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A STUDY OF CARBURETOR/INDUCTION SYSTEM ICING IN GENERAL AVIATION ACCIDENTS

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16. Abstract

The purpose of this study was to perform a current assessment of the frequency and severity of carburetor/induction icing in general-aviation accidents. The available literature and accident data from the National Transportation Safety Board were collected. A computer analysis of the accident data was performed. Between 65 and 90 accidents each year involve carburetor/induction system icing as a probable cause/factor. Under conditions conducive to carburetor/induction icing, between 50 and 70 percent of engine malfunction/failure accidents (exclusive of those due to fuel exhaustion) are due to carburetor/induction system icing. Since the evidence of such icing may not remain long after an accident, it is probable that the frequency of occurrence of such accidents is underestimated; therefore, some extrapolation of the data was conducted in this study. The problem of carburetor/induction system icing is particularly acute for pilots with less than 1000 hours of total flying time. The severity of such accidents is about the same as any accident resulting from a forced landing or precautionary landing. About 144 persons, on the average, are exposed to death and injury each year in accidents involving carburetor/induction icing as a probable cause/factor.

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A STUDY OF CARBURETOR/INDUCTION SYSTEM ICING IN GENERAL AVIATION ACCIDENTS

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SUMMARY

The purpose of this study was to perform a current assessment of the frequency and severity of carburetor/induction icing in general-aviation accidents. The available literature and accident data from the National Transportation Safety Board were collected. A computer analysis of the accident data was performed. Between 65 and 90 accidents each year involve carburetor/induction system icing as a probable cause/factor. Under conditions conducive to carburetor/induction icing, between 50 and 70 percent of engine malfunction/failure accidents (exclusive of those due to fuel exhaustion) are due to carburetor/induction system icing. Since the evidence of such icing may not remain long after an accident, it is probable that the frequency of occurrence of such accidents is underestimated; therefore, some extrapolation of the data was conducted in this study. The problem of carburetor/induction system icing is particularly acute for pilots with less than 1000 hours of total flying time. The severity of such accidents is about the same as any accident resulting from a forced landing or precautionary landing. About 144 persons, on the average, are exposed to death and injury each year in accidents involving carburetor/induction icing as a probable cause/factor.

INTRODUCTION

The conditions in the carburetor and induction system of aircraft engines are such that ice can be formed, even on sunny, warm days. There are ordinarily some indications to the pilot of the onset of such icing such as a decrease in RPM or manifold pressure. If the pilot does not take appropriate timely action engine malfunction/failure may occur, and at times airstart of the engine may be difficult or impossible. The pilot must be aware of the possibilities of carburetor/induction icing and routinely make proper use of carburetor heat controls. The pilot must also be aware that use of carburetor heat controls at the wrong times can also lead to difficulty.

It is generally known that carburetor/induction system icing causes a number of accidents each year. The purpose of this study is to make a current assessment of the frequency and severity of the problem, to provide a basis for determining if corrective research should be conducted.

A broad definition of "carburetor ice" will be used in this report. Generally, the term carburetor/induction system ice will be used in this report to indicate icing throughout the fuel, carburetor, or induction systems while in operation. Carburetor/induction system icing consists of three categories: (1) Impact ice, which occurs when super-cooled moisture-laden air strikes elements of the induction system. Build-up of such ice occurs when operating in snow, sleet, rain, or clouds. (2) Throttle icing, which occurs when moisture in the induction air condenses and freezes due to the expansion cooling and lower pressure as the air passes the restriction imposed by the throttle. (3) Fuel-evaporation icing, which occurs when cooling of the fuel mixture by fuel vaporization causes entrained moisture to freeze.

The current study collected available literature and accident data, and subsequently analyzed the accident data to determine the frequency of occurrence and severity of accidents for which carburetor/induction system icing was a probable cause or factor. The study included the following specific tasks: (1) establishment of available data sources, (2) search of the available literature, (3) collection of data from specific individuals and organizations, and organized data bases of accident records, (4) formation of a computer data base of relevant accident data, and (5) performance of an analysis of these data and a statistical summary. The results of these efforts, along with discussion and conclusions, are presented in this report.

SURVEY ANALYSES

Three types of searches were conducted during the course of this study: (1) a search for accident data bases relevant to the study of carburetor/induction icing in general aviation, (2) a search for published literature pertinent to aviation accident statistics, accident investigation methods, carburetor/induction system icing, engineering for icing protection, and analyses of pilot error-related accidents, and (3) a follow-up survey to determine the extent of the future use of carburetors in aircraft design.

Search for Accident Data

Based on a survey of information available in the NASA Flight Research Center Library, an initial list was made of federal aviation agencies, safety institutions, flight schools, recognized authorities, foreign agencies, and manufacturers of airframes, engines and carburetors. These sources were queried by mail or telephone: Did they have relevant information? Were they aware of data existing elsewhere? Who else would they suggest we contact? In this way, data were collected and additional sources were discovered. When no new sources were uncovered, the process was stopped, and it was assumed that complete coverage had been achieved. A list of the persons and organizations contacted is presented in Appendix A.

The search for accident data extended throughout the United States, Canada, and Mexico. While specific documents were elicited from many sources, it became clear there is but one organized general aviation accident data base which is maintained by the National Transportation Safety Board. No organized data base is maintained in Canada and Mexico. In this country, both the National Transportation Safety Board (NTSB) and the Federal Aviation Agency (FAA) conduct accident investigations, but the maintenance of a data base is the responsibility of NTSB.

As a result, the efforts of this study subsequently concentrated on familiarization with the NTSB data base and with acquisition of a subset of the data base suitable for this study. Speific training information for accident investigators was provided by the Transportation Safety Institute, Oklahoma City, Oklahoma (ref. 1) and personal contact established with NTSB personnel. A description of the data base contents is provided in references 2, 3 and 4.

Literature Search

The Southern California area is host to many fine libraries which were available for the conduct of this study. In particular, the University of California, Los Angeles; the University of Southern California, California State University, Northridge; and Los Angeles Pierce College have all been extensively searched. The National Aeronautics and Space Administration Flight Research Center Library provided many aviation-specific documents these other sources could not. As might be expected, the literature pertinent to the topic of this study is not large. The References and Selected Bibliography of this report presents the results of the search of these libraries.

Many of these documents influenced the conduct of this study: however, three are selected for specific comment in this report:

Special Study: Carburetor Ice in General Aviation (Ref. 5).- The authors cite that: "During the latest 5-year period for which complete data are available, there was a total of 360 general aviation accidents involving carburetor ice as a probable cause or factor. There were 40 fatalities and 160 persons injured, 40 of them seriously, in these accidents. The number of persons exposed to death or injury in these accidents was 636; 47 aircraft were destroyed and 313 others substantially damaged."

The blame for these accidents is laid squarely on the pilot, stating that these can be attributed to the pilot in virtually all cases. Further, carburetor icing is considered by NTSB as one of the "unnecessary" causal factors in general aviation accidents, since "carburetor icing can be avoided because the means to preclude it are readily available." While it may be true that the pilot has the means to prevent carburetor icing, consider the following complex procedures which are recommended in this document to avoid such icing:

"1. Periodically check carburetor heat systems and controls for proper condition and operation.

"2. Start engine with carburetor heat control in the "cold" position, to avoid possible damage to the carburetor heat system.

"3. As preflight item, check carburetor heat availability by noting heat "on" power drop.

"4. When the relative humidity is above 50 percent and the ambient temperature is below 299.8°K (80°F), use carburetor heat immediately before takeoff. In general, carburetor heat should not be used during taxi because of possible foreign matter entry when intake air is unfiltered in the "alternate" or carburetor heat "on" position.

"5. Conduct takeoff without carburetor heat unless extreme carburetor icing conditions are present, when carburetor heat may be used if approved by aircraft manufacturer, and when conditions are such that there will still be ample power for takeoff without incurring engine overheat damage.

"6. Remain alert for takeoff for indications of carburetor icing, especially when the relative humidity is above 50 percent, or when visible moisture is present.

"7. With supplemental instrumentation, such as a carburetor air temperature gage, partial carburetor heat should be used as necessary to maintain gage temperatures to forestall icing. Without such instrumentation, use full heat but only intermittently if considered necessary.

"8. If carburetor ice is suspected of causing a power loss, immediately apply full heat. Do not disturb throttle initially, since throttle movement may kill engine if heavy icing is present. Watch for further power loss to indicate effect of carburetor heat, then rise in power as ice melts.

