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AN ANALYSIS OF PILOT ERROR-RELATED AIRCRAFT ACCIDENTS

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16. Abstract

A multidisciplinary team approach to pilot error-related U.S. air carrier jet aircraft accident investigation records successfully reclaimed hidden human error information not shown in statistical studies. New analytic techniques were developed and applied to the data to discover and identify multiple elements of commonality and shared characteristics within this group of accidents.

Three techniques of analysis were used: (1) Critical element analysis, which demonstrated the importance of a subjective qualitative approach to raw accident data and surfaced information heretofore unavailable. Using this approach to extract and analyze causal elements, attributes, events and conditions which significantly contributed or were related to the selected accidents, a model was developed. This model was applied to training, midair, and non-training/non-midair accidents. (2) Cluster analysis, which was an exploratory research tool that will lead to increased understanding and improved organization of facts, the discovery of new meaning in large data sets, and the generation of explanatory hypotheses. The technique also provides a simple automated straightforward means for visually presenting an otherwise unmanageably large set of data in matrix form, for organizing the data, clustering the accidents and disclosing and summarizing the structure of the matrix with a minimum loss of information. (3) Pattern recognition, by which accidents can be categorized by pattern conformity after critical element identification by cluster analysis.

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Cluster analysis

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INTRODUCTION

Aircraft accidents in the United States which involve air carrier aircraft on either revenue, training or ferry flights receive a thoroughgoing evaluation conducted by an accident investigation team manned by experts from the National Transportation Safety Board (NTSB). The team is supplemented by technical experts from the Federal Aviation Administration (FAA), other government agencies, airframe and engine manufacturers, the airline, the airline pilot group, and other interested parties. (Other aircraft accidents may also be investigated by the NTSB, but are not the subject of interest in this study.) The NTSB team performs its investigation at the site of the accident initially, arriving at the scene as rapidly as possible. Analysis of the information gathered at the scene and through other sources is carried out over a period of time lasting from days to months; results are presented to the Board and an official report of the accident is publicly released, assigning a cause or causes and contributing factors to the accident. The major classification of accidents by NTSB may be grouped into those factors related to mechanical failure (e.g. airframe, power plant, component), environmental (e.g. weather, airport, terrain), and those factors related to human actions (e.g. pilot/personnel-human error). Human error has been a consistently high category (9,14,15,16,21), with NTSB data relating cause factors for air carrier accidents (all operations) for the period 1964-1969 indicating, for example, that pilot factor was assigned as one of the causal factors in 58 percent of fatal accidents (1). In fact, 55 percent of U.S. air carrier accidents continue to involve "pilot/personnel" as a cause or factor element (6). General aviation data are even more impressive with the pilot listed as at least partially responsible in as high as 83 percent of reported accidents (2). Applying the 58 percent figure to the average of 30 U.S. air carrier accidents investigated annually by the NTSB, it is estimated that 17 of these are pilot error-related.*

Accident prevention is generally identified as the primary objective of flight safety programs and policies. The primary goal of accident investigation is to unravel in a time sequence all the events which led up to an accident in order that some action can be taken toward prevention of similar accidents. Equipment or material which fails to perform the specific function for which it is designed can generally be traced and the

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*The problem of human error in maritime accidents is receiving increasing attention. The Human Error Panel of the Maritime Transportation Research Board, National Academy of Sciences, is currently exploring means of identifying the nature of human error contingencies in ship accidents (12).

cause of the accident can be stated with some certainty; e.g. the brakes failed because of loss of hydraulic pressure. There can be and usually are a host of "contributing" factors, each of which has an impact upon the primary cause of the accident.

Other events are involved, particularly when no critical material failure occurs and a pilot's act of omission or commission could have prevented the accident. In an accident investigation when no significant material failure is identified and the occurrence of many contingencies are involved, the accident is frequently classified: "primary cause - pilot error". Those involved in analyses of accident data were the first to recognize the limitations of using a single primary cause factor. The analysts compiled data and published analyses of situations, conditions, and places where major accidents occurred. Using this approach, many pilot error studies were published; for example, analysis of undershoot and overshoot accidents, midair collisions, and disorientation accidents. While this type of study contributes somewhat to the understanding of the factors involved and occasionally provides some indication of the corrective action to be taken, no organized or systematic approach has been used in relating the many contingencies which are hidden under the term "pilot error".

To know that no equipment failed but that the pilot committed an error which caused or contributed to the accident is of little consequence unless action is taken to prevent the future occurrence of similar human error accidents. To place the blame on the pilot does little to prevent others from committing the same error unless design changes are instituted, procedures modified, or training programs altered to eliminate that type of human error. Early in accident investigation it was recognized that if similar accidents were to be grouped, a standardized data format was essential. It was also important to assign a primary cause factor so that like accidents could be categorized into distinct classes, e.g. human error accidents. From the standardization of definitions, the artificial grouping of accidents by various criteria and the assignment of causal factors arose some of the difficulties in making precise statements about human error accidents. When human error data are normalized or grouped into distinct classes, a determinable amount of specific information is lost in that transformation. It is easy to relate all human error accidents identified as those in which "pilot failed to use proper judgement". However, it is not easy to show the relationship of major situational constraints, equipment and system influences, and decision-making (or cognitive processes) which contributed to a "situation" resulting in the pilot's failure to use proper judgement.

Review of the human error literature reveals distinct categories of accident studies. First, there are those publications showing accident frequencies. These are "impact" studies. The reports show how many aircraft have been destroyed or the number of accidents which resulted in major damage. They show numbers of fatalities or major injuries and the frequencies are distributed by type of aircraft, hours flown, pilot experience, time of day, length of runway, etc. Other types of publications include case histories in which a particular accident is described in detail. Others include study of specific problems or failures in aircraft subsystems which occurred during flight, focusing close attention on failures of hydraulics, navigation systems, etc. Insufficient emphasis has been directed to the study of human error and only a fraction of the money spent in altering aircraft systems or correcting material failures is invested in attempting to analyze and correct failures resulting from human limitations.

There is a school of thought which holds that nothing can be done to prevent the human error type of aircraft accident and that data accumulated during accident investigations are of limited value for establishing research programs in this area. We feel, however, that accident data are indeed a valuable source of human factors information and these data should be extracted and made available to research agencies to assist in research planning. The solution to the problem of how to utilize accident data as a basis for human factors research is not simple. However, the problem can be stated concisely: Accident analysis data are not presently precise enough, and neither are they in an appropriate form to be used for the prediction of future human error accidents, nor even for establishing criteria for human error research. There have been notable exceptions such as the studies which led to the relocation of communications equipment to prevent disorientation. The U.S. Air Force has attempted to approach the problem through the use of annual USAF Industry System Safety Conferences dealing with research needs. The U.S. Navy has attempted to study accident causes in the human factors field through the medium of the Human Error Research and Analysis Program (HERAP) (5,16). A longitudinal systems approach related mission and system requirements to human error. The purpose of the program was "to obtain and use appropriate information concerning human engineering as related to cockpit design and layout, as well as lighting, communications, training, personnel selection and assignment, and the total flight/operation environment and the interface between man and machine" (5). The project was also involved in examining pilot performance in long duration simulation studies.

Past studies of human error accidents did not generally evolve from a systematic study of the data. The analyst, in acquiring human error statistics, noted the occurrence of these accidents more predominantly under certain conditions, places or times. It was noted, for example, that a large proportion of accidents occurred during the landing phase of flight. This prompted interest in measuring the distance of the crash from the end of the runway; hence, the definition of the problem of undershooting the runway. As a result of these studies, a host of new problems were identified: visibility, judgement, procedures training, and engineering requirements. The importance of this problem-oriented approach is not questioned. However, if human error research planning is to insure that all research requirements are identified, some systematic methodology must be utilized.

A piecemeal attack on human error has failed to provide the perspective needed to approach the problem in an organized and systematic manner. A synthesis of the various bits of data accumulated by the studies done to date could only provide a disjointed and confusing result, since these studies have for the most part been performed for the purpose of solving a particular problem at a particular point in time. A new approach must be taken to reclaim the hidden human error information in accident investigation records which is not currently shown by statistical studies of accidents. The systems approach evolved primarily from or along with the research and development of aeronautical and space systems. Integral to this systems approach was the consideration of safety.

The investigators have conducted a human factors system analysis evaluation of certain NTSB basic accident investigation records in order to construct a human error accident model which allows graphic demonstration of critical event information. This information can be utilized to establish future human factors research programs in aeronautics. Analysis of the data also provides a basis for evaluating the adequacy of the reporting and data-gathering format currently used in the human factors portion of accident investigation.

With the close cooperation of the NTSB Bureau of Aviation Safety, the Department of Aerospace and Environmental Medicine of the Lovelace Foundation for Medical Education and Research has employed a systematic methodology to examine the characteristics of the flight prior to the accident (environmental factors, aircraft systems, pilot performance, facilities, policies and procedures) as well as the contingencies pertaining at the time of the accident, to afford consideration of all the elements interfacing and interacting in the operation of a complex aeronautical system. The multidisciplinary research approach has avoided the negative concept of "accident" traditionally used (an unforeseen, unanticipated sudden event that could not be helped). An aircraft accident has been viewed as an eminently successful event that is inevitable when preceeded by a series of one or more accident-enabling factors or conditions which have to be present and without which the accident could not occur. This approach deemphasizes pilot "fault" and focuses on the actions and decisions, both proper and improper, that are carried out, as well as those factors that prompt these actions and decisions. The concept encompasses all conditions leading to accidents in the man-machine-environment complex, including material failures, etc. It is this concept that was used in collecting and analyzing the critical conditions and decisions data in our study.

The aim of the study was to devise and use a new approach to reclaim the hidden human error information in accident investigation records not currently shown by conventional statistical studies of accidents for the purposes of:

1. establishing a human error accident system model,
2. performing an in-depth contingency analysis and integrating these data within the framework of the system model, and
3. developing a research planning paradigm for the system model.

A major objective of the study was to discover and identify multiple elements of commonality occurring in pilot error-related accidents. Figure 1 graphically presents the analytic model developed for this study.

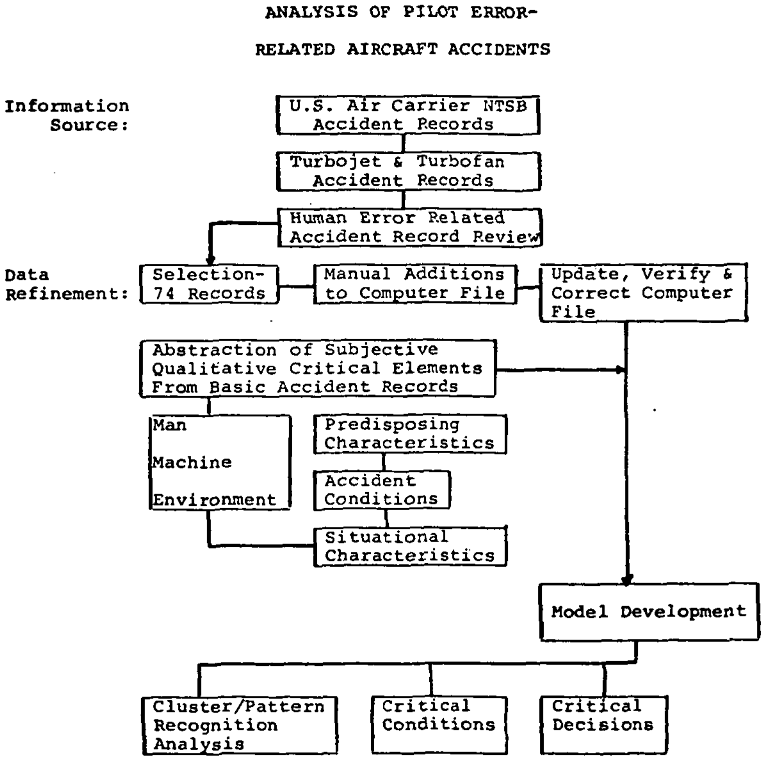

Figure 1.

METHODOLOGY

Air carrier accident investigations are thorough and recognized authorities in their respective fields from both industry and government are used as members of the investigation team. As a result, minute details about many factors impinging upon the accident are reflected in the reports. It was therefore felt that the NTSB records on air carrier accident investigations represented the most thorough and complete sources of accident data available to us, with the highest level of expert input.

With the close cooperation of the NTSB Bureau of Aviation Safety, the Lovelace Foundation research team subjected certain basic NTSB accident records to a human factors/systems analysis evaluation. The research approach was multidisciplinary with a team whose cumulative experience consisted of a broad background in aircraft accident investigation, airline flying, human factors engineering, aviation medicine, mathematics, logic and cluster analysis and psychology.

Selected for analysis are accidents with assigned causes involving human error for U.S. air carrier turbojet and turbofan aircraft from 1958 through 1970. In selecting the accidents for this retrospective study, the existing NTSB definition of the cause factor classification of human error was neither questioned nor challenged. We were not concerned with the primary cause factor per se nor the findings of the accident investigation board, nor were we interested in identifying a particular accident by number, name or location. The primary cause factor was used only for the purpose of selecting the basic human error accident records for analysis. We accepted the NTSB definition of the set.

Over 200 pilot error-related accident records were reviewed for U.S. air carrier jet aircraft from 1958 through 1970. Selected for final in-depth study were 74 accidents. Criteria for selection excluded incident reports relating to minor accidents such as ground taxi accidents and clear air turbulence passenger injuries, reports of which were too brief to be of value in this study.

Data Collection

Accident data available to us in the NTSB information storage system consisted of the basic accident investigation record, including all the factual data, group chairman factual reports, hearing proceedings, transcripts from cockpit voice recorders, air traffic control recorders, flight recorder tracings, flight crew and witness statements, weather reports, and the accident narrative report. The NTSB computer file which lists selected information abstracted from the records was also utilized. Figure 2 presents the NTSB computer file format in which data are stored in both raw and coded form. The information collected for analysis in this study was of two major types: accident characteristics or variables and critical element information.

Accident Characteristics and Variables

Of over 350 possible items of data available on each accident in the computer file, 37 were selected as having some possible relationship to pilot error. These variables, listed in Table 1 as variables 00 through 36, include man, machine and environmental data. Also selected for study were certain crew-related data not listed in the computer file but available in some of the records. These latter items are listed as variables 37 through 48 in Table 1. Data appearing in the computer file were manually verified, corrected, and in some cases previously uncoded information entered. The additional information on crew flight time, duty time and rest periods, where available, was extracted and listed. Accidents occurring prior to 1962 do not appear in the NTSB computer file, and these were manually identified, searched and data abstracted. Using this data a matrix was constructed consisting of 49 variables on each of 74 accidents. Of a total of 3626 cells in the matrix, 583 or 16% list "no data available", providing an information content of 84%. To this matrix was then added the critical element information described in other sections of this report.

The clustering methodology outlined in Appendix A was applied to various portions of the data set. The 74 accidents were divided into three groups: "non-training/non-midair" (56 accidents), "training" (12 accidents), and "midairs" (7 accidents).* Table 2 lists the variables studied (by matrix column number), the scaling used for each variable, assigned levels of logic, and a frequency count of the logic states (by the above-noted three accident groups). Assigned levels of logic range from "1" (highest level) through "5". "Not applicable" was assigned "8" and "no data" assigned "9" (the lowest level of logic).

