w_s = 6 ft	90 to 150 knots (130 m.p.h.)	4 (ambient)	1000 to 26 000	0.1 to 1.2	30 to 50	Gelatin slide (J&W)	T. Bryerton (717)748-6711	Not summer	....
D.5	Flight Systems T-33 Tanker (Mojave, CA)	FLT	ICE, R, FR, N	45	At L_B = 200 ft d = 5 ft	h_s = 1 ft w_s = 3 ft	125 to 175 knots (150 m.p.h.)	4 (ambient)	1000 to 26 000	0.1 to 1.0	20 to 50 desired	Knollenberg spectrometer (")	J. Ligon (805)824-4601	All year	Planned for fall of 1979

[a] Types of icing and anti-deicing tests run: CPU - complete propulsion unit, EDC - engine direct connect, FSC - full-scale aircraft component (including wing, tail, fuselage, windshield, stores, gear, etc.), MS - model scale tests and instrumentation, IA - ice adhesion, CP - cloud physics, R - rotating experiments (e.g., helicopter rotor models and propellers), G - general transport and A/C in freezing rains, FS - full scale aircraft, FLT - flight tests of aircraft, I - inlets with suction, P - complete propeller engines.

[b] Whether simulated, ICE - icing cloud environment, SI - solid ice particles, FR - freezing rain, R - rain, N - natural icing.

[c] Parameter ranges vary with conditions; request operating envelopes from contact person.

EUROPEAN ICING TEST FACILITIES

COUNTRY	FACILITY NAME LOCATION	TEST CHAMBER DIMENSIONS (M)	MAX SPEED (M/S)	MIN TEMP (°C)	MVD ICING (μm)	CLOUD LWC gm/M³	TEST MODELS/ITEMS	REMARKS
AUSTRIA (AU)	ÖVTS VIENNA	4.9 x 4.9	32	15	--	----	Full scale - automotive A/C parts.	Snow and ice tests.
FRANCE	CEAT TOULOUSE	ϕ 0.25 ϕ ≤ 1	250 80	-40	20÷30	----	Small a/c equip.	Two test section.
	CEPR SACLAY R2 CELL R3 CELL	ϕ 1.1 ϕ 2	150	-60 -60	15÷30 15÷30	0÷6 0÷10	Full scale engines - air intakes - nacelles.	Duplication of flight conditions.
	ESTABLISSEMENT TECHN. BOURGES	L=3.75÷5.5 H=3 ÷ 4.1	22÷44	-40	---	----	Large ground veh., helicopter engines & air intakes.	Steam injection - no ice tests, although possible.
	ONERA MODANE S1 MA W.T.	ϕ 8	150	-5 to -15	10÷20	0.4÷10	Full scale components (wings/tails) radomes - scale models.	According to ambient conditions - spray grid - force meas. ice accretion
ITALY	FIAT RESEARCH	3 x 4	45	-45	---	----	Ground vehicles - automotive.	No icing test until now.
FRG	VOLKSWAGEN	S=37m²	55	-35	---	----	Ground vehicles - automotive.	No icing test until now.

Note: ϕ means diameter.

S = area

EUROPEAN ICING TEST FACILITIES (continued)

COUNTRY	FACILITY NAME LOCATION	TEST CHAMBER DIMENSIONS (M)	MAX SPEED (M/S)	MIN TEMP (°C)	MVD ICING (μm)	CLOUD LWC gm/M³	TEST MODELS/ITEMS	REMARKS
UK	A&EE BOSCOMBE DOWN BLOWER TUNNEL & ICING FACILITY	Φ 1.2 Φ 1.8	140 110	-30 -30	30 30	3 3	A/C wings - engines air intakes - W/S helicopters.	LN_2 injection free air tunnel.
	ARTINGTON ICING TUNNEL	0.30 x 0.30	100	-40	---	---	Small aeronautical equipment.	Extension of engine test range under study.
	BURNLEY ALTITUDE TEST FACILITY	Φ 4	---	---	---	---	Air intakes - deicers - small helicopters	
	NGTE - CELL NO. 3 CELL NO. 3 WEST FARNBOROUGH	Φ 6.1 Φ 7.6	--- 90	--- -37	--- 20	--- 02-2.5	Engines air intakes - A/C & helicopters.	Icing conditions wet or mixed (ice & water).
SWEDEN	FFA BROMMA WIND TUNNEL	Φ 3.6	40	---	---	---	2D airfoils C=0.65m	Simulated ice accretion shapes - no icing tests until now. 2D: 1m width moulding technique.

Note: Φ means diameter
S - area

CANADIAN ICING TEST FACILITIES

FACILITY NAME LOCATION	TEST CHAMBER DIMENSIONS	MAXIMUM SPEED	MINIMUM TEMP (°C)	MVD ICING (μm)	CLOUD LWC (gms/M³)	TEST MODELS ITEMS	REMARKS
NRC, OTTAWA LOW SPEED ICING TUNNEL		-	20 to -40	15+	0-3	Wings, tail sections, propellers.	Airstream cooled by direct evaporation of ammonia - closed circuit.
NRC, OTTAWA	1 ft sq x 18 in. long	Up to M=0.9 300 kn with insert	-40	20	2	Icing instrumentation research and calibration models.	Altitude simulation to 30K.
NRC, OTTAWA HELICOPTER SPRAY RIG	Cloud 75 ft wide x 15 ft deep	Reqd wind velocity 10 mph	-25	30	0.8	Helicopters at ≈ 50 ft altitude.	161 steam nozzles used for spray.
NRC, MANITOBA ENGINE ICING TEST CELL	25 ft dia	- -	15°F depression	---	---	Engines 500 lbm/s airflow.	Ice ingestion tests - mechanical system for making ice crystals.