"9. In case carburetor ice persists after a period of full heat, gradually move throttle to full open position and climb aircraft at maximum rate available in order to obtain greatest amount of carburetor heat. If equipped with mixture control, adjust for leanest practicable mixture, (approach this remedy with caution - although carburetor ice generally serves to enrich mixture, the reverse can be true; if the engine is lost through excessive leaning, an airstart might be impossible with an iced induction system).

"10. Avoid clouds as much as possible.

"11. In severely iced conditions, and when equipped with mixture control, backfiring the engine can sometimes be effective in dislodging induction system ice. With carburetor heat control "off", lean engine while at full throttle (observe caution note in No. 9, above).

"12. Consider that carburetor icing can occur with ambient temperature as high as 310.9^{o}K (100^{o}F) and humidity as low as 50 percent. Remain especially alert to carburetor icing possibilities with a combination of ambient temperature below 294.3^{o}K (70^{o}F) and relative humidity above 80 percent. However, the possibility of carburetor ice decreases in the range below 273.1^{o}K (32^{o}F). This is because of (a) lessened humidity as the temperature decreases, and (b) at around 263.7^{o}K (15^{o}F) any entrained moisture becomes ice crystals which pass through the induction system harmlessly. It should be remembered that if the intake air does contain these ice crystals, carburetor heat might actually cause carburetor icing by melting the crystals and raising the moisture-laden air to the carburetor icing temperature range.

"13. Prior to closed-throttle operation, such as for a descent, apply full heat and leave on throughout throttled sequence. Periodically, open throttle during extended closed throttle operation so that enough engine heat will be produced to prevent icing. Be prepared to remove carburetor heat if go-around is initiated.

"14. Return control to "cold" position immediately after landing. If carburetor heat should be further required, observe ground operation precaution in (4), above."

The above routing use of carburetor heat, and the awareness of possible icing conditions in the induction system, are probably not appreciated by any but the more experienced pilots. Consequently, this special study by NTSB was produced to improve pilot awareness, attention, and/or carefulness to reduce the number of accidents of this type.

Aircraft Carburetor Icing Studies (Ref. 6).- The National Research Council of Canada conducted an investigation into the prevention of carburetor icing in aircraft by the use of gasoline-soluble inhibitors. In addition to, or instead of, using gasoline additives, the possibility of treating interior components of the carburetor on which ice is formed was investigated.

An engine test procedure was developed that (1) produced sufficient carburetor ice to affect engine performance, and (2) allowed engine performance to be monitored. It was possible to select temperature, humidity, and throttle plate settings to give the most severe icing conditions.

The importance of this study is that it established a basis for hoping that the best possible solution to the problem of carburetor icing can be achieved -- that of eliminating the problem. In this study the use of a teflon-coated throttle plate was studied and found to virtually eliminate any ice formation on the plate. The use of ethylene glycol monomethyl ether at 0.10 - 0.15 percent by volume in the gasoline and the teflon-coated plate was shown to prevent both carburetor and fuel system icing. Coating the shaft at the point where it enters the barrel wall may be required to eliminate all ice deposits.

Icing-Protection Requirements for Reciprocating-Engine Induction Systems (Ref. 7).- This study provides an extensive and comprehensive discussion of the various types of icing associated with the generic term of "carburetor icing", and, from these investigations, establishes criteria for safe operation and for design of new induction systems.

The opinion is reinforced that "the symptoms associated with induction-system icing are not always discernible and recognition of icing conditions generally requires considerable operational experience." And, "The icing problem remains a serious hazard, despite the fact that the induction systems on most licensed aircraft are capable of providing sufficient protection in all weather conditions if the protection is correctly applied and at the proper time". Further, a study by Weick (ref. 8) of light-airplane power plant failures in 1947 is cited, in which it is indicated that "34 percent of the forced landings were caused by ineffective carburetor heat or by non-application or improper application of carburetor heat". This analysis was based on one-seventh of the total 9253 privately operated airplane mishaps recorded by the Civil Aeronautics Board for the year.

The methods and techniques for this research are presented, including both airborne and ground-based test installations. The temperature and the pressure of the air supplied to either the airborne or ground-based induction system were carefully controlled and measured at the carburetor inlet. Moisture content of the air was regulated by steam jets to control humidity and by water sprays to provide water in excess of saturation. Instrumentation was provided to measure rates of air flow, fuel flow, and simulated rain injection, as well as carburetor and supercharger pressures, carburetor metering pressures, and other variables affected by icing.

This study also reflects on a possible approach to the carburetor icing problem: displaying information to the pilot which will allow him to more readily detect and diagnose carburetor/induction system icing. It is pointed out that numerous instruments have been designed for this purpose, including (1) interruption of a light beam focussed on a photocell, (2) the blocking of special air passages to upset a pressure-differential system, (3) a comparison of pressure drop through an ice-free air passage and the induction system, and (4) the change in capacitance between charged plates due to icing.

The authors conclude that none of these ice detectors is entirely satisfactory because of the difficulty in locating the sensing elements in positions in which they will register any type of icing. Further, many detectors have been erratic and indicate falsely. The authors feel that "a suitable ice detector must be an extremely reliable instrument to retain pilot confidence." In general, the use of ice-warning devices had been unsatisfactory and none had been accepted for general use at that time (circa 1950).

Trends in the Future Use of Carburetor-type Aircraft

While fuel-injected engines retain the danger of induction system icing, the danger of icing in a carburetor is removed. High-performance engines using fuel injection are available in general aviation. If fuel-injected engines were to eventually exclude carburetor designs from future aircraft, then the nature of the carburetor/induction system icing problem could change. To test this hypothesis, and to collect data on future trends in aircraft manufacture, a questionnaire was sent to the major airframe manufacturers to determine their future plans. Unfortunately, the attempt was fruitless, and no meaningful data were collected in regard to this question. Informal communication with the four major engine manufacturers (Continental, Franklin, Avco-Lycoming, and Pratt & Whitney) indicate a desire to increase production of fuel-injection-type engines, but the situation is not expected to change in the near future. Examination of existing aircraft designs and lists of available engine types for future design indicates that the carburetor-type aircraft will predominate in the near future.

THE COMPUTER DATA BASE

The computer data base was formed using data provided on magnetic tapes by the Safety Analysis Division, Bureau of Aviation Safety, National Transportation Safety Board, Department of Transportation. Data were requested on all accidents involving engine malfunction/failure in general aviation from 1968 through 1973. The magnetic tapes provided were compatible with the IBM 360 computer system on which they were produced, and therefore required conversion to run on the CDC Cyber 70 computer system at the NASA Flight Research Center.

The information potentially contained for each accident in the data base is shown in Figure 1 in the form of the analysis sheet which is completed by the accident investigator and subsequently key-punched for computer entry. While only 55 of over 350 data items are mandatory for each accident, the total amount of data is large and much is unnecessary for this study. Consequently, to increase the efficiency of analysis, the data base was reduced in content and number of accidents.

First, the content of each accident record was reduced to those items of information relevant to the current study. The 41 items selected are presented in Table I. The codes used for those items which are not entered directly as a numerical quantity are given in Table II.

Secondly, only accident records for the years 1969 through 1973 were retained (five years). Accident records for the few accidents which occurred outside the continental United States were also discarded, as most of these contained very little information. Also, only accident records for fixed-wing aircraft with reciprocating engines were retained. It was believed that the problems of rotary-wing aircraft were inconsistent with the problems of fixed-wing aircraft. Only reciprocating-engine-type aircraft accidents were retained, since the term "carburetor ice" does not apply to turbine engines.

Lastly, accident records which involved fuel exhaustion were removed from the data base since (1) a large number of engine-malfunction/failure accidents are due simply to running out of gasoline (approximately 170 accidents per year), and (2) such accidents are irrelevant to a study of carburetor icing. The final data base contained 3555 records of the original 5930 records.