Figure 3 presents a matrix of data (levels of logic) on 49 variables of the 56 non-training/non-midair accidents, recorded in the order in which the data were collected by the investigators. The columns (variables) are ordered consecutively 00 through 48 as listed in Tables 1 and 2. The accidents (rows) were assigned a permanent identification number, listed at the left of the matrix in such a manner as to preserve anonymity.

Results of the clustering procedure on the data in this group of accidents are shown in Figure 4. The numbers along the

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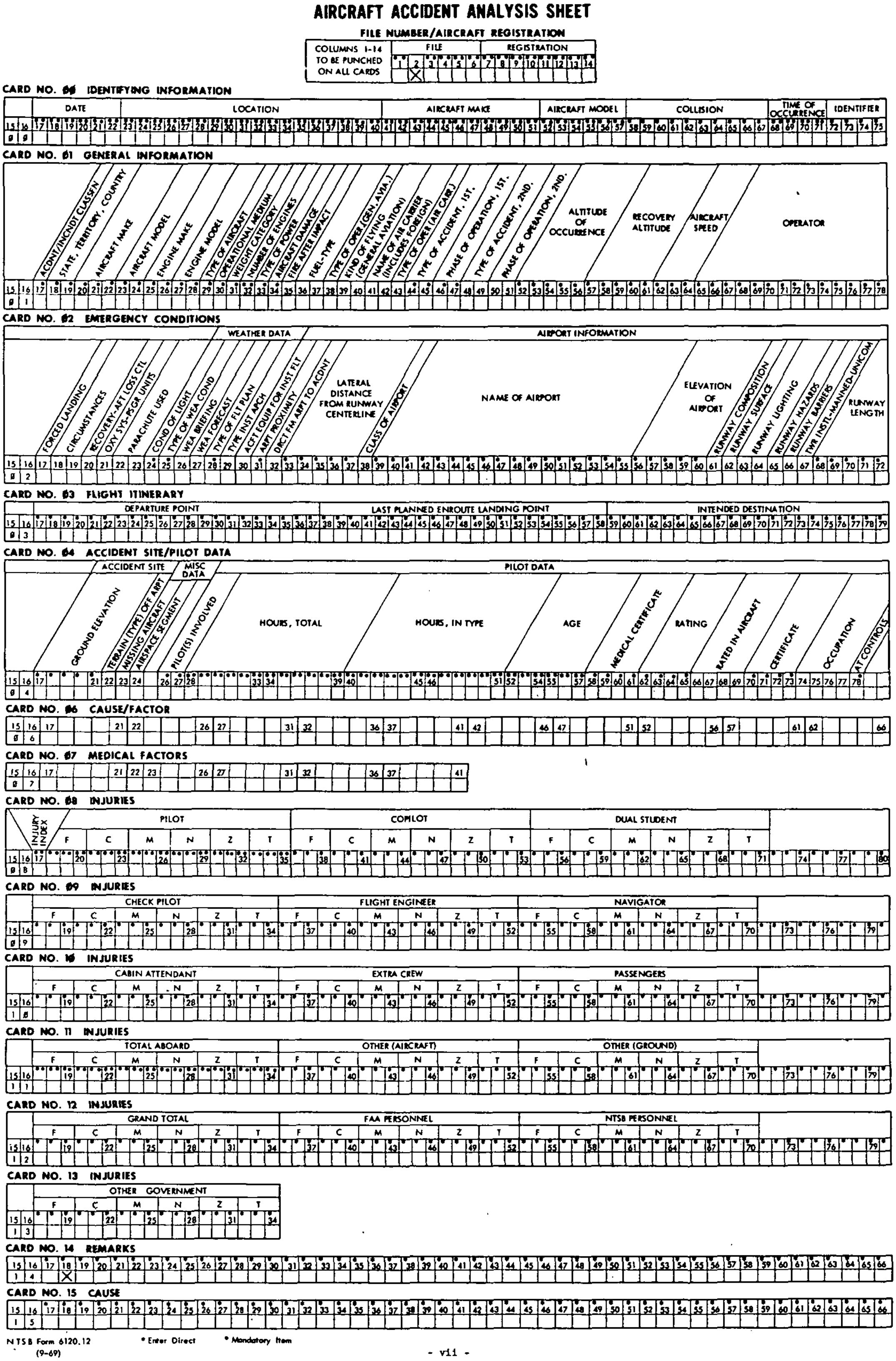
*One training accident was a midair collision and is listed in both the training and midair groups.



AIRCRAFT ACCIDENT ANALYSIS SHEET

FILE NUMBER/AIRCRAFT REGISTRATION

COLUMNS 1-14 TO BE PUNCHED ON ALL CARDS — FILE (1–6) — REGISTRATION (7–14)

CARD NO. 00 IDENTIFYING INFORMATION
DATE — LOCATION — AIRCRAFT MAKE — AIRCRAFT MODEL — COLLISION — TIME OF OCCURRENCE — IDENTIFIER

CARD NO. 01 GENERAL INFORMATION
ACDNT/INCNDT CLASSFN — STATE, TERRITORY, COUNTRY — AIRCRAFT MAKE — AIRCRAFT MODEL — ENGINE MAKE — ENGINE MODEL — TYPE OF AIRCRAFT — OPERATIONAL MEDIUM — WEIGHT CATEGORY — NUMBER OF ENGINES — TYPE OF POWER — AIRCRAFT DAMAGE — FIRE AFTER IMPACT — FUEL-TYPE — TYPE OF OPER (GEN. AVIA.) — KIND OF FLYING (GENERAL AVIATION) — NAME OF AIR CARRIER (INCLUDES FOREIGN) — TYPE OF OPER (AIR CARR.) — TYPE OF ACCIDENT, 1ST. — PHASE OF OPERATION, 1ST. — TYPE OF ACCIDENT, 2ND. — PHASE OF OPERATION, 2ND. — ALTITUDE OF OCCURRENCE — RECOVERY ALTITUDE — AIRCRAFT SPEED — OPERATOR

CARD NO. 02 EMERGENCY CONDITIONS
WEATHER DATA — AIRPORT INFORMATION
FORCED LANDING — CIRCUMSTANCES — RECOVERY-AFT LOSS CTL — OXY SYS-PSGR UNITS — PARACHUTE USED — COND OF LIGHT — TYPE OF WEA COND — WEA BRIEFING — WEA FORECAST — TYPE OF FLT PLAN — TYPE INST APCH — ACFT EQUIP FOR INST FLT — ARPT PROXIMITY — DRCT FM ARPT TO ACDNT — LATERAL DISTANCE FROM RUNWAY CENTERLINE — CLASS OF AIRPORT — NAME OF AIRPORT — ELEVATION OF AIRPORT — RUNWAY COMPOSITION — RUNWAY SURFACE — RUNWAY LIGHTING — RUNWAY HAZARDS — RUNWAY BARRIERS — TWR INSTL-MANNED-UNICOM — RUNWAY LENGTH

CARD NO. 03 FLIGHT ITINERARY
DEPARTURE POINT — LAST PLANNED ENROUTE LANDING POINT — INTENDED DESTINATION

CARD NO. 04 ACCIDENT SITE/PILOT DATA
ACCIDENT SITE — MISC DATA — PILOT DATA
GROUND ELEVATION — TERRAIN (TYPE) OFF ARPT — MISSING AIRCRAFT — AIRSPACE SEGMENT — PILOT(S) INVOLVED — HOURS, TOTAL — HOURS, IN TYPE — AGE — MEDICAL CERTIFICATE — RATING — RATED IN AIRCRAFT — CERTIFICATE — OCCUPATION — AT CONTROLS

CARD NO. 06 CAUSE/FACTOR

CARD NO. 07 MEDICAL FACTORS

CARD NO. 08 INJURIES
INJURY INDEX — PILOT (F C M N Z T) — COPILOT (F C M N Z T) — DUAL STUDENT (F C M N Z T)

CARD NO. 09 INJURIES
CHECK PILOT (F C M N Z T) — FLIGHT ENGINEER (F C M N Z T) — NAVIGATOR (F C M N Z T)

CARD NO. 10 INJURIES
CABIN ATTENDANT (F C M N Z T) — EXTRA CREW (F C M N Z T) — PASSENGERS (F C M N Z T)

CARD NO. 11 INJURIES
TOTAL ABOARD (F C M N Z T) — OTHER (AIRCRAFT) (F C M N Z T) — OTHER (GROUND) (F C M N Z T)

CARD NO. 12 INJURIES
GRAND TOTAL (F C M N Z T) — FAA PERSONNEL (F C M N Z T) — NTSB PERSONNEL (F C M N Z T)

CARD NO. 13 INJURIES
OTHER GOVERNMENT (F C M N Z T)

CARD NO. 14 REMARKS

CARD NO. 15 CAUSE

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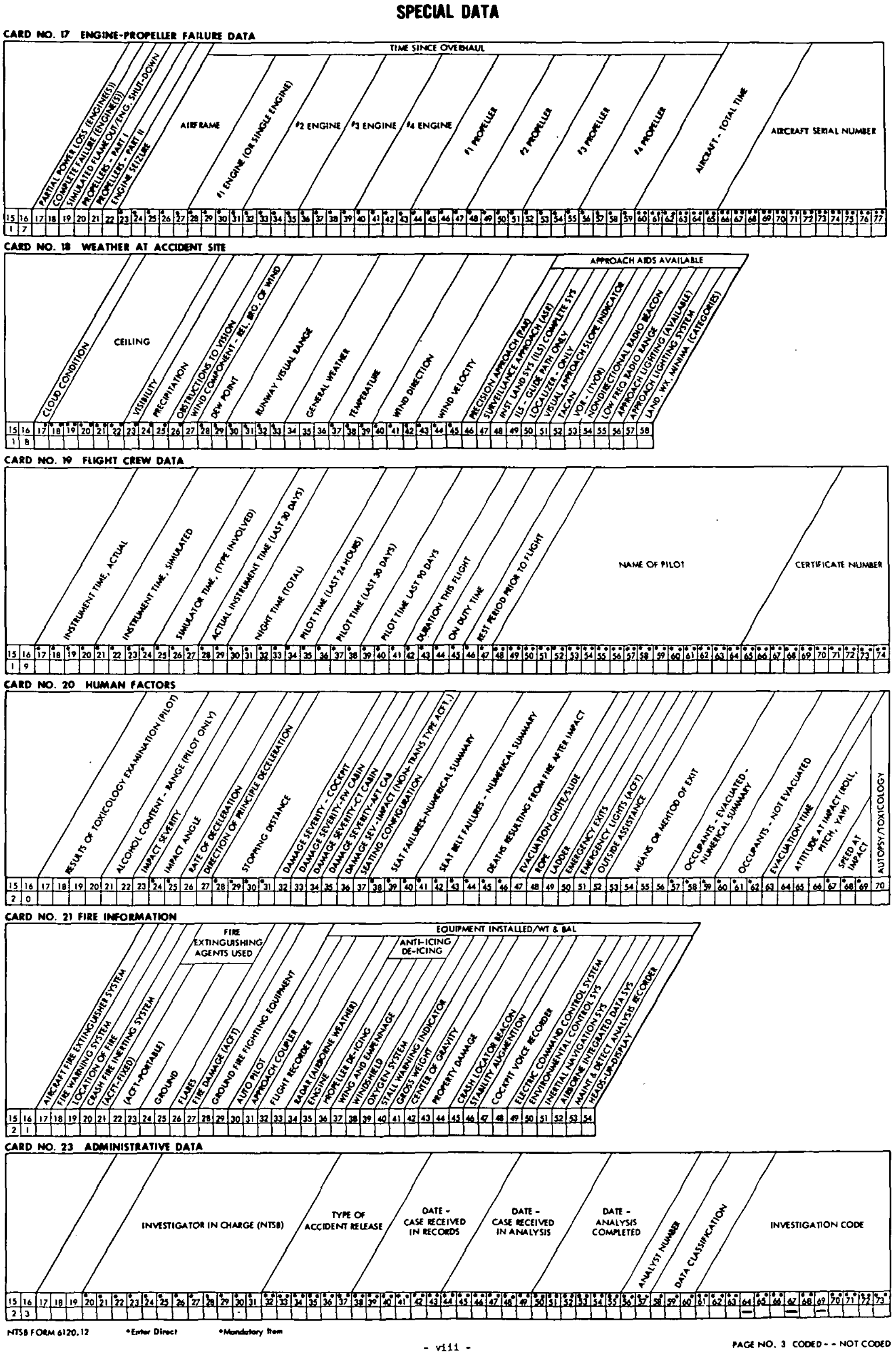
Figure 2. (page 1 of 3)*



SPECIAL DATA

CARD NO. 17 ENGINE-PROPELLER FAILURE DATA

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

15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77
1 7

CARD NO. 18 WEATHER AT ACCIDENT SITE

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)

15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58
1 8

CARD NO. 19 FLIGHT CREW DATA

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

15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74
1 9

CARD NO. 20 HUMAN FACTORS

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

15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70
2 0

CARD NO. 21 FIRE INFORMATION

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 AUGMENTION
COCKPIT VOICE RECORDER
ELECTRIC COMMAND CONTROL SYSTEM
ENVIRONMENTAL CONTROL SYS
INERTIAL NAVIGATION SYS
AIRBORNE INTEGRATED DATA SYS
MAINT & DETECT ANALYSIS RECORDER
HEADS-UP-DISPLAY

15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54
2 1

CARD NO. 23 ADMINISTRATIVE DATA

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

15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73
2 3

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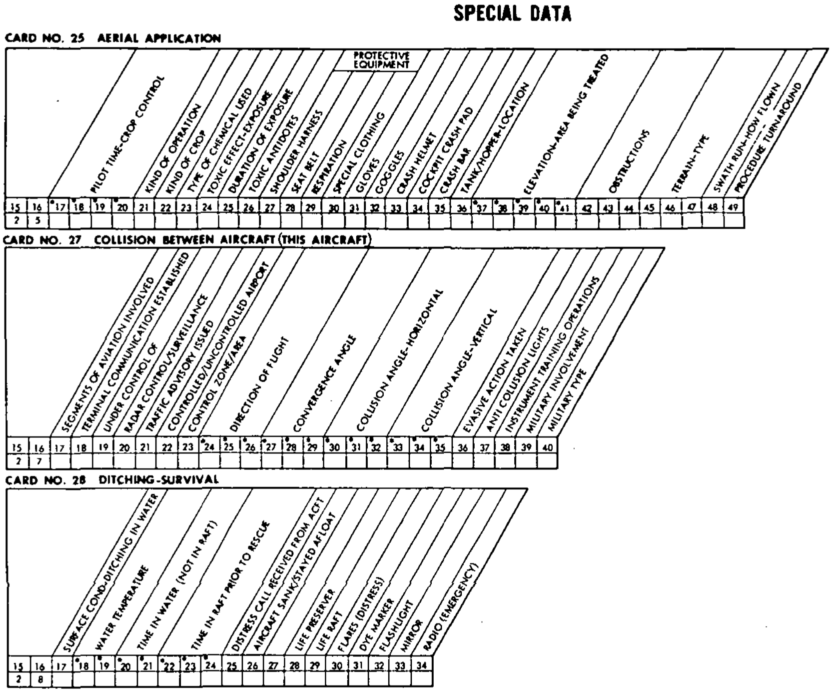
Figure 2. (page 2 of 3)