Summary.- The final data base of 3555 records is characterized by the following conditions:

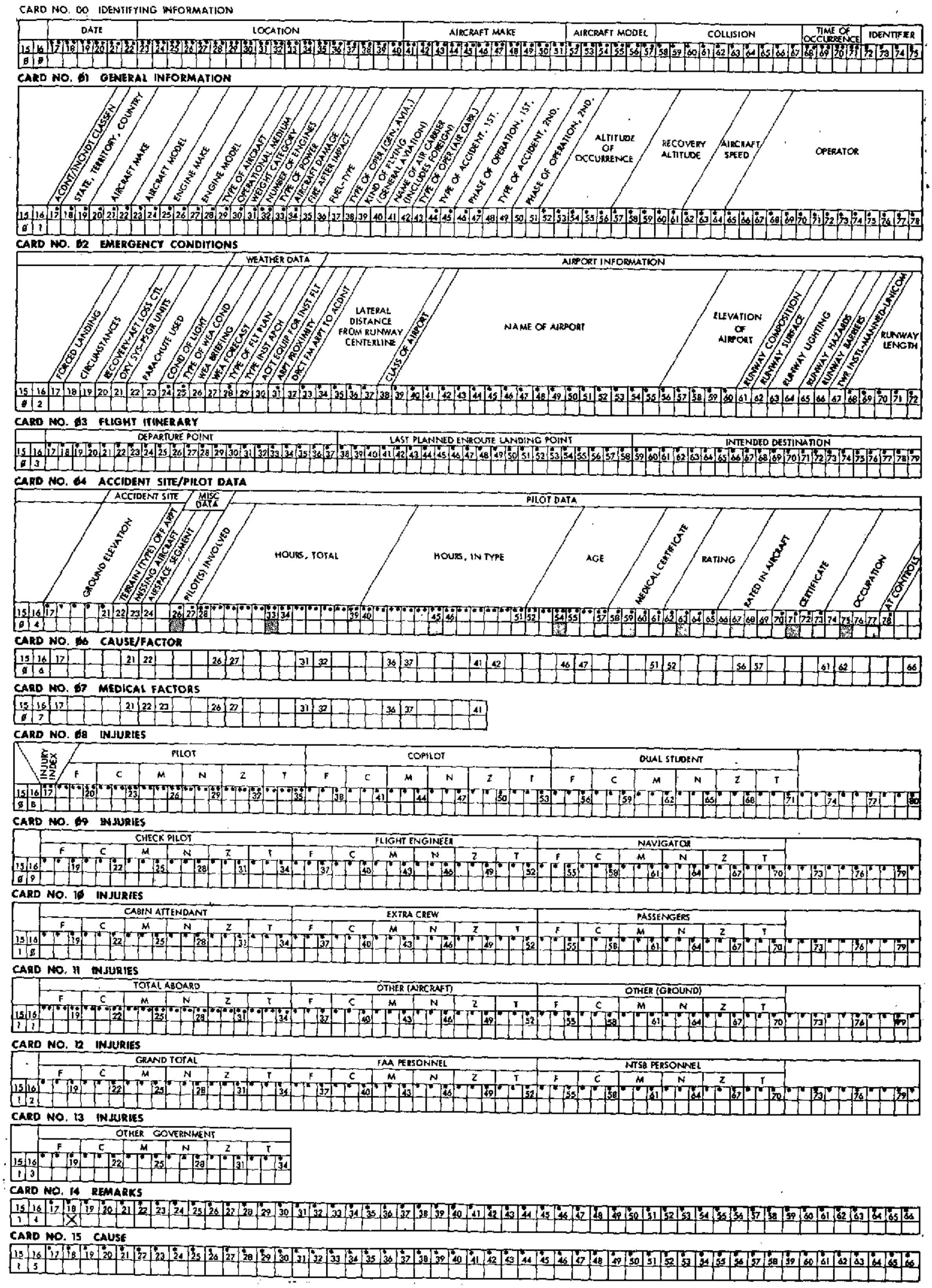

Figure 1. (page 1 of 3)

CARD NO. 17 ENGINE-PROPELLER FAILURE DATA

Columns 15–77 (card no. 1 7 in columns 15–16)

- PARTIAL POWER LOSS (ENGINE(S))
- COMPLETE FAILURE (ENGINE(S))
- SIMULATED FLAMEOUT/ENG. SHUT-DOWN
- PROPELLERS - PART I
- PROPELLERS - PART II
- ENGINE SEIZURE
- TIME SINCE OVERHAUL:
  - AIRFRAME
  - #1 ENGINE (OR SINGLE ENGINE)
  - #2 ENGINE
  - #3 ENGINE
  - #4 ENGINE
  - #1 PROPELLER
  - #2 PROPELLER
  - #3 PROPELLER
  - #4 PROPELLER
- AIRCRAFT - TOTAL TIME
- AIRCRAFT SERIAL NUMBER

CARD NO. 18 WEATHER AT ACCIDENT SITE

Columns 15–58 (card no. 1 8 in columns 15–16)

- CLOUD CONDITION
- CEILING
- VISIBILITY
- PRECIPITATION
- OBSTRUCTIONS TO VISION
- WIND COMPONENT - REL. BRG. OF WIND
- DEW POINT
- RUNWAY VISUAL RANGE
- GENERAL WEATHER
- TEMPERATURE
- WIND DIRECTION
- WIND VELOCITY
- APPROACH AIDS AVAILABLE:
  - PRECISION APPROACH (PAR)
  - SURVEILLANCE APPROACH (ASR)
  - INST LAND SYS (ILS) COMPLETE SYS
  - ILS - GLIDE PATH ONLY
  - LOCALIZER - ONLY
  - VISUAL APPROACH SLOPE INDICATOR
  - TACAN
  - VOR - (TVOR)
  - NONDIRECTIONAL RADIO BEACON
  - LOW FREQ RADIO RANGE
  - APPROACH LIGHTING (AVAILABLE)
  - APPROACH LIGHTING SYSTEM
  - LAND. WX. MINIMA (CATEGORIES)

CARD NO. 19 FLIGHT CREW DATA

Columns 15–74 (card no. 1 9 in columns 15–16)

- INSTRUMENT TIME, ACTUAL
- INSTRUMENT TIME, SIMULATED
- SIMULATOR TIME, (TYPE INVOLVED)
- ACTUAL INSTRUMENT TIME (LAST 30 DAYS)
- NIGHT TIME (TOTAL)
- PILOT TIME (LAST 24 HOURS)
- PILOT TIME (LAST 30 DAYS)
- PILOT TIME LAST 90 DAYS
- DURATION THIS FLIGHT
- ON DUTY TIME
- REST PERIOD PRIOR TO FLIGHT
- NAME OF PILOT
- CERTIFICATE NUMBER

CARD NO. 20 HUMAN FACTORS

Columns 15–70 (card no. 2 0 in columns 15–16)

- RESULTS OF TOXICOLOGY EXAMINATION (PILOT)
- ALCOHOL CONTENT - RANGE (PILOT ONLY)
- IMPACT SEVERITY
- IMPACT ANGLE
- RATE OF DECELERATION
- DIRECTION OF PRINCIPLE DECELERATION
- STOPPING DISTANCE
- DAMAGE SEVERITY - COCKPIT
- DAMAGE SEVERITY-FW CABIN
- DAMAGE SEVERITY-CT CABIN
- DAMAGE SEVERITY-AFT CAB
- DAMAGE SEV.-IMPACT (NON-TRANS TYPE ACFT.)
- SEATING CONFIGURATION
- SEAT FAILURES-NUMERICAL SUMMARY
- SEAT BELT FAILURES - NUMERICAL SUMMARY
- DEATHS RESULTING FROM FIRE AFTER IMPACT
- EVACUATION CHUTE/SLIDE
- ROPE
- LADDER
- EMERGENCY EXITS
- EMERGENCY LIGHTS (ACFT)
- OUTSIDE ASSISTANCE
- MEANS OR MEHTOD OF EXIT
- OCCUPANTS - EVACUATED - NUMERICAL SUMMARY
- OCCUPANTS - NOT EVACUATED
- EVACUATION TIME
- ATTITUDE AT IMPACT (ROLL, PITCH, YAW)
- SPEED AT IMPACT
- AUTOPSY/TOXICOLOGY

CARD NO. 21 FIRE INFORMATION

Columns 15–54 (card no. 2 1 in columns 15–16)