SPECIAL DATA

CARD NO. 25 AERIAL APPLICATION

PILOT TIME-CROP CONTROL
KIND OF OPERATION
KIND OF CROP
TYPE OF CHEMICAL USED
TOXIC EFFECT-EXPOSURE
DURATION OF EXPOSURE
TOXIC ANTIDOTES
SHOULDER HARNESS
SEAT BELT
PROTECTIVE EQUIPMENT
RESPIRATION
SPECIAL CLOTHING
GLOVES
GOGGLES
CRASH HELMET
COCKPIT CRASH PAD
CRASH BAR
TANK/HOPPER-LOCATION
ELEVATION-AREA BEING TREATED
OBSTRUCTIONS
TERRAIN-TYPE
SWATH RUN-HOW FLOWN
PROCEDURE TURNAROUND

15 16 *17 *18 *19 *20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 *37 *38 *39 *40 *41 42 43 44 45 46 47 48 49
2 5

CARD NO. 27 COLLISION BETWEEN AIRCRAFT (THIS AIRCRAFT)

SEGMENTS OF AVIATION INVOLVED
TERMINAL COMMUNICATION ESTABLISHED
UNDER CONTROL OF
RADAR CONTROL/SURVEILLANCE
TRAFFIC ADVISORY ISSUED
CONTROLLED/UNCONTROLLED AIRPORT
CONTROL ZONE/AREA
DIRECTION OF FLIGHT
CONVERGENCE ANGLE
COLLISION ANGLE-HORIZONTAL
COLLISION ANGLE-VERTICAL
EVASIVE ACTION TAKEN
ANTI COLLISION LIGHTS
INSTRUMENT TRAINING OPERATIONS
MILITARY INVOLVEMENT
MILITARY TYPE

15 16 17 18 19 20 21 22 23 *24 *25 *26 *27 *28 *29 *30 *31 *32 *33 *34 *35 36 37 38 39 40
2 7

CARD NO. 28 DITCHING-SURVIVAL

SURFACE COND.-DITCHING IN WATER
WATER TEMPERATURE
TIME IN WATER (NOT IN RAFT)
TIME IN RAFT PRIOR TO RESCUE
DISTRESS CALL RECEIVED FROM ACFT
AIRCRAFT SANK/STAYED AFLOAT
LIFE PRESERVER
LIFE RAFT
FLARES (DISTRESS)
DYE MARKER
FLASHLIGHT
MIRROR
RADIO (EMERGENCY)

15 16 17 *18 *19 *20 *21 *22 *23 *24 25 26 27 28 29 30 31 32 33 34
2 8

Figure 2. (page 3 of 3)

*Aircraft Accident Analysis Sheet from Manual of Code Classifications, Aircraft Accidents and Incidents, National Transportation Safety Board, Department of Transportation, Washington, D.C., June 1970, 3rd Edition.

NTSB FORM 6120.12 * ENTER DIRECT

TABLE 1

ACCIDENT CHARACTERISTICS AND VARIABLES

00	Number of engines
01	Time of occurrence
02	Type of accident (1st)
03	Phase of operation (1st)
04	Condition of light
05	Type weather conditions
06	Type instrument approach
07	Airport proximity
08	Airport elevation
09	Runway composition
10	Runway condition
11	Runway lighting
12	Runway length
13	Type of terrain
14	Pilots involved
15	Total flight time (1st)
16	Total flight time (2nd)
17	Hours in type (1st)
18	Hours in type (2nd)
19	Pilot age (1st)
20	Pilot age (2nd)
21	Pilot at controls
22	Sky condition
23	Ceiling
24	Visibility
25	Precipitation
26	Obstruction to vision
27	Relative wind component
28	Temperature
29	Wind velocity
30	Approach lighting availability
31	Pilot time last 24 hours (1st)
32	Pilot time last 30 days (1st)
33	Pilot time last 90 days (1st)
34	Duration of this flight (1st)
35	On duty time (1st)
36	Rest period prior to flight (1st)
37	Pilot time last 24 hours (2nd)
38	Pilot time last 24 hours (FE)
39	Pilot time last 30 days (2nd)
40	Pilot time last 30 days (FE)
41	Pilot time last 90 days (2nd)
42	Pilot time last 90 days (FE)
43	Duration of this flight (2nd)
44	Duration of this flight (FE)
45	On duty time (2nd)
46	On duty time (FE)
47	Rest period prior to flight (2nd)
48	Rest period prior to flight (FE)

TABLE 2

(Page 1 of 4)

Matrix Col. No.	Variable (Characteristic)	Scale	Level of Logic	Level of Logic Frequency Count		
				Non-Trng/ Midair	Trng	Midair
00	Number of engines	Four	1	36	10	2
		Three	2	10	1	2
		Two	3	10	1	3
01	Time of occurrence	2200-0559 hours	1	8	3	1
		0600-1359 hours	2	18	5	4
		1400-2159	3	29	4	2
02	Type of accident (First)	On runway	1	28	2	-
		Off runway	2	24	4	-
		Midair/Cruise/Departure	3	3	2	7
		Engine failure	4	1	4	-
03	Phase of operation (First)	Landing	1	24	4	-
		Approach	2	14	4	3
		Inflight/Departure	3	5	3	4
		Takeoff to 1st pwr. red.	4	11	1	-
		Static/Ramp	5	2	-	-
04	Condition of Light	Night	1	30	3	1
		Daylight	2	26	9	6
05	Type weather conditions	Below minimums	1	1	-	-
		IFR	2	26	2	1
		VFR	3	29	10	6
06	Type of instrument approach	Non-precision	1	1	-	2
		Contact/visual	2	15	8	1
		Precision	3	18	1	-
		Not applicable	4,8	18	3	4
		No data	9	4	-	-
07	Airport proximity	On airport	1	40	5	-
		Under 5 miles	2	9	6	2
		Over 5 miles	3	6	1	4
		Not applicable	8	1	-	1
08	Airport elevation (ft.)	Over 2000	1	3	2	-
		101-2000	2	10	4	-
		Sea level - 100	3	34	4	1
		Not applicable	8	6	2	6
		No data	9	3	-	-
09	Runway composition	Macadam	1	25	3	1
		Concrete	2	18	5	-
		Not applicable	8	6	3	6
		No data	9	7	1	-
10	Runway condition	Wet	1	19	2	-
		Clear	2	17	5	1
		Other	3	6	3	2
		Not applicable	8	7	1	4
		No data	9	7	1	-
11	Runway lighting	On	1	27	2	1
		Off	2	11	4	2
		Not applicable	8	6	1	4
		No data	9	12	5	-
12	Runway length (ft.)	Under 6000	1	4	-	-
		6000 - 8000	2	17	3	1
		Over 8000	3	26	7	-
		Not applicable	8	6	2	6
		No data	9	3	-	-
13	Type of Terrain (off airport)	Level	1	13	7	2
		Hilly/Rolling/Mountainous	2	7	1	-
		Water	3	4	-	-
		Other	4	1	-	1
		Not applicable	8	30	3	4
		No data	9	1	1	-
14	Pilots involved	PIC/Dual student	1	-	9	1
		PIC/Check pilot	2	1	1	-
		PIC/copilot	3	55	2	6

TABLE 2 (Page 2 of 4)

Col. No.	Variable (Characteristic)	Scale	Logic	Non-Trng/ Midair	Trng	Midair
15	Total flight time (hrs.) (Captain)	Under 6000	1	1	1	-
		6000 - 15,000	2	24	3	1
		Over 15,000	3	31	8	6
16	Total flight time (hrs.) (First Officer)	Under 3500	1	14	3	3
		3500 - 10,000	2	19	5	-
		Over 10,000	3	23	4	3
		No data	9	-	-	1
17	Hours in type (Captain)	0 - 500	1	18	4	3
		501 - 2000	2	25	4	2
		Over 2000	3	12	4	2
		No data	9	1	-	-
18	Hours in type (First Officer)	0 - 500	1	26	8	5
		501 - 2000	2	22	2	2
		Over 2000	3	7	2	-
		No data	9	1	-	-
19	Pilot age (Captain)	Under 40	1	6	1	1
		40 - 50	2	35	10	4
		Over 50	3	13	-	1
		No data	9	2	1	1
20	Pilot age (First Officer)	Under 35	1	19	3	3
		35 - 45	2	28	6	3
		Over 45	3	6	3	-
		No data	9	3	-	1
21	Pilot at controls	First Officer	1	22	2	2
		Other (incl. both)	2	3	8	-
		Captain	3	29	2	5
		No data	9	2	-	-
22	Sky condition	Broken - Overcast	1	31	3	4
		Clear - Scattered	2	15	7	3
		P. obscured - Obscured	3	8	-	-
		No data	9	2	2	-
23	Ceiling (ft.)	Under 500	1	7	1	1
		500 - 2000	2	22	1	1
		Over 2000	3	25	9	5
		No data	9	2	1	-
24	Visibility (mi.)	Eq/Under 1	1	9	-	-
		Over 1 - 4	2	12	3	1
		Eq/Over 5	3	34	8	5
		No data	9	1	1	1
25	Precipitation	Yes	1	27	2	1
		No	2	27	9	6
		No data	9	2	1	-
26	Obstruction to vision	Fog, haze	1	16	3	3
		Other	2	1	1	-
		None	3	35	6	3
		No data	9	4	2	1
27	Relative wind component	Tail	1	8	1	1
		Cross	2	11	2	-
		Calm	3	3	1	-
		Head	4	21	4	2
		Not applicable	8	6	1	4
		No data	9	7	3	-
28	Temperature (^{o}F.)	Over 70	1	11	3	2
		41 - 70	2	13	3	3
		0 - 40	3	9	1	-
		Not applicable	8	4	-	1
		No data	9	19	5	1

TABLE 2

(Page 3 of 4)

Col. No.	Variable (Characteristic)	Scale	Logic	Non-Trng/ Midair	Trng	Midair
29	Wind velocity (knots)	Under 10	1	26	6	3
		10 - 20	2	18	3	2
		Over 20	3	-	-	1
		Not applicable	8	4	-	1
		No data	9	8	3	-
30	Approach lighting	Not available	1	9	4	1
		Available	2	16	1	1
		Not applicable	8	18	3	4
		No data	9	13	4	1
31	Pilot time last 24 hrs (hrs) (Captain)	Over 6	1	5	1	-
		4 - 6	2	22	2	4
		Under 4	3	27	7	2
		No data	9	2	2	1
32	Pilot time last 30 days(hrs) (Captain)	Over 70	1	10	1	1
		50 - 70	2	9	-	1
		Under 50	3	8	2	-
		No data	9	29	9	5
33	Pilot time last 90 days(hrs) (Captain)	Over 210	1	5	-	-
		150 - 210	2	15	-	1
		Under 150	3	16	1	1
		No data	9	20	11	5
34	Duration this flight (hrs) (Captain)	Over 6	1	2	-	-
		3 - 6	2	19	5	1
		Under 3	3	35	4	6
		No data	9	-	3	-
35	On duty time (hrs) (Captain)	Over 7	1	14	-	2
		4 - 7	2	26	6	3
		Under 4	3	13	3	1
		No data	9	3	3	1
36	Rest period prior to flight (hrs) (Captain)	Under 12	1	4	-	-
		12 - 16	2	9	3	3
		Over 16	3	41	6	3
		No data	9	2	3	1
37	Pilot time last 24 hrs (hrs) (First Officer)	Over 6	1	5	1	-
		4 - 6	2	22	2	4
		Under 4	3	25	4	2
		No data	9	4	5	1
38	Pilot time last 24 hrs (hrs) (Second Officer)	Over 6	1	5	-	-
		4 - 6	2	13	2	3
		Under 4	3	20	4	-
		No data	9	18	6	4
39	Pilot time last 30 days(hrs) (First Officer)	Over 70	1	7	-	-
		50 - 70	2	8	-	2
		Under 50	3	7	-	1
		No data	9	34	12	4
40	Pilot time last 30 days(hrs) (Second Officer)	Under 70	1	2	-	1
		50 - 70	2	10	-	-
		Under 50	3	2	1	-
		No data	9	42	11	6
41	Pilot time last 90 days(hrs) (First Officer)	Over 210	1	7	-	1
		150 - 210	2	12	-	-
		Under 150	3	11	-	1
		No data	9	26	12	5
42	Pilot time last 90 days(hrs) (Second Officer)	Over 210	1	2	-	-
		150 - 210	2	5	1	-
		Under 150	3	10	-	-
		No data	9	39	11	7
43	Duration this flight (hrs) (First Officer)	Over 6	1	2	-	-
		3 - 6	2	19	3	1
		Under 3	3	33	7	6
		No data	9	2	2	-

TABLE 2 (Page 4 of 4)