- AIRCRAFT FIRE EXTINGUISHER SYSTEM
- FIRE WARNING SYSTEM
- LOCATION OF FIRE
- CRASH FIRE INERTING SYSTEM
- FIRE EXTINGUISHING AGENTS USED:
  - (ACFT-FIXED)
  - (ACFT-PORTABLE)
  - GROUND
- FLARES
- FIRE DAMAGE (ACFT)
- GROUND FIRE FIGHTING EQUIPMENT
- EQUIPMENT INSTALLED/WT & BAL:
  - AUTO PILOT
  - APPROACH COUPLER
  - FLIGHT RECORDER
  - RADAR (AIRBORNE WEATHER)
  - ANTI-ICING DE-ICING:
    - ENGINE
    - PROPELLER DE-ICING
    - WING AND EMPENNAGE
    - WINDSHIELD
  - OXYGEN SYSTEM
  - STALL WARNING INDICATOR
  - GROSS WEIGHT
  - CENTER OF GRAVITY
  - PROPERTY DAMAGE
  - CRASH LOCATOR BEACON
  - STABILITY AUGMENTATION
  - COCKPIT VOICE RECORDER
  - ELECTRIC COMMAND CONTROL SYSTEM
  - ENVIRONMENTAL CONTROL SYS
  - INERTIAL NAVIGATION SYS
  - AIRBORNE INTEGRATED DATA SYS
  - MAINT & DETECT ANALYSIS RECORDER
  - HEADS-UP-DISPLAY

CARD NO. 23 ADMINISTRATIVE DATA

Columns 15–73 (card no. 2 3 in columns 15–16)

- INVESTIGATOR IN CHARGE (NTSB)
- TYPE OF ACCIDENT RELEASE
- DATE - CASE RECEIVED IN RECORDS
- DATE - CASE RECEIVED IN ANALYSIS
- DATE - ANALYSIS COMPLETED
- ANALYST NUMBER
- DATA CLASSIFICATION
- INVESTIGATION CODE

Figure 1. (page 2 of 3)

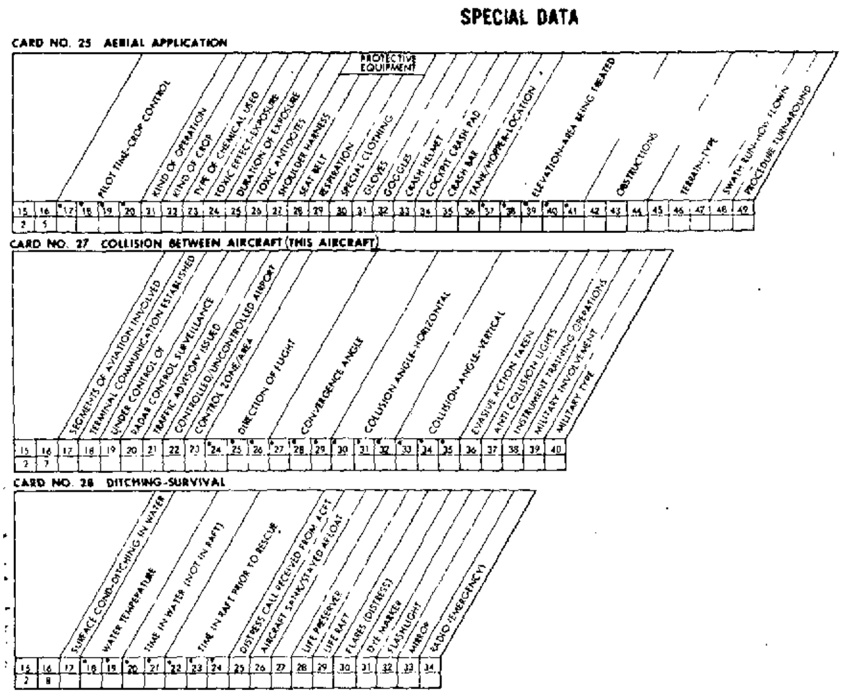

Figure 1. (page 3 of 3)

Aircraft Analysis Sheet (from Manual of Code Classifications, Aircraft Accidents and Incidents, National Transportation Safety Board, Department of Transportation, Washington, D.C., June 1970, Third Edition).

TABLE I
ACCIDENT FILE CONTENTS

NO.	LABEL	CHAR	FORMAT	NAME
001	FILENO.	5	F5.0	FILE NUMBER
002	MONTH	2	F2.0	MONTH OF ACCIDENT
003	YEAR	2	F2.0	YEAR " "
004	HOUR	2	F2.0	HOUR " "
005	LOC	2	F2.0	LOCATION OF ACCIDENT
006	ACMAKE	3	F3.0	AIRCRAFT MAKE
007	ACMOD.	2	F2.0	AIRCRAFT MODEL
008	ENGMAKE	2	F2.0	ENGINE MAKE
009	ENGMOD.	2	F2.0	ENGINE MODEL
010	NO.ENG.	1	F1.0	NUMBER OF ENGINES
011	DAMAGE	1	A1	AIRCRAFT DAMAGE
012	KIND	1	A1,1K	KIND OF FLYING
013	PHASE1	2	A1,1X	PHASE OF <u>1ST</u> ACCIDENT (TYPE = ENG.MALF./FAIL.)
014	TYPE2	1	A1	TYPE OF SECOND ACCIDENT
015	PHASE2	2	A1,1X	PHASE OF SECOND ACCIDENT
016	ALT.	5	F4.0,1X	ALTITUDE OF OCCURRENCE
017	FLAND	1	A1	FORCED LANDING
018/019	CIRCUM1/CIRCUM2	2	2A1	EMERGENCY CIRCUMSTANCES
020	TERRAIN	1	A1	TERRAIN
021	TOTHRS	5	F4.0,1X	TOTAL HOURS - PILOT
022	PLT.CNTRL	1	A1	PILOT AT CONTROL
023	INJURY	1	A1	INJURY INDEX

TABLE I

NO.	LABEL	CHAR	FORMAT	NAME
024	TOTABRD	3	F3.0	TOTAL ABOARD
025	PARTPWR	1	A1	PARTIAL POWER LOSS
026	TOTPWR	1	A1.	COMPLETE POWER LOSS
027	SKYCOND	1	A1	SKY CONDITIONS
028/029	PRECIP1/PRECIP2	2	2A1	PRECIPITATION (2 CODES)
030	DEWPTSPRD	2	F2.0	DEW POINT SPREAD
031	TEMP.	3	F3.0	TEMPERATURE
-	-	1	1X	- NOT APPLICABLE -
032	INDAIR	1	F1.0	PROBABLE CAUSE/FACTOR: INDUCTION AIR/PREHEAT CONTROLS, MISUSE
033	UNDET	1	F1.0	" " " : UNDETERMINED CAUSE
034	FUELHTR	1	F1.0	" " " : FUEL HEATER
035	CARBICE	1	F1.0	" " " : CARB. DE-ICING SYSTEM
036	FUELDEICE	1	F1.0	" " " : FUEL DE-ICING SYSTEM
037	CONDCI	1	F1.0	" " " : CONDITIONS CONDUCIVE TO CARB. ICE
038	AIEQUIP	1	F1.0	" " " : IMPROPER USE: ANTI-ICE, DE-ICE
039	ICEFUEL	1	F1.0	" " " : ICE IN FUEL
040	ICECARB	1	F1.0	" " " : ICE IN CARBURETOR
041	ICEIND	1	F1.0	" " " : ICE IN INDUCTION SYSTEM

TABLE II
ACCIDENT FILE CODES

AIRCRAFT DAMAGE

D - DESTROYED
S - SUBSTANTIAL
M - MINOR
N - NONE
Ƶ - UNKNOWN/NOT REPORTED

KIND OF FLYING

A - INSTRUCTIONAL
B - NONCOMMERCIAL
C - COMMERCIAL
D - MISCELLANEOUS

TYPE OF ACCIDENT

A	GRND/WATER LOOP/SWERVE	N	COLLISION -
B	DRAGGED WING,POD,FLOAT	O	
C	WHEELS-UP	P	BIRD STRIKE
D	WHEELS DWN LNDG - WATER	Q	STALL
E	GEAR COLLAPSED	R	FIRE OR EXPLOS
F	GEAR RETRACTED	S	AIRFRAME - FAIL
G	HARD LANDING	T	ENGINE - TEARAWAY
H	NOSE OVER/DOWN	U	ENG MALF/FAIL
I	ROLL OVER	V	PROP/ROTOR FAIL
J	OVERSHOT	W	PROP/ROTOR ACC - PERS
K	UNDERSHOOT	X	JET INTAKE EXH - PERS
L	COLLISION WITH A/C	Y	PROP/JET/ROTOR BLAST
M	COLLISION - GRND/WATER	Z	TURBULENCE