Col. No.	Variable (Characteristic)	Scale	Logic	Non-Trng/ Midair	Trng	Midair
44	Duration this flight (hrs)	Over 6	1	2		-
	(Second Officer)	3 - 6	2	15		1
		Under 3	3	23		3
		No data	9	16	5	3
45	On duty time (hrs)	Over 7	1	15	-	2
	(First Officer)	4 - 7	2	26	6	3
		Under 4	3	12	3	1
		No data	9	3	3	1
46	On duty time (hrs)	Over 7	1	11	1	1
	(Second Officer)	4 - 7	2	17	5	2
		Under 4	3	10	1	-
		No data	9	18	5	4
47	Rest period prior to flight	Under 12	1	4	1	-
	(hrs) (First Officer)	12 - 16	2	11	-	3
		Over 16	3	37	7	2
		No data	9	4	4	2
48	Rest period prior to flight	Under 12	1	4	-	-
	(hrs) (Second Officer)	12 - 16	2	7	1	2
		Over 16	3	27	5	1
		No data	9	18	6	4

```
                          CHARACTERISTICS

                 0000000000111111111122222222223333333333444444444
                 0123456789012345678901234567890123456789012345678
                 -------------------------------------------------
            001  1211223132113832311213321111922323223332323292221
            002  1322232132223833222321233234111223323223222332233
            003  1222232132223833221223223232111333223333939222233
            005  1322232231222133311323233234921219333229999333333
            006  1311122131123833211323121131129219212223299221122
            007  1211239131893833321221233234811399333339999333333
            008  1311123131312832311223112112992299311229999331111
            009  1311123132112833331313132134991222223223239222233
            010  1222232122992833232223133233999323333239913331323
            011  1111123131113332221233112211212199113119999111133
            012  1321232131292833232223233234119292312239939331122
            013  1211232131222933221321133234221332333332293333333
            014  2322132211993133311223133234212399333239999332323
            015  1311123132213833232321123134322311223331222222233
            016  1223239331992233311229223232999312323392929392939
            017  1311123132112833223323322124322323223322233222232
            018  1311123132213833311211112112222339223339999222233
            019  1222232132292833332311233234129119212112299221122
            020  2322122131112832111213112112922299213229999221133
            022  1311132121213833111211233233222993393339933333333
            023  1211233132292832199211233234819399113339999111133
            026  1322123221113232121213322112911322222392999222929
            030  3111123131112132121991321134322392333399912393939
            031  2222223131193132122213121114922293223299919292939
            032  2222223231912432111123921211212233322992999999999
            033  1221233139323132223131123234119333233332333332933
            035  1311133131112232322211133131112112313191929391939
ACCIDENTS   037  3311232131121132312211123134912293313299939391939
            040  3311239132323132321191233134919291223299939292939
            041  3222113232311133321221331211219299312299999391929
            042  1222223299119332222339123191992211312299999391929
            043  3321132299319231122113233234911399333399999393939
            046  2211233111993832111113133134229393223319999222132
            049  1314224388888833312223133138288233323221113332233
            050  1114134131193833332321123939228292212229923221122
            051  1314134122212833132211133232318393323339922332233
            053  1115124122113832222223122119318399323339999332233
            054  2124124122213832121223123132328223311222232331111
            056  1224124221313133333221332213318339333333399333333
            057  2323124388888332323213222118218393333333992333333
            060  2315134121113832122113233239118199321119999332211
            064  2114134132111832322221123219118399323339999332233
            067  1324234132223833233231133232218111312111111331122
            069  1311229139113833222323122199999312293999999229933
            070  1133128888888883221123119998998399223339999222233
            071  1211223139212333222321111299999299223229999222233
            078  3322128388888223211223311138888393333399939393939
            080  1114138131113833121222933132218392333339921333333
            083  3344234131993132122212233239928392323339929332233
            084  3322121299999233332213123112912322323391929392939
            085  1324124121113132233232113114318211223221219222233
            055  3224124122212133311213122114328222331293929393919
            074  1211232119223833311993133231119992339999933333399
            079  3933134388888233322223123238988232223291919292939
            086  2311232131221132212223233234121299393999999999999
            092  1333234388888833333321391138888299329229999332299
```

Figure 3. Data on 56 Non-Training/Non-Midair accidents.

```
                               CHARACTERISTICS

                0020021120022112431142332022431333314340344440101
                7024251899310076556368204173199173827688434025564
                -------------------------------------------------
          018   11111111|22111211223822322321992339333333222992333
          008   11111111|91132311113819922321992229221113333992233
          009   11111111|22131133223829212343333222223333322229233
          ---------------------------------------------------------
          035   1111111|211111123113291123313212112923393333999323 3
          053   1111111|212532121222823982192992339333332333992243
          015   1111111|222112233222823123342213331333333222222333
          ---------------------------------------------------------
          006   111111|2121132113112811121312933229232223222222323
          ---------------------------------------------------------
          011   11111|21111133121112312922111992119133333111992233
          051   11111|21212411233221823983323292333323332333923343
          050   11111|99221412133113812983192293222232223222933343
          ---------------------------------------------------------
          085   1111|211311423131222123163341112221233332222292243
          ---------------------------------------------------------
          069   111|2111299132129992899192392993392933333222992393
          071   111|2121299112229222329991291993229223333222992333
          074   111|2122119139213333831993213399992939991333933323
          013   111|2122121112223332932313243923332323333333233323
                    ---------------------------------------------
          067   111|2222312413233112812183323112111132223333113343
          033   111|2222319113323222191393242331333333333333233233
          010   111|2229292232933132839293233192323322332333933323
          ---------------------------------------------------------
          022   11|21121121111213391832923333392933333323339 33323
          007   11|22129111112823333838913243992339333333333993393
          023   11|22129912111293111818993243992339323333111993233
          003   11|22222112232223222821313222332333333333222993323
          002   11|22222212212223222821213343233223233333333223323
          012   11|22229211132233112811993343392222322223333993323
          019   11|22229222112331138111932439231191222232222293323
                   ----------------------------------------------
          017   11|31111322132122226232223423233332233232222232333
          001   11|32111122131111223829221212222333332313229332233
          080   11|21111111422123331832983123292332333333339133 83
          ---------------------------------------------------------
ACCIDENTS 064   1|211121212412121223821983192992339313333333993243
          020   1|211211121231111111819922321992229223333222992223
          054   1|211211122432223111813283122322223231112333222243
          046   1|212119121131913221812993243991333133321222993233
          031   1|212219221231121221199921242192223933393229992233
          060   1|221121211531123221821983393991119131112333993243
          086   1|222122221132213992191913343992299919393399993223
                  -----------------------------------------------
          055   1|311211122431211333193222242232222921192339992343
          037   1|312112211111131131999233423922391339333999 3223
          040   1|322112112119323223199993343391221933393229993293
          083   1|322429221421923221129983393292332333333333993243
          030   1|331111121119123331193921142199332923393339922233
          ---------------------------------------------------------
          042   2112211299293129112399123212993221992299339992233
          005   2122222121232213333139113343993229223333333993323
          026   2131211111231121221299212322922332932292222992233
          056   2131221311412331333133382233932339333323333392343
                 ------------------------------------------------
          014   2211229111232913233132923343992329332331333993323
          032   2292221111232911921492321212921293929293399992233
                 ------------------------------------------------
          084   2311219219231931223299223322212332993399339992313
          043   2321221219131323331299913343991339993399339993123
          041   2331221112212321113192991213992229912293339991333
          ---------------------------------------------------------
          049   3112118288432813223822383383112223253338333132343
          016   3122229191392913223299193222222332923393339993393
          092   3132318388312833223828981389993229289998333993343
                 ------------------------------------------------
          057   3221218318331821333332982382292333383338333932243
          079   3311328288332823223299383982112222983398229993343
          078   3331218188232813332298981381392333983398339992382
          070   8111398198313819222829989189992339383338222992283
```

Figure 4. Clustered data on 56 non-training/non-midair accidents. Lines demarcate major clusters and subclusters.

upper border of the matrix identifying the variables (00 through 48) correspond to those listed in Tables 1 and 2. In studying a clustered matrix, patterns and interrelationships are more easily visualized if each level of logic is assigned a color which is then superimposed on each matrix cell. As a result of the nature of clustering methodology certain patterns of data migration occur within the matrix. Accidents and variables having high information content drift toward the upper left portion of the matrix, while variables and accidents having relatively low information content drift toward the lower right of the matrix. Furthermore, the scaling to which a variable is subjected before matrix entry (and the resultant frequency of levels of logic within that variable) assumes importance in terms of the clustering results. The decisions regarding scaling of the variables listed in Table 2 were reached based on the experience of the research team. This matrix can be used as an investigative model to examine the effects on clusters and patterns of manipulating variables (rescaling, combinations of variables, ratios, etc.).

The clustered matrix of the 56 accidents in Figure 4 points out a number of interesting results and commonly shared traits. The 56 accidents are divided into three distinct clusters on the basis of airport proximity (the first column, 07). Forty accidents occurred on the airport, nine at less than five miles and seven over five miles. The cluster of 40 on-airport accidents is further divided into three subclusters on the basis of "number of engines" (column or variable 00) - over one half of the on-airport accidents involved four-engine aircraft. Eighteen accidents are identified as having occurred on the airport, in four-engine aircraft, in broken to overcast sky conditions. Of these latter 18, 11 occurred at night and seven of these were associated with precipitation. The foregoing is an example of the kinds of observations possible using this technique. One other interesting finding in this matrix which is corroborated in Table 2 is that within this group of 56 accidents, 41 list the captain as having had over 16 hours of rest prior to that flight. Simple observation of the "no data" points within the matrix (listed as "9") quickly demonstrates the magnitude of missing data and areas requiring standardization of accident data collection. Many hours have been spent in studying these clusters and many patterns emerge despite the small number of accidents. This technique is a useful tool in studying large data sets of aircraft accident information.

The clustered data on the twelve training accidents is shown in Figure 5. Although the total number of accidents is relatively small, a number of commonly shared characteristics are visible. All 12 accidents were actual training (or proficiency) flights. Of the ten involving four-engine aircraft, six had a low experienced first officer (0-500 hours in type). All but one of the 12 occurred on or within five miles of the airport (column 07). Nine of the 12 occurred during daylight hours (column 04). Ten occurred in VFR conditions (column 05). The captain was between 40 and 50 years of age in ten of the accidents. These data must be related to the characteristics of the general population of routine training flights.

```
                                  CHARACTERISTICS
                 0111201030221002221001124133224304332143403444343
                 0483977304206198650821916517737265544236458820319
                 -------------------------------------------------
            039  1111112112223229323212929311933922223323939999999
            027  1111112812223183323349222233433922233233333399999
            025  1111121291232122222329229339331323333232939999999
            073  1111921292932389992822222399999922229829239999999
            066  1118233382223381128838232322833942223823232399999
ACCIDENTS   072  1119911382222299922232229299939989993299939999999
            048  1121122482211221322249222322433942293332333399999
            021  1131223312232211322142222333433922223332233399999
            087  1231113192123212121349233333133923332333333399999
            034  1328923191911129111321239139419139992333929999999
            077  2312121221122322319221211333223323332333322223399
            036  3118212112111131932311912923923992992339993999999
```

Figure 5.

The clustered data on the seven midair accidents are depicted in Figure 6. Due to the limited number of accidents the clustering procedure by itself yields little or no new information. However, it is evident from the matrix data that six of the accidents occurred in daylight under VFR conditions. All but one had been in flight under three hours. Six of the seven captains involved had over 15,000 hours total flight time but three of the seven had relatively little time in type (0-500 hours). Five of the seven first officers had low time in type (0-500 hours). Four of the flights had a 3-man crew; the other three had a 2-man crew.

```
                                  CHARACTERISTICS
                 1221221432002120011423314204330343043431024131004
                 8207966558061354191630241790713678789345544032282
                 -------------------------------------------------
            094  1111111991243422228938139881993229322333323898389
            024  1111311229381822218938933889333399393332339838389
            075  1121893118143112228128939889222992899333293898389
ACCIDENTS   029  1213131222213822222232931189223222329333333328389
            066  1223213221143822328238919889223332339223332898389
            028  2122233112323822332919239489222229292333339298389
            038  2292139332311121191931939419332339299333339392339
```

Figure 6.

Determinative or Identification Schemes

Another aspect of this clustering methodology is the ability to determine, when the next event occurs, what the shortest route would be to identify that event as being similar to or different from previous events. This requires a method for constructing identification schemes from accumulated data. The variables to select in optimally identifying the new event are those variables which, on the basis of past experience, separate or partition previous events at the most efficient rate.

The theoretical aspects of this separating or partitioning of events are discussed in Appendix B and applied to the critical element data on page 40.

ACCIDENT CRITICAL ELEMENTS

In the critical element portion of the data collection, each of the selected accident records was reviewed by the team members. From these records were extracted critical conditions and decisions. Critical elements were considered to be those causal elements, attributes, events or conditions which significantly contributed or were related to the occurrence of the accident. These critical elements were broadly divided into "critical conditions" and "critical decisions" and consisted of subjective, qualitative statements whose subject and predicate were then listed for each accident. The critical elements thus identified and previously submerged in the records were collected in a format amenable to meaningful analysis both by themselves and in combination with the accident variables previously mentioned. For purposes of matrix entry and analysis, the 19 critical elements were transformed into binary data (element present or absent, yes or no). The elements were also studied in subject/predicate form and results and discussion of these data follow.

Critical Conditions

The critical condition category model is depicted in Table 3.

Table 4 depicts the type of accident by phase of operation. Classification and phase of operation are as coded by the NTSB. Those operations that are concerned with reaching the runway touchdown point have the highest frequency of occurrence in the accident population, i.e. 13 undershoots, nine hard landings, eight overshoots, and seven ground-loop/swerves. Forty-seven out of the 74 accidents (64%) occurred during the landing phase of operation.

Table 5 depicts critical conditions in 56 non-training/non-midair accidents, seven midair accidents and 12 training accidents. On the ordinate are listed the ten critical conditions and on the abscissa are listed the code numbers for each accident in its respective grouping. The parenthetical number shown with each critical condition (e.g. 38 following "experience") indicates that there were 38 accidents in which experience was a critical condition within the accident set.

Of the 12 training accidents, one accident was actually an on-line training event. The 11 others were training or proficiency type flights. In the training group, there were eight machine-related accidents, six decision-related accidents and

TABLE 3

CRITICAL CONDITION CATEGORIES

1. Experience
    a. Low pilot time in type
    b. Low copilot time in type
    c. Low pilot time in position (as Captain)
    d. Low copilot time (total)
    e. Other (includes: recent experience, training, flight engineer, age differences, student pilot new, crew new, student pilot dull, new airport)

2. Distraction
    a. Communications or traffic (excessive communications with ATC or looking out for traffic)
    b. Confusion (last minute approach changes or other confusion)
    c. Hurry (close departure on same runway or other hurrying)
    d. Holding or delay
    e. Other (includes: wake turbulence, numerous distractions, foreign student, first officer monitoring instruments, interrupted checklist, fuel burn, paperwork, poor destination weather, instructor pilot checklist, takeoff position holding, ashtray fire)

3. Crew Coordination
    a. Disagreement (disagreement on approach or configuration, or other pilot calls "off profile")
    b. Jumpseat occupant or other additional crew
    c. No required altitude callouts
    d. Pilot acting as instructor
    e. Other (includes: loose student/instructor relationship or other interactions such as flaps without student knowing, altitude confusion, distrust first officer, thought continuing takeoff, gear up without visual verification, both pilots on controls, non-compliance, confusion on who was flying)

4. Neglect
    a. No cross-check on ILS
    b. Improper use of checklist
    c. Improper rest/procedure
    d. Other (includes: company did not revise checklist, other aircraft collision light off, ATC, Mach trim switch, engine reversing indicator lights, VOR out, clearance deviation)

5. Air Traffic Control
    a. Delayed landing clearance
    b. Confusing radar vector
    c. Advised of traffic
    d. Poor, weak or malfunctioning radar or radar return
    e. Other (includes: no acknowledgement, no advisories, vector confirmation, advisory holds)

TABLE 3
CRITICAL CONDITION CATEGORIES (continued)

6. "Decisions"
   a. Off acceptable profile
   b. Institutional decisions: OK to operate
   c. Copilot flying, taken over by pilot

7. Work/Rest (fatigue)
   a. On duty over 8 hours
   b. Minimum rest
   c. Early morning departure

8. Machine
   a. Gross weight (overweight or heavy gross weight)
   b. Simulated engine shutoff (engine failure simulation)
   c. System failure
   d. Other (includes: simulated rudder loss, flight director oscillation, spoiler deployment and retraction, battery switch, 3 & 4 engine reverse, slow spool, air noise, parking brake versus mechanical failure, seat failure)

9. Airport
   a. Stopping problem (runway slippery, wet, slush, braking action poor, or tire residue)
   b. Touchdown problem (runway short or displaced threshold)
   c. Vertical guidance problem (no approach light, approach lights out, or localizer only)
   d. Runway hazards (upslope threshold, exposed lip or dropoff)
   e. Other (includes: runway markings obliterated, uncontrolled airport, irregular lights, loose pavement, hilly terrain)

10. Weather
    a. Visibility problem (heavy rain at threshold, below circling minimums, fog, snow or haze or other visibility restrictions)
    b. Thunderstorm influencing airport or enroute weather
    c. Wind gusty
    d. Other (includes: same route, weather above circling minimums, enroute weather, freezing drizzle, venturi wind)

TABLE 4

	Type of Accident	Phase of Operation			
No.	NTSB Code/Description	Taxi	Takeoff	Inflight	Landing
7	A Ground Loop/Swerve	2	2	-	3
1	B Dragged wingtip	-	-	-	1
1	C Wheels up	-	-	-	1
2	E Gear collapsed	-	2	-	-
9	G Hard landing	-	-	-	9
8	J Overshoot	-	-	-	8
13	K Undershoot	-	-	-	13
6	L0 Collision with A/C (both inflight)	-	-	4	2
4	M1 Collision with ground/ water (uncontrolled)	-	1	1	2
4	M0 Collision with ground/ water (controlled)	-	-	2	2
4	N1 Collided with trees	-	-	1	3
1	N6 Collided with runway/ approach lights	-	-	-	1
2	NB Collided with ditches	-	2	-	-
1	0 Hail damage	-	-	1	-
3	Q Stall	-	3	-	-
1	S0 Airframe failure (inflight)	-	-	1	-
5	U Engine failure/ malfunction	-	2	1	2
2	3 Uncontrolled altitude deviation	-	-	2	-
74		2	12	13	47

TABLE 5

CRITICAL CONDITIONS

Non-Training/Non-Midair (56)

	1. Experience (38)	2. Distraction (19)	3. Crew Coord. (14)	4. Neglect (10)	5. ATC (5)	6. Decisions (31)	7. Work/Rest (7)	8. Machine (19)	9. Airport (32)	10. Weather (28)
1	X					X			X	X
2					X				X	
3	X								X	
5	X					X			X	
6	X					X	X	X		X
7	X	X		X						
8	X	X				X	X		X	X
9	X	X							X	X
10	X	X				X			X	
11	X		X			X	X	X	X	X
12				X		X			X	
13	X					X				
14	X		X			X				
15						X			X	
16	X									
17	X	X				X			X	X
18	X					X			X	X
19	X		X			X	X			
20	X	X								X
22	X		X			X				
23	X	X				X	X			
26	X		X			X			X	X
30	X	X				X			X	X
31					X	X		X	X	X
32	X		X					X		X
33	X					X			X	X
35		X				X	X		X	
37	X	X	X			X			X	X
40	X					X		X		
41	X			X						X
42			X			X				X
43		X		X					X	
46	X							X	X	X
49	X									X
50						X			X	
51	X	X	X	X				X		
53									X	
54	X	X				X	X	X		
55	X			X				X		
56		X		X				X	X	X
57	X					X		X		X
60		X		X					X	
64	X	X						X	X	
67		X							X	
69			X			X			X	X
70	X	X		X				X		
71						X		X	X	X
74	X			X				X		
78	X				X					X
79					X					X
80	X		X					X	X	
83			X			X		X		
84	X		X						X	X
85		X				X		X	X	X
86	X		X					X	X	X
92						X		X		X

Midair (7)

	1. Experience (1)	2. Distraction (5)	3. Crew Coord. (1)	4. Neglect (3)	5. ATC (4)	6. Decisions (0)	7. Work/Rest (1)	8. Machine (1)	9. Airport (1)	10. Weather (0)
24	X	X	X		X					
28					X					
29		X			X					
38		X		X					X	
66					X			X		
75		X		X			X			
94		X		X						

Training (12)

	1. Experience (5)	2. Distraction (4)	3. Crew Coord. (4)	4. Neglect (1)	5. ATC (1)	6. Decisions (6)	7. Work Rest (1)	8. Machine (8)	9. Airport (3)	10. Weather (1)
21		X	X					X		
25	X		X			X	X	X		
27						X		X	X	
34	X	X	X	X		X				
36						X				
39	X		X			X				
48								X		
66					X			X		
72	X							X		
73	X	X				X		X		
77		X							X	X
87								X	X	

five experience-related accidents. Excluding the on-line training accident, the significant observation is that seven of the 11 training flights were operating with simulated engine failures. In most cases of operating with simulated engine failures, profiles of flight were unacceptable (decision information). Flight parameters were allowed to continue beyond the point where the instructor could regain control of the aircraft before the accident. Three out of the five accidents where experience was involved included an instructor pilot who was new at his job. Two of the crew coordination items out of the four were interruption of cockpit routine by a jumpseat occupant or additional crew member. The one item of neglect was an instance where the company did not update the emergency checklist. In general the training accidents involve conditions of relatively good weather and relatively few airport problems.

Of the seven midair accidents, one was also a training accident. In this event set of midair accidents, both distractions and ATC problems predominate. In fact, each accident has either a distraction or an ATC condition or both. Distractions included "hurryup" approaches, evaluating runway identifier lights, an ashtray fire and a radio frequency change. Of the four ATC conditions, two involved poor or malfunctioning ATC radar equipment, and two involved situations in which no traffic advice or warnings were given. If one ATC problem was shifted to neglect, the seven midair accidents would then be: two accidents where ATC radar was malfunctioning or of inadequate quality; one where ATC did not advise or warn of traffic; one where the air carrier aircraft exceeded its clearance limit; and three where neglect on the part of the aircraft other than the air carrier aircraft played a vital role in the accident (such as not reporting position, not using navigation lights, or deviating from a clearance).

Some general observations may be made about the 56 non-training/non-midair accidents. The most commonly observed characteristic among the 56 accidents is experience, which occurs in 38 accidents. Second in occurrence is airport conditions which appear in 32 accidents. Decisions appeared in 31 accidents, and weather in 28. Further partitioning of the data is possible. For example, in the experience grouping, there were 28 accidents with copilot low in time in type. Twenty accidents occurred with low pilot time in type. Sixteen accidents occurred where both the pilot and copilot had low time in type. Again, low time in type is described as less than 500 hours in the particular type of airplane involved. Partitioning the condition of airport, we find 16 accidents where there was a stopping problem, nine accidents where there was a touchdown problem and seven accidents where there was a vertical guidance problem. In the decision classification, the most frequent characteristic appearing was "off profile", occurring in 21 accidents. The predominant weather condition was visibility, occurring in 20 accidents.

In an attempt to more closely study certain subcharacteristics (e.g. subcategories of decisions, such as 6a, off acceptable profile), a screening technique was applied to the data. The technique is graphically presented in Figure 7.

Of 21 off profile accidents (first screen):

> Seven were experience only related, with one or both pilots having low time in type;
>
> Four involved changeover of control from the copilot to pilot (In only one of these cases was there an experience-related problem; three of the four had weather problems, and of these three, two had airport problems);
>
> Four shared a common characteristic of a disagreement of aircraft operation. In three of these, the pilot in command was also acting as instructor pilot. Two were also related to experience, with both pilot and copilot having low time in type;
>
> Three experience-related accidents had no attending weather or airport problems, but all had copilot low time in type;
>
> The remaining three accidents showed airport problems, with two being touchdown problems and one a vertical guidance problem.

Of 16 accidents with low copilot time in type (second screen):

> No off profile condition noted;
>
> Nine associated with weather problems (seven with poor visibility, two with thunderstorms);
>
> Four were machine-related, with such problems as antiskid device inoperative, stall warning device inoperative, etc.;
>
> Three shared no common trait other than low copilot time in type, but all three were accidents in which information was sparse;
>
> In the total group of 74 accidents, seven had some type of system malfunction; six of these occurred in this group.

Of 14 accidents with airport-related problems:

> Neither off profile nor low time in type for copilot were present;

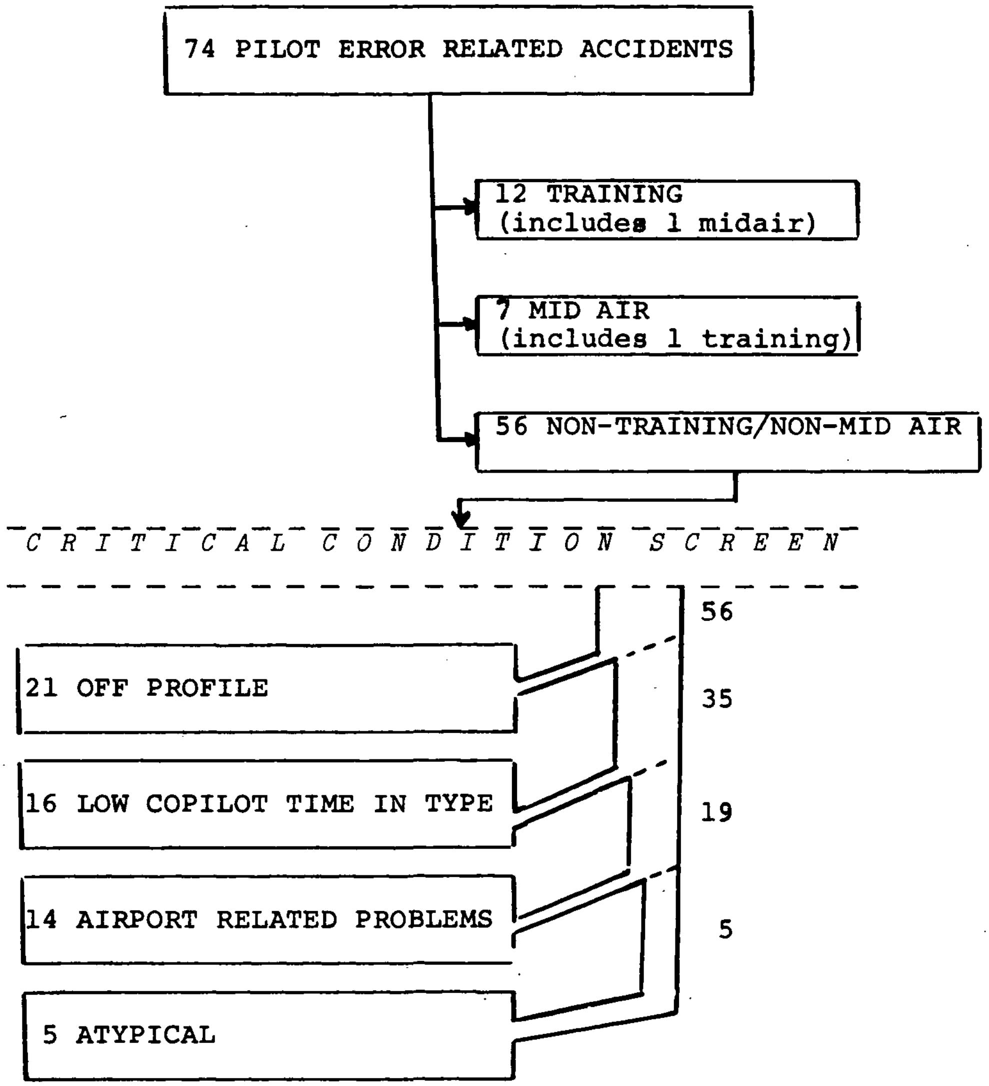

74 PILOT ERROR RELATED ACCIDENTS
12 TRAINING (includes 1 midair)
7 MID AIR (includes 1 training)
56 NON-TRAINING/NON-MID AIR
CRITICAL CONDITION SCREEN
56
21 OFF PROFILE
35
16 LOW COPILOT TIME IN TYPE
19
14 AIRPORT RELATED PROBLEMS
5
5 ATYPICAL

Figure 7.

Seven had stopping problems;

Four had runway hazards;

Two had touchdown problems;

One had a vertical guidance problem;

Eight contained elements of distraction,
with five accidents having holding or
other delays.

The remaining five accidents (fourth screen) do not have the above characteristics in common. Further observation of the data on these accidents, however, reveals other interesting facts. For example, none were in the approach and landing phase of operation; all captains had over 6000 hours total flying time, were well rested, and had not flown in excess of 210 hours in the preceding 90 days; pilots had had less than six hours flying time in the preceding 24 hours; and all accidents occurred between 1400 and 2200 hours, local time.

The 56 non-training/non-midair accidents are baffling and complex in nature. Another technique was devised to study this group. This method was opposite in nature to previous methods. Those characteristics found in the largest number dealt with experience, decisions, airport and weather problems. In reverse, we withdrew those accidents which showed none of the most common traits. Seven such accidents were of this type. The most unique trait observed within this group of seven was that they contained the five atypicals described above. In an examination of the seven accidents it was found that each accident was so unique that a sibling could not be found in the accident group of 74. While some of these seven accidents were complex, it could be observed that if one condition in the enabling factors could be changed, an accident might not have happened. Due to the sensitive nature of the accident data, specific description of enabling factors cannot be mentioned. In general the "one of a kind" atypical accident enabling factor falls into such groups as design hazards, physical hazards, and system malfunctions. It may be that there is such a thing as an "irreducible minimum" of human factors accidents and that these atypical or "freak" accidents may represent that minimum. Certainly we cannot subscribe to the ludicrous concept that there is an acceptable tolerance level for human factors accidents, but we do feel that there indeed may be a small group of accidents that will not be classifiable as reasonably preventable; and zero human error, while a superb ideal, remains a utopian goal.

There were 11 accidents in which only one of the common traits could be found. This group will be the subject for further examination. It presently appears to be related to the previously discussed seven (none of which contained a common trait) but in less subtle enabling factors.

The remaining group of 37 accidents possesses two or more of the common traits. Again, reviewing the common traits: experience, i.e. low pilot time in type, low copilot time in type; decisions, i.e. off profile flight conditions; airport, i.e. stopping problem, touchdown problem, vertical guidance problem; weather, i.e. visibility problem. It appears to this group of investigators that methods can be devised to limit or provide warning in the event that two or more of these enabling factors are present. If such a system could be devised and placed in use, it should be the foundation of an effective accident prevention program.

Critical Decisions

The purpose of this portion of the study was to examine in detail those pilot decisions that were made in the period just prior to the accident event. This data set was collected separately from the critical conditions using a somewhat different approach. Consequently, the "decisions" listed in the critical condition classification are distinct from the decisions in this section.

Inappropriate decisions preceding a pilot error-related aircraft accident are often the result of inaccurate perceptions or of failure to make timely decisions (19). In order to analyze critical decisions collected on 73 accidents (one of the selected 74 accidents had no available information from which to abstract critical decision elements), a listing in the form of one-sentence descriptors was made for each accident following review of the record. Inter-investigator variability was checked by having each record analyzed independently by several analysts. This cross-check showed no meaningful differences between investigators.

The working definition of a critical decision adopted for data collection considered it to be a critical information processing function (choice) of a flight crew member occurring in the time period just prior to the accident event. Identification of critical decisions was cued to the review of factual accident records for control inputs, verbal communications, post-accident flight crew statements, flight profile, etc. When all the decision data had been collected, Altman's classification scheme was adapted in order to catalog and classify the data set (3). Table 6 lists the major categories of critical decisions in the 73 accidents.