PHASE

A - STATIC
B - TAXI
C - TAKEOFF
D - INFLIGHT
E - LANDING
Ƶ - UNKNOWN/NOT REPORTED

TERRAIN

A - MOUNTAINOUS
B - HILLY
C - ROLLING
D - LEVEL, FLAT
E - FROZEN
F - ROCKY
G - SANDY
H - DENSE WITH TREES
I - CITY AREA
J - PLOWED
K - WATER
Y - OTHER
Ƶ - UNKNOWN/NOT REPORTED

PILOT AT CONTROLS

A - PILOT IN COMMAND
B - COPILOT
C - DUAL STUDENT
D - CHECK PILOT
E - NONE
F - BOTH PILOTS
Y - OTHER
Ƶ - UNKNOWN/NOT REPORTED

INJURY INDEX

F - FATAL
G - SERIOUS
M - MINOR
N - NONE
Ƶ - UNKNOWN/NOT REPORTED

PARTIAL/COMPLETE POWER LOSS

A - ONE ENGINE
B - TWO ENGINES
C - THREE ENGINES
D - FOUR ENGINES
Ƶ - UNKNOWN/NOT REPORTED

FORCED LANDING - PRECAUTIONARY LANDING

CODE

A	FORCED LANDING ON AIRPORT/SEAPLANE BASE HELIPORT
B	FORCED LANDING OFF AIRPORT ON LAND
C	FORCED LANDING OFF AIRPORT ON WATER (DITCHING)
D	PRECAUTIONARY LANDING ON AIRPORT
E	PRECAUTIONARY LANDING OFF AIRPORT
Z	UNKNOWN/NOT REPORTED

EMERGENCY CIRCUMSTANCES

CODE

A	LOW ON FUEL
B	SMOKE IN COCKPIT
C	PASSENGER DISTURBANCE
D	FALSE FIRE WARNING
E	LATERAL CONTROL PROBLEM
F	PITCH CONTROL PROBLEM
G	DIRECTIONAL CONTROL PROBLEM
H	ADVERSE/UNFAVORABLE WEATHER
I	APPROACHING DARKNESS
J	SUSPECTED OR KNOWN AIRCRAFT DAMAGE
K	SUSPECTED MECHANICAL DISCREPANCY
L	DOOR/PANEL OPEN
M	AIRFRAME BUFFET
N	UNUSUAL NOISE
P	PHYSICAL CONDITION OF PASSENGER
Q	FUMES IN CABIN
R	PROP/ENGINE VIBRATION
Z	UNKNOWN/NOT REPORTED

TABLE II

SKY CONDITION (Local weather at time of accident)

CODE

A	CLEAR
B	SCATTERED (Above 1,000 feet)
C	SCATTERED (Below 1,000 feet)
D	BROKEN
E	BROKEN/LOWER SCATTERED
F	OVERCAST
G	OVERCAST/LOWER SCATTERED
H	PARTIAL OBSCURATION
I	OBSCURATION
Z	UNKNOWN/NOT REPORTED

PRECIPITATION OF ACCIDENT SITE

CODE

A	HAIL (A)
B	SLEET (E)
C	DRIZZLE (L)
D	RAIN (R)
E	RAIN SHOWERS (RW)
F	SNOW (S)
G	SNOW GRAINS (SG)/SNOW PELLETS (SP)
H	SNOW SHOWERS (SW)
I	THUNDERSTORM (T)
J	FREEZING DRIZZLE (ZL)
K	FREEZING RAIN (ZR)
L	NONE
Z	UNKNOWN/NOT REPORTED

(1) Included accidents for the years 1969, 1970, 1971, 1972, and 1973.

(2) Included only engine malfunction/failure accidents.

(3) Included only fixed-wing, reciprocating engine accidents which occurred within the continental U.S.

(4) Excluded accidents due to fuel exhaustion.

DATA ANALYSIS

The analyses performed on the computer data base consisted primarily of crosstabulations of variables selected from the 41 variables included in the data base, and subsequent statistical analysis of the resulting comparisons. The primary tool used for this purpose was the Statistical Package for the Social Sciences (SPSS) (ref. 9). SPSS is an integrated package of programs for statistical analysis, data base management and file manipulation. Using these programs, selected variables may be transformed or recoded, new variables created through computations based on existing variables, and statistical procedures executed. This package of programs provides efficient analysis of a given data base with minimal programming effort. In addition, special-purpose statistical programs were used, and hand calculations performed in selected cases. The principal results of all analyses are summarized in the following sections.

Examination of Aircraft and Engine Makes Under Conditions Conducive to Carburetor/Induction System Icing

As part of an initial examination of the data base to determine data base variables important to the study of carburetor/induction system icing, aircraft makes and engine makes were compared under conditions conducive and not conducive to carburetor/induction system icing. One of the cause/factor variables included in the data base was an indication of whether the accident investigator considered the conditions conducive to carburetor icing. For the present it is assumed that the conditions are not conducive to icing if the accident investigator did not indicate such conditions existed; the validity of this assumption will be discussed later.

The results comparing aircraft makes are presented in Table III, while the results for engine makes are given in Table IV. As no practical or statistical significance exists between the major manufacturers of either airframes or engines, no distinction between makes was carried through the subsequent analyses. These results contradict informal reports that specific manufacturers produced designs more or less prone to carburetor icing difficulties.

Probable Cause/Factor by Year

Selected causes/factors, indicated by the accident investigator, are tabulated in Table V by year. The causes/factors selected are: (1) induction air, preheat cockpit controls, (2) power plant failure for undetermined reasons, (3) anti-icing, de-icing, and carburetor de-icing systems,

TABLE III
COMPARISON OF AIRCRAFT MAKE SENSITIVITY TO
CARBURETOR/INDUCTION SYSTEM ICING CONDITIONS

AIRCRAFT MAKE	NO. OF ACCIDENTS THAT OCCURRED UNDER - CONDITIONS CONDUCIVE TO ICING*	NO. OF ACCIDENTS THAT OCCURRED UNDER - OTHER CONDITIONS	PERCENT OF TOTAL ACCIDENTS THAT OCCURRED UNDER CONDITIONS CONDUCIVE TO ICING
A	13	88	12.9
B	17	298	5.4
C	126	989	11.3
D	7	43	14.0
E	11	84	11.6
F	97	935	9.4
G	5	39	11.4
H	8	73	9.9
Other	32	690	4.4

*As defined by the accident investigator.

TABLE IV
COMPARISON OF ENGINE MAKE SENSITIVITY TO
CARBURETOR/INDUCTION SYSTEM ICING CONDITIONS

AIRCRAFT MAKE	NO. OF ACCIDENTS THAT OCCURRED UNDER - CONDITIONS CONDUCIVE TO ICING*	NO. OF ACCIDENTS THAT OCCURRED UNDER - OTHER CONDITIONS	PERCENT OF TOTAL ACCIDENTS THAT OCCURRED UNDER CONDITIONS CONDUCIVE TO ICING
A	6	86	6.5
B	144	1376	9.5
C	153	1437	9.6
D	7	246	2.8
E	3	37	7.5
Other	3	57	5.0
Total	316	3239	8.9

*As defined by the accident investigator.

(4) weather conditions conducive to carburetor/induction system icing, (5) improper use, or failure to use, anti-icing de-icing equipment, (6) ice in fuel, (7) ice in carburetor, and (8) ice in the induction system. More than one (usually five or more) cause/factor may be indicated by the investigator for a given accident.

A number of results accrue from examination of Table V:

(1) There is a statistically significant trend for accidents within the selected data base to decrease over the five year period examined ($P<.05$).

(2) Relatively few accidents involve identifiable failures of the controls and systems associated with carburetor/induction system icing.

(3) There are a large number of powerplant failures for undetermined reasons.

(4) There are approximately 65 accidents per year, on the average, for which evidence of ice is found in the fuel or induction system.

(5) The number of cases for which ice in the carburetor is cited as a probable cause/factor often exceeds the number of cases for which it is cited that conditions are conducive to carburetor/induction system icing. Apparently the investigators may omit indicating that the conditions are conducive to carburetor icing when other, more specific, evidence exists.