The critical decisions listed for all the accidents were then sorted by accident into three major groups: Non-training/non-midair (55 accidents), training (12 accidents), and midairs (7 accidents). One training accident was a midair collision; thus both the training and midair groups share one accident (a total of 18 accidents).

TABLE 6

CRITICAL DECISION CATEGORIES

1. Decisions resulting from out-of-tolerance (off profile) conditions
    - a. Takeover of controls
    - b. Verbal instructions between pilots
    - c. Excessive deviation called out
    - d. Inadequate braking observed
    - e. Assistance in flight control operation
    - f. Attempt to regain directional control
    - g. Go-around initiated
    - h. Other*
2. Decisions based on erroneous sensory inputs
    - a. Approach continued visually
    - b. Decided profile within limits
    - c. Misleading cockpit display
    - d. Misleading navigation information
    - e. Runway/braking misinformation
    - f. Final approach/flare profile misinformation
    - g. Standard operating procedure distraction
    - h. Other
3. Decisions delayed
    - a. Takeover of flight controls or assistance
    - b. Go-around decision
    - c. Takeoff abort
    - d. Thrust lever movement
    - e. Other
4. Decision process biased by necessity to make destination or press-on (meet schedule)
    - a. Continued flight with equipment failure
    - b. Altered cockpit procedures
    - c. Continue with weather conditions deteriorating
    - d. Runway misinformation
    - e. Decision involved approach procedure
    - f. Other
5. Incorrect weighting of sensory inputs or responses to a contingency
    - a. Deviation from checklist/altitude callouts
    - b. Icing of aircraft
    - c. Disregard of cockpit displays
    - d. Traffic information disregarded
    - e. Disregard information on landing environment or conditions
    - f. Safety degradation due to training
    - g. Other

TABLE 6
CRITICAL DECISION CATEGORIES (continued)

6. Incorrect choice of two alternatives based on available information
    a. Left cockpit
    b. Landed runway with unfavorable conditions
    c. Flew visual approach
    d. Other

7. Correct decision
    a. Checked approach light level
    b. Confirmed minimums
    c. Took over and flew approach
    d. Other

8. Overloaded or rushed situation for making decision
    a. Primary attention diverted
    b. Aircraft power difficulty
    c. Observed traffic and rolled aircraft
    d. Other

9. Desperation or self-preservation decision
    a. Directional control or stopping problem
    b. Airborne loss of control
    c. Avoid ground contact
    d. Avoid other aircraft
    e. Other

* Critical decisions listed as "other" in each category were miscellaneous and too few in number to list herein.

Non-Training/Non-Midair Accidents. Table 7 summarizes the critical decisions listed for the 55 non-training/non-midair accidents. (Entries are not mutually exclusive; one accident may have critical decisions listed under several categories.) Within this group of 55 accidents, the greatest number of critical decisions, 37, were made as a result of conditions being out of tolerance with respect to a normal flight profile. A pilot often accepts an off-profile deviation to accommodate air traffic control constraints, airport noise regulations, passenger comfort and other restrictions. The second highest number of critical decisions, 30, in this group were those that were based on erroneous sensory inputs. Leak observed this phenomenon in a study of USAF approach and landing accidents: "Although a number of areas need increased emphasis, the critical one appears to be information." (11) Willis and Bryant refer to the false hypothesis concept where the more limited or the more vague the information, the less time the pilot has for evaluation (23).

The next group of decisions, 27, involves incorrect weighting of sensory inputs or responses to a contingency. Scucchi and Sells refer to this hazard of inaccurate information processing as one that flight training and flight operations must come to recognize (19). Those decisions which are biased by pressure to make the destination or to meet the schedule account for the next highest number of critical decisions, 26. This kind of decision may be a result of conditioning pilots receive every day of continuing the planned flight profile. There seems to be a "continue on and it will work out" attitude in accidents involving this type of decision.

Training Accidents. Table 8 summarizes the critical decisions made in 12 training type aircraft accidents. The two most common critical decision categories in this group are those decisions delayed beyond the time required and those made as a result of conditions out of tolerance, eight. "Delaying decisions" is inherent in pilot training procedures employed by flight instructors. The tendency is to allow the student as much time as possible to recognize and correct a dangerous situation before taking over.

Midair Collision Accidents. In the midair collision accidents the most frequent decision listed is that based on the requirement to continue to the destination or make schedule, five. Decisions based upon incorrect weighting of inputs numbered three. An example of this kind of decision is one where the pilot is issued air traffic information while other cockpit duties require his primary concentration. Table 9 summarizes the decisions made in the seven midair collisions.

Combinations of Critical Decisions. The critical decision data were also studied in terms of the combinations of decisions appearing within a given accident. Table 10 lists the frequency of more common combinations of two and three decisions found within the 55 non-training/non-midair accidents. Whenever

TABLE 7

SUMMARY OF CRITICAL DECISIONS IN 55 NON-TRAINING/NON-MIDAIR ACCIDENTS

TYPE OF DECISION	NO. OF DECISIONS
1. Conditions out of tolerance	37
2. Erroneous inputs	30
5. Incorrect weighting of inputs	27
4. Make destination/Press-on	26
3. Delayed	20
9. Desperation	10
8. Overloaded or rushed	9
7. Correct decision	8
6. Incorrect choice	5

TABLE 8

SUMMARY OF CRITICAL DECISIONS IN 12 TRAINING ACCIDENTS

TYPE OF DECISION	NO. OF DECISIONS
3. Delayed	8
1. Conditions out of tolerance	8
5. Incorrect weighting of inputs	7
2. Erroneous inputs	3
9. Desperation	3
8. Overloaded or rushed	2
4. Make destination or Press-on	1
6. Incorrect choice	2
7. Correct decision	-

TABLE 9

SUMMARY OF CRITICAL DECISIONS IN 7 MIDAIR COLLISIONS

TYPE OF DECISION	NO. OF DECISIONS
4. Make destination or press-on	5
5. Incorrect weighting of inputs	3
1. Conditions out of tolerance	2
2. Erroneous inputs	2
9. Desperation	2
8. Overloaded or rushed	1
3. Delayed	-
6. Incorrect choice	-
7. Correct decision	-

TABLE 10

COMBINATIONS OF CRITICAL DECISIONS IN NON-TRAINING/MIDAIR ACCIDENTS (55)

COMBINATION OF 2 DECISION CATEGORIES	NO. OF ACCIDENTS
Conditions out of tolerance and Erroneous inputs	18
Conditions out of tolerance and Make destination or press-on	17
Conditions out of tolerance and Incorrect weighting of inputs	16
Conditions out of tolerance and Delayed	16
Erroneous inputs and Make destination or press-on	13
Erroneous inputs and Incorrect weighting of inputs	13
Delayed and Incorrect weighting of inputs	11
Make destination and Incorrect weighting of inputs	11
COMBINATION OF 3 DECISION CATEGORIES	
Conditions out of tolerance, Delayed and Incorrect weighting of inputs	10
Conditions out of tolerance, Erroneous inputs and Make destination or press-on	8
Conditions out of tolerance, Erroneous inputs and Delayed	6
Conditions out of tolerance, Erroneous inputs and Incorrect weighting of inputs	6
Conditions out of tolerance, Delayed and Make destination or press-on	6
Conditions out of tolerance, Make destination or press-on and Incorrect weighting of inputs	6

sequential decisions of the categories listed in this table were made, they often resulted in inaccurate information processing. There appears to be a need for further research into more efficient means for a pilot to make decisions involving conditions out of tolerance, incorrect weighting of inputs, erroneous sensory inputs and combinations thereof.

Associations of Critical Decisions with Critical Conditions

The following chart lists the number and type of critical decisions found to appear concurrently within an accident, with specific critical conditions:

1. Condition: Off acceptable profile (21 accidents)

Associated Decisions	No. of Decisions
1. Resulting from "out of tolerance"	23
2. Erroneous inputs	12
4. Make destination/press-on	12
5. Incorrect weighting of inputs	12
3. Delayed	9
7. Correct decision	3
8. Overloaded	1
9. Desperation	1
6. Incorrect	-

2. Condition: Low copilot time in type (16 accidents)

Associated Decisions	No. of Decisions
1. Resulting from "out of tolerance"	11
4. Make destination/press-on	10
2. Erroneous inputs	9
3. Delayed	6
5. Incorrect weighting of inputs	5
9. Desperation	5
6. Incorrect	3
8. Overloaded	2
7. Correct decision	1

3. Condition: Airport (14 accidents)

Associated Decisions	No. of Decisions
5. Incorrect weighting of inputs	11
1. Resulting from "out of tolerance"	10
2. Erroneous inputs	7
3. Delayed	6
4. Make destination/press-on	5
7. Correct decision	4
8. Overloaded	3
6. Incorrect	1
9. Desperation	-

It should be noted that with each of the three critical conditions listed above, the five most frequently associated critical decisions were (1) decision regarding conditions out of tolerance, (2) decisions from erroneous inputs, (3) delayed decisions, (4) make destination/press-on based decisions, and (5) decisions based on incorrect weighting of inputs. "Airport problem" accidents most often involve erroneous decisions due to incorrect weighting of sensory inputs. Accidents associated with low copilot time in type and off-profile are often associated with decisions regarding conditions out of tolerance.

CLUSTER ANALYSIS OF CRITICAL ELEMENTS

The clustering method using truth table classification (Appendix A) was applied to the critical conditions and decisions data available for the 56 non-training/non-midair accidents. The input data matrix consisted of 19 critical elements (in binary form, "present" or "not listed") on 56 accidents. Results of the clustering procedure are depicted in Figure 8. One can see in the matrix how this agglomerative type of clustering links, by the state of a variable (in this case a given critical element present or not listed), the 56 accidents and creates progressively smaller subclusters. Also evident are groups of accidents sharing multiple critical element states.

Using this clustered matrix of critical elements the determinative or identification scheme (Appendix B) was applied. The partitioning or separation ability of each critical element was calculated and these are listed in Table 11. Critical element 10 separates 784 of the 1540 pairs. Critical elements 10 and 15 separate 1175 of the 1540 pairs. The first nine elements listed in the Table separate 1538 (99.9%) of the 1540 possible pairs of accidents---these then are the "nine best tests" that, applied in sequence, will provide optimal separation of events. This information is graphically presented in Figure 9 and compares the resultant curve of separation with the theoretical curve (in which the nine best tests would separate 100% of the pairs).

These selected nine critical elements were then used to construct a matrix of the 56 accidents and the data were clustered using truth table classification. Figure 10 shows the clustered results and demonstrates how the nine critical elements, when applied in sequence listed, progressively partition the 56 events optimally. For example, the critical element "weather" (number 10) partitions the events into two clusters of equal size. The next element, "decisions based on incorrect weighting of sensory inputs" (number 15), partitions each cluster created by element 10 into nearly equal subclusters (independent of element 10). This partitioning is continued by the other critical elements in sequence. An inference that can be made from the foregoing is that on the basis of this data set (past experience), a future accident could be examined most efficiently by studying the critical elements in the sequence shown, and that the nine elements listed will most economically and quickly provide information on a new given non-training/non-midair accident. It should be noted that the methodology described earlier for calculating likelihood for patterns of states of variables is also applicable to this data particularly when information regarding frequency of patterns that have occurred is available.

ACCIDENTS	CRITICAL ELEMENTS
	0100111110001011010
	1196205438239487765
01	1111111112222222222
11	1111112121211222122
26	1111112122212222222
08	1111112212122221122
18	1111112222222222222
10	1111122122122222222
30	1111212122121222222
84	1112111212212221222
86	1112111221212212222
46	1112112121221222222
80	1112121211211222222
09	1112212122122222212
64	1112221111122222222
57	1121112221221212222
06	1121211122222222111
14	1121221112212222222
23	1121221212122222122
13	1121221212222222222
19	1121222112212222122
22	1121222112212222222
40	1121222222122212222
20	1122112222122212222
49	1122112222222222222
41	1122212122222121222
07	1122221212121112222
70	1122222211122112212
37	1211111122112222222
33	1211112122222222222
05	1211122122222222222
17	1211211122122222212
03	1212122122222222222
54	1221121221122221122
78	1222111122222222221
51	1222121221111122212
74	1222122221221122222
32	1222212111212222222
55	1222221211222122222
16	1222222222222222222
71	2111111211222222222
15	2111122112222222222
69	2111211112212222222
50	2111221212222222222
35	2111222222122221122
60	2112122122122122222
02	2112122212222222221
53	2112221222222222222
42	2121111122212222222
92	2121211221221222222
83	2121222221211211222
12	2211121222222122222
31	2211211121222221221
85	2211212211122211222
43	2212121222122122222
67	2212121222122222222
56	2212211121122112222
79	2222112122222222221

Critical Elements:

Conditions:
01. Experience
02. Distraction
03. Crew Coordination
04. Neglect
05. Air Traffic Control
06. "Decisions"
07. Work/Rest
08. Machine
09. Airport
10. Weather

Decisions based on:
11. "Out of tolerance" conditions
12. Erroneous sensory inputs
13. Delayed decisions
14. Make destination/press-on
15. Incorrect weighting
16. "Incorrect choice"
17. Correct decisions
18. Overloaded or rushed situation
19. Desperation (self-preservation decisions)

Figure 8. Clustered critical elements* on 56 non-training/non-midair accidents.

*1 = Present, 2 = Not listed.

TABLE 11

OPTIMAL SEPARATION OF EVENTS BY CRITICAL ELEMENTS

** 9 BEST TESTS ***

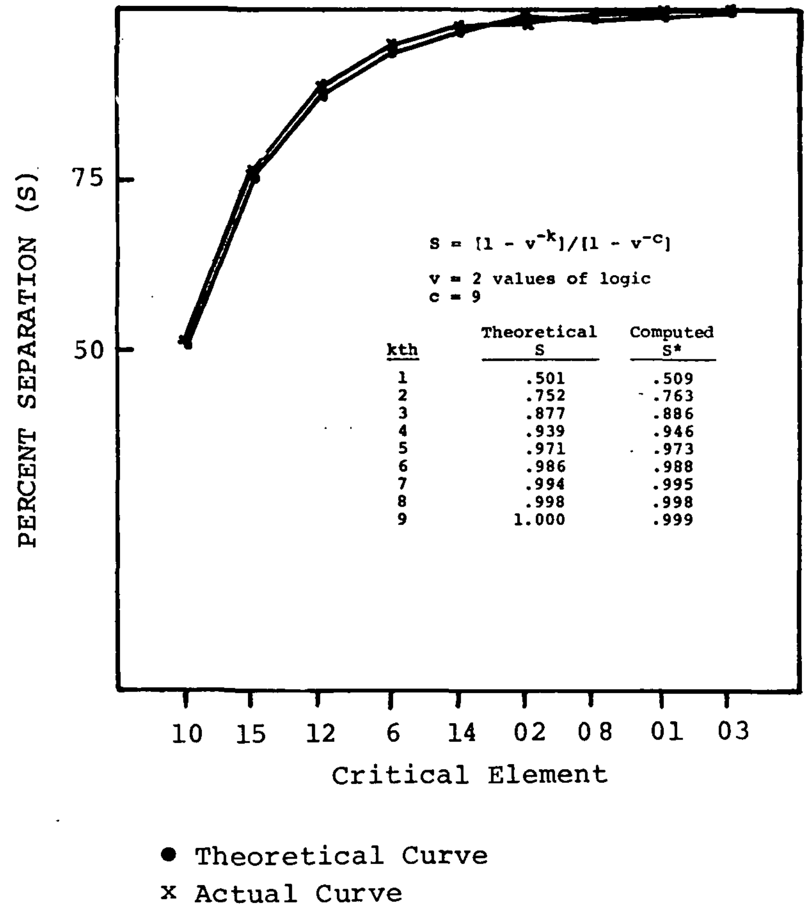
Critical Element:	10	15	12	6	14	2	8	1	3	7	11	4	13	9	19	17
Pairs of Events Separated by Critical Elements*	784	783	780	775	780	703	703	684	588	343	703	460	720	768	460	384
	0	1175	1166	1167	1124	1131	1135	1124	1076	955	1135	996	1112	1160	1014	974
	0	0	1364	1363	1337	1344	1350	1333	1317	1261	1347	1279	1337	1363	1288	1270
	0	0	0	1457	1444	1443	1449	1438	1428	1407	1435	1410	1430	1447	1421	1405
	0	0	0	0	1498	1495	1501	1494	1490	1479	1492	1473	1492	1496	1487	1478
	0	0	0	0	0	1521	1520	1519	1513	1511	1517	1510	1514	1519	1512	1509
	0	0	0	0	0	0	1533	1531	1530	1526	1529	1526	1527	1531	1529	1526
	0	0	0	0	0	0	0	1537	1537	1535	1534	1534	1534	1536	1534	1534
	0	0	0	0	0	0	0	0	1538	1538	1538	1538	1537	1537	1537	1537
% Pairs Separated:	(50.9)	(76.3)	(88.6)	(94.6)	(97.3)	(98.8)	(99.5)	(99.8)	(99.9)							

16	5	18
255	255	423
911	907	995
1237	1232	1279
1387	1393	1414
1469	1471	1478
1508	1504	1507
1525	1525	1523
1534	1534	1533
1537	1537	1537

*e(e-1)/2 = 1540 pairs of events to be separated

Critical Elements ("Nine Best Tests")

10. Weather
15. Incorrect weighting
12. Erroneous sensory inputs
06. "Decisions"
14. Make destination/press-on
02. Distraction
08. Machine
01. Experience
03. Crew Coordination



$S = [1 - v^{-k}]/[1 - v^{-c}]$

v = 2 values of logic
c = 9

kth	Theoretical S	Computed S*
1	.501	.509
2	.752	.763
3	.877	.886
4	.939	.946
5	.971	.973
6	.986	.988
7	.994	.995
8	.998	.998
9	1.000	.999

Figure 9.

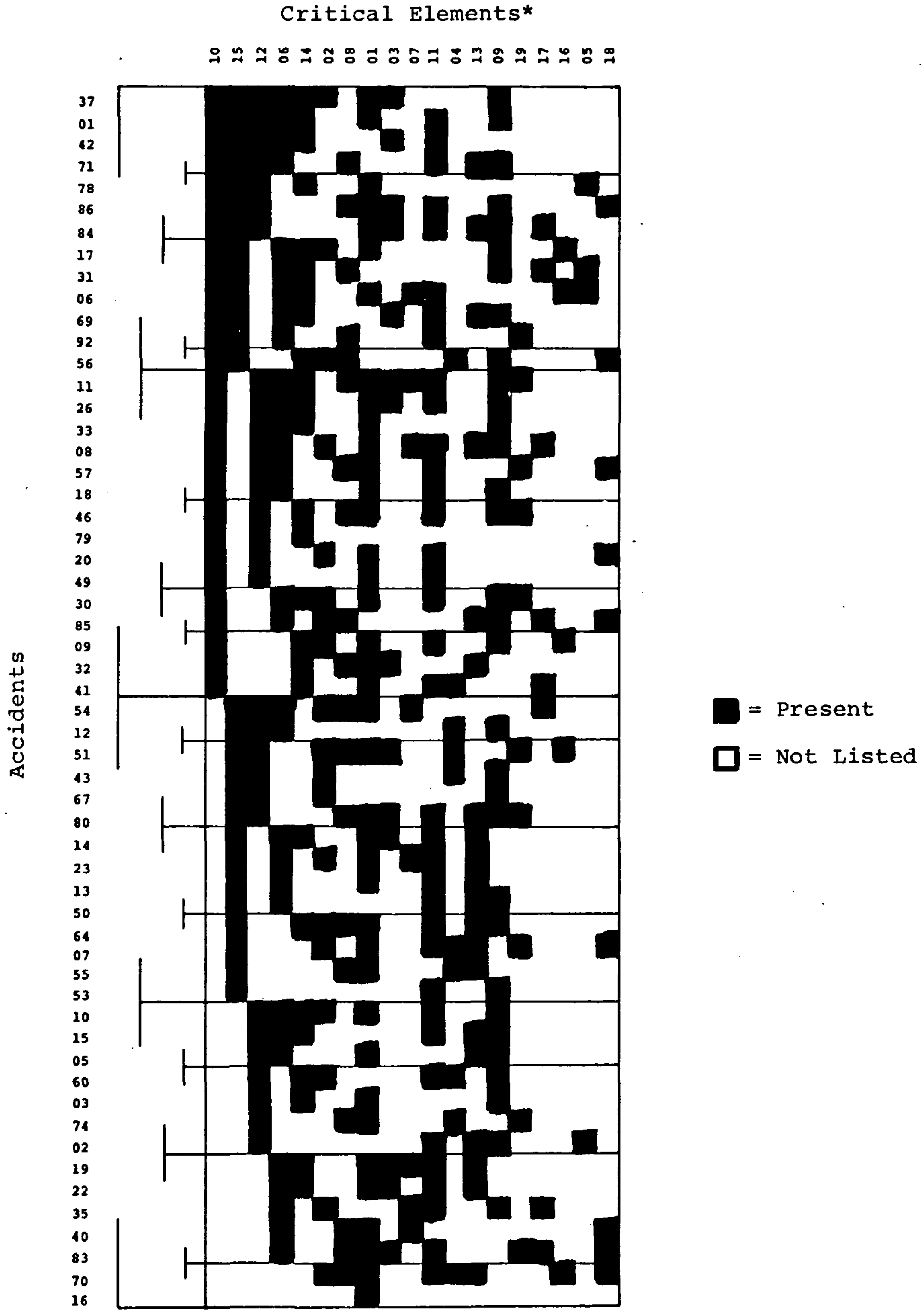


Figure 10. Reclustered critical elements on 56 non-training/non-midair accidents.

*Refer Figure 8 for listing of the 19 elements.

The many different kinds of clustering methodology in themselves are barren. The crux of the matter is interpretation of results after clustering and, hopefully, that the clusters generated in the data set are well differentiated and will provide corroborative evidence of being sensitive and stable. Each person is his own clusterer or classifier; there is no general theory of clustering or classifying anything. In parallel, there are many different kinds of clustering methodology and the open-minded investigator should entertain many alternative ways of handling his data set. In the discussion above, no so-called truth is ascribed to rearrangements of numbers automatically done by machines. A lower level of abstraction with more meaning is required - the statements of characteristics describing events are symbolized with numbers and are used in creating a compound definition of events. These are presented in combination with descriptions of other events thus allowing for new inferences and possible discovery. No fountainhead of truth in itself is implied, merely a form of descriptive statistics and the basis for inference.

GENERAL DISCUSSION AND RECOMMENDATIONS

A multidisciplinary human factors systems analysis has been conducted on all those NTSB records of U.S. air carrier jet accidents with human factors cause elements identified which were complete enough for exhaustive analysis. The time period covered was from 1958 through 1970. The human factor classification of the 74 accidents as assigned by the NTSB was accepted without question by the study investigators, but we have no quarrel with the classification of these accidents after exhaustive study of the records.

The analytic techniques applied here are new to accident analysis and provide a systematic evaluation of human factors data of such complexity as to be normally resistant to analysis by even sophisticated techniques (10). The critical decision and critical condition data are new and were not heretofore available or highlighted. The models for critical decisions and critical conditions are workable and offer promise for future accident evaluation. They have been most useful in identifying out of a morass of data those elements deserving further study and/or research.

The NTSB computer data alone would not provide information on whether a given accident or set of accidents was human error-related, if that descriptor were not a part of the computer file for that accident. That is, the computer data have no selective qualities of identifiability from the viewpoint of critical elements we have outlined. This area is therefore deserving of further development. One could speculate that the relative barrenness of the data collection in the human elements of the computer filed information may have been due to a lack of satisfactory means of reducing the information to the computer language. In that case, the model presented here may help. Further, the model may add objectivity to the collection and interpretation of subjective information bits. The paucity of data could also be at least partly accounted for because of the lack of emphasis on such data collection or the absence of appropriate regard for the value of such data. Appropriate emphasis for all elements of data is imperative, with weightings due to individual bias on the part of the accident investigators precluded by the very nature of the investigative scheme.

Human error versus non-human error partitioning may be felt to be a fundamental mistake in classification and it may be that a man-machine-environment or host-agent-environment scheme may be more fruitful, especially in longitudinal analyses.

However, "human error" as a classification, regardless of its shortcomings, has the overwhelming advantage of centering attention on the group of accidents (with at least one major common element) to which a significant amount of attention should be devoted, and to the group where a high likelihood of success exists. We have experienced no serious difficulty in applying the analytic techniques described earlier, which include the epidemiologic host-agent-environment scheme, as an overlay to the already categorized human error accident set.

Inherent in the many difficulties faced by investigators and analysts who must attempt to make meaning out of collected bits of information is the changing quality of the contingencies affecting the accumulation of happenings and the gathering of data relating to these events. Observer variations, variations in the quality and quantity of data collected, variations in the techniques and efficiency of the coders of the data, are only a few of the problems. The nature of these problems is so complex that it would require a separate treatise to deal with this subject alone. In fact, many would point out that these very problems introduce such variability into the data that it is impossible to analyze and gather from the analysis any meaningful results or conclusions.

Jacobs (10), in a paper devoted to a discussion of some of the conceptual and methodological problems in accident research, deals particularly with problems encountered in formal statistical inference, when use is made of traditional techniques. He feels that the existence of the pitfalls and difficulties have contributed largely to the lack of research achievement in the field despite many years of effort. Pointing out that analysis of data on a large number of accidents in aggregate has rarely produced any practicable remedy which would have prevented any substantial number of accidents, he attributes the problems of analysis to the fact that in any single accident there are a number of combined coincidental events and circumstances of a causal nature, in the absence of any one of which, there would not have been an accident, and that the production of the accident required the combination. To answer why analytical and correlational studies have seldom led to the development and application of useful countermeasures, he offers two explanations. First, he points out that this type of research presents very difficult methodological and conceptual problems, most of which are not commonly perceived, and, secondly, he states that the treatment of these methodological problems requires a magnitude of effort which goes far beyond that which is generally required for productive research in most other fields of inquiry. However, the data on accidents collected by the NTSB is virtually all of the information we have, and a system of interpreting such data, with all the inherent defects of the data admitted, is badly needed. The techniques used here provide, we feel, a method of dealing with an overwhelming mass of data, and a method of comparing apples and oranges without forcing the investigator into the hopeless corner of bit-by-bit analysis with which the human mind cannot cope.

Another major problem which has plagued the entire field of accident investigation is that provided by the semantic restraints inherent in the definition of the term accident itself. Webster's Third New International Dictionary of the English Language(22) defines accident as follows (irrelevant comments are excluded for purposes of brevity):

> <u>accident</u> *n.* (fr Latin root *accidens* meaning nonessential quality or circumstance, accident, chance, from present participle of *accidere* to happen). 1a: an event or condition occurring by chance or arising from unknown or remote causes, b: lack of intention or necessity: CHANCE - often opposed to design, c: an unforeseen unplanned event or condition. 2a: a usually sudden event or change occurring without intent or volition through carelessness, unawareness, ignorance, or a combination of causes and producing an unfortunate result, b: an unexpected medical development especially of an unfortunate or injurious nature occurring in apparently good health or during the course of a disease or a treatment, c: an unexpected happening causing loss or injury which is not due to any fault or misconduct on the part of the person injured but from the consequences of which he may be entitled to some legal relief.
> 3: an adventitious characteristic that is either inseparable from the individual and the species or separable from the individual but not the species; *broadly:* any fortuitous or nonessential property, fact or circumstance.
> 4: an irregularity of a surface (as of the moon).
> Syn: chance, quality. Syn for <u>accidental</u>: fortuitous, adventitious, contingent, casual, incidental.

Note the synonyms for the words accident and accidental. The definition of the word causes semantic responses which are not fruitful - that is, the definition is inherently negative, both from the viewpoint of the victim and from the viewpoint of the person involved in dealing with the accident externally, such as the investigator trying to take a constructive approach. Social acceptance of the phenomenon leads to apathy and a feeling of helplessness and futility in trying to deal with accidents. Since they are fortuitous, there is nothing we can really do about them anyway, so why try? Suchman (20) points out that the term "accident" implies unexpectedness, undesirability, with the implication that unanticipated turns of events cannot be prevented and that there is little to do but clean up the damage. He further elaborates on the climate of helplessness and despair and attributes this climate to contributing heavily toward keeping this area of human activity out of the realm of scientific investigation. He then goes on to point out that most accidents do not appear to be solely chance events, but compose a set of events which can be identified, classified and analyzed in terms of antecedent and associated events with an eventual goal being explanation of causation.

Gibson, in discussing the contribution of experimental psychology to the formulation of the problem of safety (8), refers to the term accident as a makeshift concept with a hodgepodge of legal, medical and statistical overtones. He states: "Two of its meanings are incompatible. Defined as a harmful encounter with the environment, a danger not averted, an accident is a psychological phenomenon, subject to prediction and control. But defined as an unpredictable event, it is by definition uncontrollable. The two meanings are hopelessly entangled in the common usage, there is no hope of defining it for research purposes. Hence, I suggest that the word be discarded in scientific discussion. The problem of accident prevention should be renamed - perhaps calling it the problem of safety. It is then, on the one hand, a matter of the ecology of dangers and the natural or artificial signs of danger, and, on the other hand, a matter of the psychology of their perceptions and reactions aroused by these signs. When thus reformulated, the problem appears in a quite different light." We wholeheartedly agree with this statement, and would add only that together with the discarding of the concept of accident as traditionally defined,should also go, once and for all, the concept of 'accident proneness' as a totally worthless and unscientific concept. Suchman (20) points out that there are good reasons for disregarding this model on theoretical, methodological and mathematical grounds. He states that he does not believe that the complexity of accidents can be adequately explained by the simplistic model of a single personality type which seeks out accidents through some neurotic motivation. Arbous and McFarland (4,13) also find the approach quite inadequate.