Composite Carburetor/Induction Ice Cause/Factor

It was noted in Table V that a number of probable causes/factors may be indicated by the accident investigator either singly or in combination. A composite cause/factor was formed to avoid this confusion. The composite indicator was defined as a probable Carburetor/Induction Ice Cause/Factor <u>if</u> any of the following cause/factors were noted by the accident investigator: (1) induction air/preheat controls, <u>or</u> (2) the carburetor de-icing system, <u>or</u> (3) improper use of anti-ice/de-ice equipment, <u>or</u> (4) ice in the carburetor, <u>or</u> (5) ice in the induction system.

The composite carburetor/induction ice cause/factor (C/I Ice Cause/Factor) is tabulated in Table VI over the five year period included in this study. While the number of carburetor/induction system ice accidents may appear to decrease over the five year period (as did the total number of accidents in the data base) the number of accidents in years 1969 and 1970 are not statistically significant from the number in years 1972 and 1973 ($P<.33$). Based on the composite index, the number of such accidents averages 74 per year.

TABLE V
ACCIDENTS WITH ICING AS PROBABLE CAUSE/FACTOR BY YEAR

PROBABLE CAUSE OF ACCIDENT	YEAR 1969	1970	1971	1972	1973	Total
	Number of Accidents					
Misuse of induction air, preheat cockpit controls	5	0	1	1	1	8
Powerplant failure - reason undetermined	206	228	203	158	173	968
Carburetor de-icing system malfunction	1	7	1	2	3	14
Conditions conducive to carburetor/induction system icing	79	47	70	65	55	316
Improper operation - failed to use anti-icing/de-icing equipment	85	58	64	69	50	326
Ice in fuel	4	3	7	8	4	26
Ice in carburetor	82	59	70	63	52	326
Ice in induction system	2	1	3	1	4	11
Total	760	730	730	661	674	3555

TABLE VI
COMPOSITE C/I ICE CAUSE BY YEAR

		YEAR 1969	1970	1971	1972	1973	Total
		Number of Accidents					
WAS C/I ICE CAUSE OF ACCIDENT?*	No	666	659	658	587	615	3185
	Yes	94	71	72	74	59	370
	Total	760	730	730	661	674	3555

*Composite C/I Cause: Misuse of induction air/preheat controls, carburetor de-icing system malfunction, improper use of de-icing system, ice in carburetor, or ice in induction system.

Also, as previously noted in Table V, Table VII indicates that a large number of carburetor/induction system icing accidents are not noted by many investigators as occurring when the conditions are conducive to icing; consequently, a better indicator of the conditions appropriate to such accidents must be constructed.

Pilot Experience as a Factor in Carburetor/Induction System Icing Accidents

Pilot experience, in terms of total number of flying hours, is cross-tabulated with the composite C/I Ice Cause/Factor in Table VIII. The percent of carburetor/induction ice accidents decreases with the total number of pilot hours; however, the decrease is statistically significant ($P<.05$) only for pilot hours greater than 1,000 hours. Stated in other terms, only pilots with over 1,000 hours experience seem to possess the skill and knowledge to perform significantly better in avoiding carburetor/induction system icing than pilots with less than 1,000 hours total flying time. About 68% of the carburetor/induction icing accidents involve pilots with less than 1,000 total hours.

TABLE VII
COMPOSITE C/I ICE CAUSE BY INVESTIGATOR'S JUDGMENT THAT CONDITIONS ARE CONDUCIVE TO C/I ICE

		Were Conditions Conducive to C/I Ice? (Investigator's Judgment)		
		No	Yes	
		Number of Accidents		Total
WAS C/I ICE CAUSE OF ACCIDENT?*	No	3173	12	3185
	Yes	66	304	370
	Total	3239	316	3555

*Composite C/I Ice Cause: Misuse of induction air/preheat controls, carburetor de-icing system malfunction, improper use of de-icing system, ice in carburetor, or ice in induction system.

TABLE VIII
EFFECT OF PILOT EXPERIENCE ON C/I ICE AS
ACCIDENT CAUSE/FACTOR

Pilot Experience Hours	Total Accidents for Experience Range	Cause of Accident			
		C/I Ice		Other	
		Number of Accidents	Percent of Total Accidents	Number of Accidents	Percent of Total Accidents
10 to 100	477	70	14.7	407	85.3
100 to 500	1000	125	12.5	875	87.5
500 to 1000	519	55	10.6	464	89.4
>1000	1559	120	7.7	1439	92.3
>10	3555	370	10.4	1559	89.6

Composite Indicator to C/I Ice Conditions

As previously noted, there is reason to believe that conditions are appropriate for carburetor/induction system icing more often than indicated by the accident investigators. A composite indicator (Conditions Appropriate) was constructed based on the following: (1) conditions were considered appropriate by the accident investigator, or (2) there was an indication of precipitation at the accident site, or (3) the temperature and dew point were within the profile presented in Figure 2. The temperature/dew point profile of Figure 2 is generated by the Department of Transportation (taken from Gardner and Moon, 1971); the solid line profile was that used in the computer implementation and is to be considered an approximate indicator of the existence of conditions appropriate for carburetor icing. Unfortunately, the existence of temperature/dew point data was rare in the NTSB data base.

The number of accidents occurring when conditions are appropriate for icing according to the composite indicator are presented in Table IX. Approximately 18% of the accidents in the reduced data base used in this study occurred when the conditions were conducive to carburetor/induction system icing. Based on these data, one may estimate the maximum number of accidents due to this cause at about 128 per year.

It is interesting to note in Table X that about 13% of the accidents for which the cause is undetermined occur when the conditions are appropriate for carburetor/induction icing.

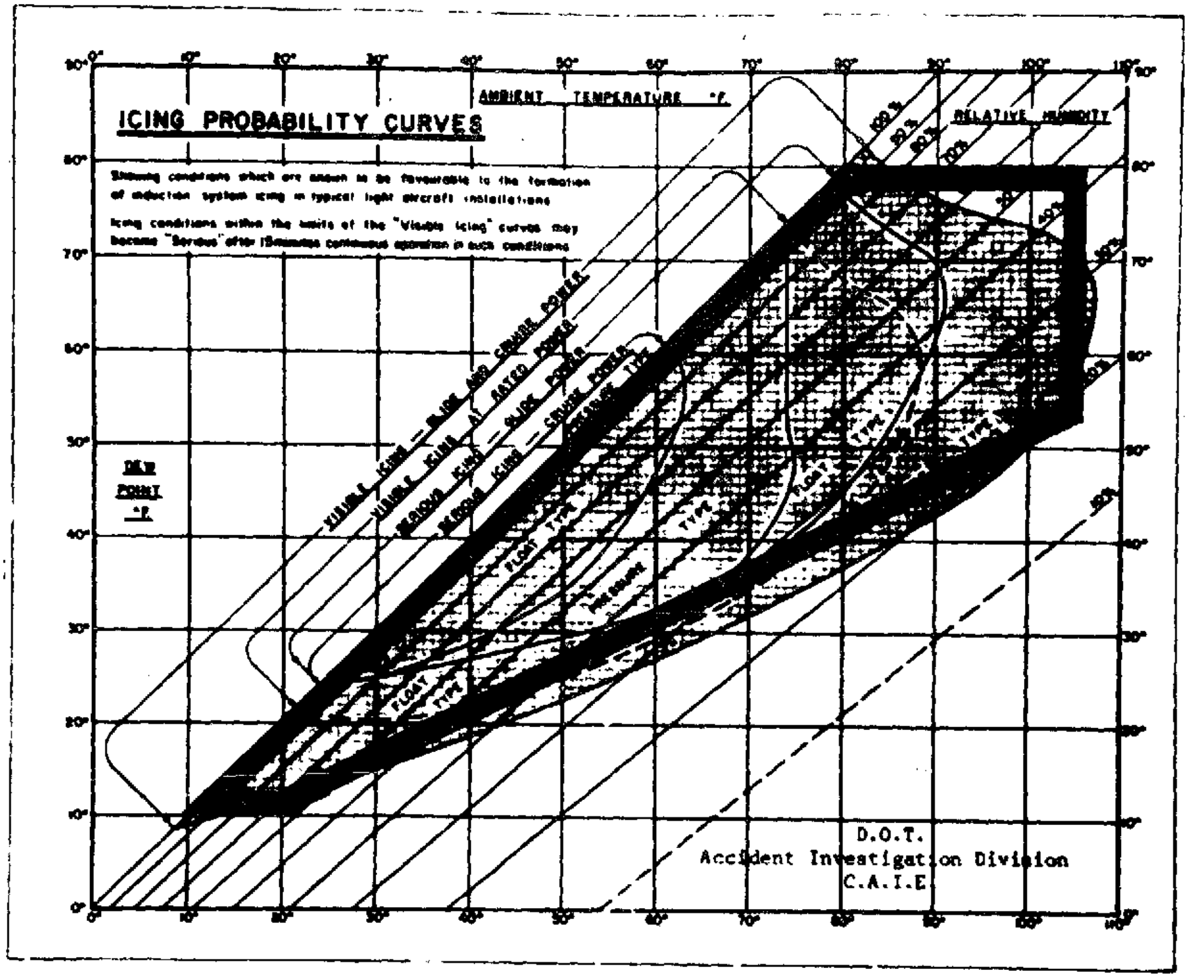

Figure 2. DOT Icing Probability Curves. (The heavy solid line is the profile implemented in the computer analysis.)

TABLE IX
NUMBER AND PERCENTAGE OF ACCIDENTS THAT OCCURRED UNDER CONDITIONS APPROPRIATE FOR C/I ICE* BY YEAR

(Year(s)	Total Accidents for Year(s)	Were Conditions Appropriate for C/I Ice?			
		Yes		No	
		Number of Accidents	Percent of Total Accidents	Number of Accidents	Percent of Total Accidents
1969	760	126	16.6	634	83.4
1970	730	134	18.4	596	81.6
1971	730	121	16.6	609	83.4
1972	661	144	21.8	517	78.2
1973	674	113	16.8	561	83.2
1969 to 1973	3555	638	18.0	2917	82.0

*Conditions appropriate for C/I ice: Indicated by accident investigator, temperature/dew point within profile, or precipitation at accident site.

TABLE X
NUMBER AND PERCENTAGE OF ACCIDENTS THAT OCCURRED UNDER CONDITIONS APPROPRIATE FOR C/I ICING* BY CAUSE DETERMINATION

	Number of Accidents	Percent
Number of accidents for which cause was determined	2587	100
Number of these accidents for which conditions were appropriate for C/I icing	511	14.4
Number of these accidents for which conditions were not appropriate for C/I icing	2076	85.6
Number of accidents for which cause was not determined	968	100
Number of these accidents for which condition was appropriate for C/I icing	127	13.1
Number of these accidents for which conditions were not appropriate for C/I icing	841	86.9

*Conditions appropriate for C/I ice: Indicated by accident investigator, temperature/dew point within profile, or precipitation at accident site.

Analysis of Accidents Occurring Under Conditions Conducive to C/I Ice

Table XI presents an analysis of accidents occurring during conditions conducive to carburetor/induction icing. At least 319 out of a total of 638 accidents are attributable to carburetor/induction icing, or about 50%. Another 127 accidents occurring under appropriate conditions are due to undetermined reasons. Thus a total of 446 accidents might be due to such icing causes, or an estimated maximum of 70%; it might be expected that about 50% of these are due to carburetor/induction icing. Consequently, it may be estimated that, when the conditions are appropriate, between 50% and 70% are due to carburetor/induction system icing.

Severity of Carburetor/Induction System Icing Accidents

It should be clear that, while a number of accidents may have involved carburetor/induction system icing as a cause/factor, the flights eventually terminated with a forced landing and possible collision with a ground object. As is the case with other engine/malfunction failure accidents, approximately 80% resulted in substantial damage to the aircraft, and the remainder resulted in destroyed aircraft (see Table XII). However, as indicated in Table XIII, 230 of 370 accidents (62%) resulted in no personal injury and only 14% resulted in serious or fatal injury. The distribution of occupants involved in C/I icing accidents is presented in Table XIV; the net result is that between 720 (for C/I ice conditions) and 977 (including possible accidents with undetermined reasons) persons have been involved in such accidents over the five year period considered in this study (between 144 and 195 per year).

TABLE XI
ACCIDENT CAUSE/FACTOR BY COMPOSITE INDICATOR
OF C/I CONDITIONS

CONDITIONS APPROPRIATE FOR C/I ICE?	NUMBER OF ACCIDENTS			TOTAL
	ACCIDENT CAUSE/FACTOR			
	C/I ICE	NO C/I ICE	UNDETERMINED	
Yes	319	192	127	638
No	51	2025	841	2917
Total	370	2217	968	3555

TABLE XII
AIRCRAFT DAMAGE DUE TO C/I ICING

	NUMBER OF ACCIDENTS				TOTAL
	AIRCRAFT DAMAGE				
	MINOR	SUBSTANTIAL	DESTROYED	NOT REPORTED	
C/I ice	1	309	60	0	370
Undetermined, with C/I ice conditions	0	80	47	0	127
Other	0	2425	632	1	3058
Total	1	2814	739	1	3555

TABLE XIII
NUMBER OF ACCIDENTS INVOLVING INJURY DUE TO
C/I ICING

Accident Cause	NUMBER OF ACCIDENTS INJURY INDEX None	Minor	Serious	Fatal	Unkn.	TOTAL
C/I Ice	230	87	34	19	0	370
Undetermined, with C/I Ice Conditions	51	38	22	16	0	127
Other	1803	652	347	255	1	3058
Total	2084	777	403	290	1	3555

TABLE XIV
NUMBER OF OCCUPANTS INVOLVED IN C/I ICING ACCIDENTS

Accident Cause	NUMBER OF ACCIDENTS NUMBER ABOARD NR*	1	2	3	4	5	6	>6	TOTAL
C/I Ice	0	143	154	38	27	4	2	2	370
Undetermined, with C/I Ice Conditions	0	51	51	13	7	2	0	3	127
Other	1	1350	1030	289	281	59	23	25	3058
Total	1	1544	1235	340	315	65	25	30	3555

Accident Cause	TOTAL PERSONS INVOLVED IN ACCIDENTS
C/I Ice	720
Undetermined, with C/I Ice Conditions	257
Other	6105
Total	7082

*Not reported

DISCUSSION

The Difficulty of Diagnosing Carburetor/Induction System Icing

A fundamental problem affecting the study of the severity of carburetor/induction system icing in general aviation accidents is the inherent difficulty of diagnosing carburetor/induction icing. If ice has caused an accident, the ice will melt and the resulting water may evaporate; so, unless the investigator is astute and has an initial strong suspicion of carburetor icing, the cause/factor associated with the accident may not be properly identified.

Since this type of accident may be so easily mis-diagnosed, it is believed that the results of this study underestimate the magnitude of the problem. A broad definition of "carburetor icing" has been taken, and some reasonable extrapolations to include the probable number of "undetermined" accidents which may be carburetor icing have been made in this study. Nevertheless, it is believed that the estimates made in this study are quite conservative and that a number of additional accidents could have included carburetor/induction icing as a probable cause/factor. Further, the findings of this study concentrate on the accident data available; a large number of forced landings occur each year which are not included in the accident data base.

A Context for Data Interpretation

Over a five-year period analyzed in this study, an average of 65 carburetor ice accidents per year are identified by the accident investigators, and one may extend this estimate to approximately 90 probable carburetor/induction icing accidents per year. That is, there are about that many general aviation accidents per year which involve carburetor/induction icing; however, a number of other probable cause/factors are generally also involved.

Compared to the approximately five thousand total general aviation accidents per year, and the approximately one thousand engine malfunction/failure accidents per year, the less than one hundred carburetor/induction accidents per year may seem small. On the other hand, it must be recognized that carburetor/induction icing can only occur when the weather conditions are appropriate. Viewed in this context, the picture changes, for when the weather conditions are conducive to icing, 50 percent to 70 percent of all engine malfunction/failure type accidents (which are not due to fuel exhaustion) include carburetor/induction icing as a probable cause/factor. That is, if the weather conditions are conducive, if the engine malfunctions or fails with fuel still available to the engine, then carburetor/induction icing is involved more than half of the time.

Further, carburetor/induction system icing is a widespread problem. Such icing can occur anywhere, even at temperatures over 310.9°K (100°F), and is equally likely throughout the year. Pilots with long experience become involved in such accidents, although more than two-thirds of carburetor/induction system icing accidents involve pilots with less than 1000 hours of total flying time. Apparently, any pilot, wherever he/she may be flying, at any time of the year, may encounter carburetor/induction system icing.

Severity of Carburetor/Induction System Icing

Of course, as with many other accident causes/factors, the injurious and damaging aspects of an accident for which carburetor/induction icing is a probable cause/factor are associated with the terminating forced or precautionary landing. One hundred and forty-four persons per year, on the average, are involved in carburetor icing accidents, about 4 of these accidents involve fatalities, about 7 per year involve serious injury, and almost all of these accidents involve substantial damage or destruction of the aircraft. Consequently, carburetor/induction system icing accidents are just about as serious as any other accident involving a forced landing or precautionary landing. Other types of accidents occur more often: for example, accidents involving fuel exhaustion occur about twice as often as those involving carburetor/induction icing; but when weather conditions are conducive, carburetor/induction system icing is the most common cause for engine malfunction/failure.

CONCLUSIONS

Carburetor/induction system icing is a serious threat existing in general aviation operations. Given that fuel is available, under the proper weather conditions, which occur frequently and regularly throughout the year, carburetor/ induction icing is the most common cause of engine malfunction/ failure in general aviation. Overall, this cause amounts for about 10 percent of engine malfunction/failures, making it a major cause for concern. Carburetor/induction icing is a particular threat to the pilot with less than 1000 hours of total flying time.

While engineering analysis was not included in the current study, the review of the literature indicates a strong possibility that this problem may be solvable. The problem may yield to (1) efforts to eliminate icing through carburetor/induction system design and fuel additives, and/or (2) efforts to either increase pilot awareness through improved display of icing information or automation of the pilots function for the control of icing countermeasures. The payoff would be high: 65-90 accidents per year could be eliminated along with the attendant death, injury and damage.

The analysis of accident data is severely limited for investigation of a problem as insidious and difficult to detect as carburetor/induction icing. Further investigation of the problem is recommended using flight or ground-based facilities permitting the control of induction icing. Under controlled conditions, the ability of the pilot to detect, recognize and take proper action can be accurately assessed. It is suspected that given such data it will be found that the findings of this study, which label carburetor/induction icing as a major problem, have underestimated the magnitude and frequency of carburetor/ induction system icing occurrences.

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APPENDIX A: INFORMATION SOURCES

GENERAL SOURCES

AEROSPACE SAFETY RESEARCH AND DATA INSTITUTE (ASRDI)
AIRCRAFT OWNERS ASSOCIATION
AIR FORCE FLIGHT DYNAMICS LABORATORY (AFFDL)
AIRWORK SERVICE DIVISION
ALLEN AIRCRAFT (DIVISION OF AAR CORP.)
AMERICAN NATIONAL STANDARDS INSTITUTE
AMERICAN SOCIETY FOR NONDESTRUCTIVE TESTING
AMERICAN SOCIETY OF SAFETY ENGINEERS
ANDREWS & ASSOCIATES
ATLANTIC AVIATION CORPORATION
AUTOMOTIVE ENGINEERING (SAE JOURNAL)
AVCO (LYCOMING DIVISION) CORP.
AVQUIPO INC.
BORG-WARNER CORP. (MARVEL-SCHEBLER DIV.)
BUREAU OF AVIATION SAFETY (NTSB: WASH., D.C.)
CALIFORNIA AVIATION COUNCIL
CANADIAN CURTISS-WRIGHT LTD.
CATERPILLAR TRACTOR CO.
CHANDLER EVANS CONTROL SYSTEMS (DIV. OF COLT INDUSTRIES)
CHEMICAL PROPULSION INFORMATION AGENCY
CHRYSLER CORP., DEFENSE SPACE GROUP
CIVIL AEROMEDICAL INSTITUTE
COLT INDUSTRIES
COMBUSTION INSTITUTE
COOPER-BESSEMER
E.I. DU PONT CO.
ETHYL CORPORATION
FAA SAFETY DATA BRANCH FLIGHT STANDARDS TECHNICAL DIVISION
FEDERAL AVIATION ADMINISTRATION (LOS ANGELES)
FIELD AVIATION CO., LTD.
FLIGHT SAFETY FOUNDATION, INC.

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GUGGENHEIM CENTER FOR AEROSPACE HEALTH AND SAFETY

JET AVIATION CORP.

JOHNS HOPKINS APPLIED PHYSICS LAB

LARSON AERODEVELOPMENT

LEAVENS BROS., LTD.

MINISTRY OF (CANADIAN) TRANSPORT ACCIDENT INVESTIGATION

NATIONAL AIRCRAFT ACCIDENT INVESTIGATION SCHOOL (NAAIS)

NATIONAL INSTITUTE FOR OCCUPATIONAL SAFETY AND HEALTH

NATIONAL SAFETY COUNCIL

NATIONAL TRANSPORTATION SAFETY BOARD (NTSB)

- LOS ANGELES, CALIFORNIA
- WASHINGTON, D.C.

ELSON AIRCRAFT CORPORATION

NONDESTRUCTIVE TESTING INFORMATION CENTER

ONAN DIVISION, ONAN CORPORATION

REGIONAL INFORMATION AND COMMUNICATION EXCHANGE

SOUTHWEST RESEARCH INSTITUTE

STANDARD OIL COMPANY (OHIO)

THE OHIO STATE UNIVERSITY:

- DEPARTMENT OF AERONAUTICAL AND ASTRONAUTICAL ENGINEERING
- DEPARTMENT OF AVIATION

TRANSPORTATION SAFETY INSTITUTE

TRW EQUIPMENT, INC.

TELEDYNE CONTINENTAL MOTORS, AIRCRAFT PRODUCTS DIVISION

TRANSAERO INC.

UNITED AIRCRAFT OF CANADA, LTD.

WHITE SUPERIOR, DIVISION OF WHITE MOTOR CORPORATION

UNIVERSITY OF ILLINOIS:

- STAN ROSCOE
- JESSE STONECIPHER

ACTUARIAL SOURCES

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AERO COVERAGES, INC.

AERO INSURANCE AGENCY

AIR ASSOCIATES, INC.

AIRBANC OF AMERICA, INC.

AIRWAY CASUALTY CO.

ALEXANDER & ALEXANDER, INC.

ASSOCIATED AVIATION UNDERWRITERS

AVEMCO AIRCRAFT INVESTMENT CORPORATION

AVEMCO CORPORATION

AVIATION INSURANCE SERVICE

AVIATION OFFICE OF AMERICA, INC.

RICHARD J. BERLOW & CO., INC.

J.H. BLADES & CO., INC.

BOWES & CO., INC.

C&A FLIGHT CREW INSURANCE, INC.

CESSNA FINANCE CORP.

C.I.T. LEASING CORP.

COMMERCIAL CREDIT EQUIPMENT CORP.

CONNECTICUT GENERAL LIFE INSURANCE CO.

CONTINENTAL ASSOCIATES, INC.

DELTA AGENCIES, INC.

ELECTRA FINANCIAL GROUP

FAIRFAX UNDERWRITERS SERVICES, INC.

G. SHANNON GROVER

HARLAN INC. OF PENNSYLVANIA

HOLTON INSURANCE AGENCY, INC.

INA REINSURANCE CO.

INSURANCE CO. OF NORTH AMERICA

INTERNATIONAL AIRCRAFT SALES

INTERNATIONAL AVIATION UNDERWRITERS, INC.

KUDLICH GENERAL INSURANCE AGENCY, LTD.

MANN-KLINE, INC.

NATIONAL AVIATION UNDERWRITERS

PACIFIC INTERNATIONAL UNDERWRITERS
PARKER & CO. INTERNATIONAL, INC.
PETER J. MC BREEN & ASSOCIATES, INC.
THE SOCIETY OF ACTUARIES
TEX-WIDE INSURANCE
TRANSWORLD INSURANCE BROKERS
WRIGHT & CO.

AIRFRAME MANUFACTURERS

AERONCA, INC.
AERO RESOURCES
AERO SPORT
AMERICAN AVIATION CORPORATION
ATLANTIC AVIATION
AVCO-LYCOMING
BEECH AIRCRAFT CORPORATION
BELLANCA AIRCRAFT CORPORATION
CESSNA AIRCRAFT CO.
CONTINENTAL
ENSTROM CORPORATION
EVANGEL AIRCRAFT CORPORATION
FAIRCHILD INDUSTRIES, INC.
FRANKLIN
MAULE AIRCRAFT CORPORATION
NORTH AMERICAN ROCKWELL CORPORATION
PIPER AIRCRAFT CORPORATION
PITTS AVIATION ENTERPRISES
PRATT & WHITNEY

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BOB SHAW: NTSB

JIM WEBSTER: FAA FLIGHT STATISTICS BRANCH

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