We have not allowed ourselves to be drawn into the problem of defining an accident. The operational concept of this research project has been to deal with each "accident" as a successful event and we have found the concept useful in helping to establish a positive frame of mind, if nothing else. Viewing accidents as successful events, we have been able to review identifiable factors pertaining to the accident in terms of what we chose to call "accident enabling factors", or factors without which the accident could not occur. Not all factors (conditions and decisions) fit the definition of accident enabling factor, of course. Another pitfall we tried to avoid in the data collection phase was thinking of the events associated with an accident as being right or wrong, good or bad. They were simply viewed as events without judgment being attached. This is not to say that judgments are not possible or should not be made, but they were not the proper subject of the data gathering portion of the study.

Accepting conditions out of tolerance (critical decision) and operating the aircraft in a condition off acceptable or optimal profile (critical condition), while not identical in their definition, as can be seen above, are prominent in both the condition and decision analyses. Accepting conditions out of tolerance and operating off-profile are inherent in everyday airline operations. The training effect of operating outside of what is taught as "proper" airmanship may have a negative long-term value in flight safety. We feel that there is a need for intensive study into the relationships that exist between pilots, airlines and regulatory bodies, with special attention to defining and understanding how institutional decisions which involve all of these groups interact to affect flight safety. As an example of an institutional decision, we refer to an operational decision to continue a flight with one generator out of service.

An over-all observation from the decision data leads us to recommend further research into the decision-making role of the pilot. The present cockpit environment has been shown to be less than ideal for a pilot to be a reliable decision maker. There are many proposals in the literature for either adding a pilot decision-maker (19,23) or restructuring the present pilot functions to include adaptive, computer-assisted decision making (7). Resistance to change of the present cockpit work situation must be met by factual data which point to past deficiencies in pilot information processing. Task off-loading and actual training of pilots in decision-making techniques (particularly with regard to "critical elements") seem to us to be the most fruitful approaches. We are not prepared at this time to make recommendations pertaining to the introduction of specific new equipment into the cockpit to automate some pilot functions. The reason for this is two-fold; first, we have not satisfied our own requirements with regard to the depth of analysis needed in this area, but may have recommendations later. Secondly, others have pointed out that addition of new equipment may not necessarily simplify cockpit duties. Additionally, the cockpit routines which are changed by introduction of new equipment may complicate the pilot's job and require changes in learning patterns and instruction which would have to be analyzed for over-all impact on the man-machine-environment-contingency model. Obviously, this process should be carried out in relation to each specific piece of equipment, and is not the subject of this study. Improving our knowledge of the pilot as a decision maker could be enhanced by developing human factors criteria for over-all flight crew-airplane system performance; by improving feedback loops from on-the-job decision making to training requirements; by determining the amount and type of decision information a pilot needs for computer-assisted information processing and developing the criteria for the display system; and attempting to determine control input task unloading during critical flight regimes, with the captain becoming a decision initiator and inhibitor who provides occasional start and override commands.

Various elements of the training environment of the pilot could well be enhanced by knowledge of the information uncovered here. For example, in the 56 non-training/non-midair accidents, decisions most often involved conditions out of tolerance followed by erroneous input information, incorrect weighting of inputs and requirements to make the destination or schedule. Training accidents most often involved decision delayed beyond the time required. Midair collisions most often involved decisions based on requirements to make the destination airport or meet the schedule. This information points to the recommendation that airline training and operational procedures must be updated to improve the reliability of the pilot as an information processor.

Some specific recommendations are made with regard to recognizing needs in accident investigation. First, there is a need for better information collection at the accident site. This information collection must be systematic and subject to verification. It also requires the insured cooperation on the part of all persons conducting the investigation. This naturally implies that the Investigator-in-Charge must be attuned to the human factors potential for each accident and must insure that data collection is not impeded. Human factors investigation personnel are too often concerned with required hospital investigations, visits to mortuaries and other relatively routine matters while human factors information is being collected by operations and ATC groups. We do not hold that operations and ATC investigators are not competent to collect human factors information, but we do believe that the human factors investigator must be constantly apprised of developments. Not only must the Investigator-in-Charge be highly sensitive to the needs in the human factors area and insure proper collection of data, but the Accident Inquiry Manager must also have the same orientation. Secondly, there is need for more information to reconstruct what transpired in the cockpit prior to the crash. The marked gaps in accident data are not only gaps in technical information, as seen by perusal of the matrix, but also significantly large gaps in human error material. The cockpit voice recorder was available in only seven of the 74 accidents studied here. The cockpit voice recorder is the best single source of information on the accident and provides an objective means of judging the cockpit activities prior to the crash. We are aware that there are many reasons why the accident data are missing, but are also aware that a better collecting system would fill in many of the gaps in the future and would result in the collection of more pertinent human error material. Cockpit voice recorders are still being damaged, especially in those crashes where serious fires occur. Further research is needed to insure indestructible cockpit voice recorders. Thirdly, there is a need for a system to let all individuals directly involved in an accident give an unimpeded and straightforward story of what transpired. There is such an overriding consideration of legal liability and vested interests that pressures on all persons directly involved often result in a self-preservation decision which diminishes the reliability of information. As long as legal liability is determined from a single investigation, this problem will continue to present itself. We recommend that consideration be given to congressional legislation which would allow parallel investigations with regard to cause and legal liability. We submit that, in the long run, cause is more important than liability. Fourthly, there is a need for developing a system to allow quick determination of the likelihood that an accident has prominent human factors problems, so that such problems may be recognized and investigated in depth, with the least amount of time spent on other unproductive activities.

The computer-stored information on the human error accidents contains objective, measurable characteristics such as runway length, ceiling, visibility, and pilot time. To this computer information must be added subjective, sensitive descriptions of the flight environment. When we were confronted with the size and bulk of accident information data, the technique devised to overcome this obstacle was for a trained researcher to read the accident report and describe those characteristics which became accident-enabling features. Most of the information derived with this technique were not available in computer-stored information. A good example of this was heavy rain at threshold. Such qualitative data may be recorded in the report, but for computer-stored information, no indication of concentration of rain was given. Neither was the position of the rainshower in relationship to the airport or the runway environment. Another characteristic observed with this technique was off-profile flying that was either high or low, fast or slow, or offset. Again, this information was reported, but no capability existed in computer storage of this information.

Few groups or individuals charged with accident analysis or investigation have been able to overcome the tendency to put greatest emphasis on the accidents associated with death and/or destruction. It is understandable that public attention is focused on the tragic accident, but we cannot agree that only those accidents or incidents deserve such attention. We were only able to use 74 of the over 200 accidents having human error associations because of the paucity of data in the non-tragic cases. The study of accidents involving human error should be justifiable on the grounds of the value of the information gained, and should not be tied to tragic outcome. Just as important is the collection and study of data related to near misses, and we feel a wealth of information is available here. This would be especially so if anonymity were guaranteed and comprehensive systematic investigations were carried out after design of experimental techniques and hypotheses to be tested (17). All parties to a near miss are available, unlike many accidents, and the information could prove invaluable.

Although not specifically shown in the presentation of matrices selected for this paper, we have noted a tendency for aircraft accidents to occur early in duty periods. Also associated was the observation that a number of crews involved in accidents had returned to duty after 16 or more hours off duty and that there is a paucity of accidents noted at the home domicile of the crews. It has been suggested that there may be some relationship to the "warmup" phenomenon seen in industrial accident studies. Further elucidation of this subject is indicated, but in order to firmly establish whether the data are meaningful, it will be necessary to determine what leg in the duty period the crew was in at the time of the accident, the number of landings, etc., in order to determine, among other things, the relative risk of accident at the home domicile.

Practical application of the concepts developed in this paper is desirable. This could take several forms:

1. Testing of the conditions-decisions models for prediction capability,

2. Use of the concepts to develop an expanded human factors accident investigation format,

3. Use of the models for further data evaluation. This could require data expansion and, of course, inherent in the use of the technique is ongoing refinement and improvement as an inescapable function of use,

4. Use of the models in simulator application.

CONCLUSIONS

A multidisciplinary team approach to pilot error-related aircraft accident investigation records has successfully reclaimed hidden human error information not currently shown in statistical studies of accidents. New analytic techniques have been developed and applied to the data in efforts to discover and identify multiple elements of commonality and shared characteristics within this group of accidents.

Three techniques of analysis were employed: (1) cluster analysis and pattern recognition, (2) critical conditions, and (3) critical decisions.

A cluster analysis technique has been modified and applied to the data. This method is an effective exploratory research tool that will lead to increased understanding and improved organization of known facts, the discovery of new meaning in large data sets, and the generation of explanatory hypotheses. The technique also provides a simple automated straight-forward means for visually presenting an otherwise unmanageably large set of data in its entirety in matrix form, for organizing the data, clustering the accidents and disclosing and summarizing the structure of the matrix with a minimum loss of information.

Initial results of the critical element analysis portion of the study have demonstrated the importance of a subjective qualitative approach to raw accident data which has surfaced information heretofore unavailable in succinct detailed summary in records. Using this approach to extract and analyze those causal elements, attributes, events and conditions which significantly contributed or were related to the occurrence of the selected accidents, a model was developed. This model, consisting of critical conditions and critical decisions, was then applied to the training, midair, and non-training/non-midair groups of accidents. Other methods of analysis included the use of a "critical condition screen".

Findings, conclusions and recommendations resulting from this study include:

1. The cluster analysis technique presents a feasible method for establishing meaningful concepts and interrelationships out of a large mass of data otherwise impossible to mentally handle.

2. Critical element analysis supplements and adds perspective to accident data and provides vital insight into real-life operational human factors data in a format amenable to meaningful analysis.

3. An aircraft accident, in our view, is a positive, eminently successful event that is inevitable when preceded by a series of one or more "accident-enabling factors" or conditions which have to be present and without which the accident cannot occur. This approach de-emphasizes pilot "fault" and focuses on the actions and decisions (both proper and improper) that are carried out as well as those factors that prompt these actions and decisions.

4. Human factors data as currently collected are inadequate in defining the "why" of pilot error and the terminology and classification gives no insight into corrective measures.

5. A number of areas have been identified that require more research. These include such items as crew interrelationships (coordination, interaction), decision making, approach monitoring, aircrew fatigue (work/rest schedules), and subtle operational indices of crew stress and performance decrement. Current airline pilot training does not seem to adequately prepare the pilot for the situations encountered in the critical elements identified in this study. Furthermore, details of cockpit activity and events are not known in sufficient detail; cockpit voice recorder data do not provide needed information.

6. There is a need for intensive study into the relationships that exist between pilot, airlines and regulatory bodies, with special attention to defining and understanding how institutional decisions which involve all of these groups interact to affect flight safety.

7. Airline training and operational procedures must be updated to improve the reliability of the pilot as an information processer.

8. There is need for improvement in accident investigation, to include:

a) More systematic collection of human factors data at the accident site.

b) More information to reconstruct what transpired in the cockpit prior to the accident.

c) Improved reliability of information by reassessing pertinent rules and principles of legal liability.

d) Development of an on-site system to allow quick determination of the likelihood that a given accident has prominent human factors aspects. This could lead to a more intensive investigation of human factors features on site, when the information is still fresh.

9. More attention should be focused on the human error aspects of near-accidents and incidents.

APPENDIX A

CLUSTER ANALYSIS AND PATTERN RECOGNITION - BASIC METHODOLOGY

Nature of the Data Set

The data set consists of information collected on aircraft accidents over a period of 12 years. Real data sets of this type present unique problems of analysis. Development of statistical theory generally assumes the use of continuous variables on an interval scale. The data set we considered, however, consists of mixed variable types. For this reason, and the desirability of scale conversion of variables, brief mention will be made of variables and scales.

Usually in mathematics, variables are classified as being binary (dichotomous), discrete, and continuous. Examples of these types of variables in this data set are:

1. Binary variables:

a. Runway lighting	on		off
b. Precipitation	yes		no
c. Condition of light	day		night

2. Discrete variables:

a. Number of engines	two	three	four

3. Continuous variables:
    a. Pilot age
    b. Temperature

Variables, in addition, may be classified on the basis of their measurement scale as nominal, ordinal, interval, and ratio. Examples in this data set include:

1. Nominal ($x_a = x_b$ or $x_a \neq x_b$):
    a. Precipitation

2. Interval (if $x_a > x_b$, a is $x_a - x_b$ units or greater than b):
    a. Temperature

In turn, variables classified by range (binary, discrete, continuous) and by scale (nominal, ordinal, interval, and ratio) may be cross-classified. For example, Pilot 1 may be older than Pilot 2 or Age Pilot 1/Age Pilot 2 means Pilot 1 is so many times older than Pilot 2, or Age Pilot 1 - Age Pilot 2 means Pilot 1 is so many years older than Pilot 2. By scale classification the variable Age is a ratio variable and by range classification the variable Age is a continuous variable.

The pilot is continuously confronted with mixed variable types, including interval, ordinal, binary, and other types. Statistically, as stated previously, an assumption is made usually that variables are continuous and on an interval scale of measurement. Many of the variables in this data set fulfill this requirement; other variables as illustrated do not. In an attempt initially not to weight the variables in the data set as to their relative importance as possible direct or indirect causative factors in pilot error-related events, and not to exclude variables arbitrarily from the data set as being unimportant, variables were scale-converted to what may be called polychotomous variables. For example, airport elevation at which accidents have occurred, or the total range of airport elevation in the U.S., might be sea level (0') to 7200". This continuous variable may be divided into intervals of sea level to 100', 101' to 2000', and over 2000'. Each interval of the variable may be given a "state" or value of logic designation. That is, 0-100' designated by 1, 101-2000' designated 2, and greater than 2000' by 3. One or more variables within the same data set may be scaled into different numbers of states which are given a "value or state of logic." This permits the construction of "truth tables", which consider every possible combination of logic states. For example, if all variables were scaled to binary (dichotomous) values (two states or values of logic) and there were 1, 2, 3, 4, etc., of these variables, the total possible number of binary sequences of yes and no (1 and 0) would be respectively $2^1=2$, $2^2=4$, $2^3=8$, $2^4=16$, etc. (See Table 12.) An important observation is that the truth tables of the higher valued states always contain the sequences of the lower valued states, i.e., truth table C is contained in truth table E (Table 12).

This methodology then permits the analysis of mixed variable types in the same matrix, closely approximating the real world data set. After the variables have been scaled, the data are analyzed by clustering, by truth table analysis to determine the frequency of patterns of variables. This enables one to establish the likelihood of occurrence of patterns as states of variables that contribute to pilot error-related events. Lastly, the method permits the selection of decision variables to be applied in studying the next event to determine if it fits previous variable patterns. The methods used are forms of matrix or concept learning which are correctable as more information becomes available with time. Statistical stability of clusters detects states of variables which may be correctable states for improving flight safety.

By use of automated data processing procedures it is possible to handle large data sets. For purposes of illustration,

TABLE 12

Examples of 2-state (A - D) and 3-state (E) conversion of variables and the possible sequences. These are truth tables and are Boolean expansions of Aristotelean truth tables.

Truth Table:	A	B	C	D	E
	2^1	2^2	2^3	2^4	3^3
	1	11	111	1111	222
	0	10	110	1110	221
		01	101	1101	220
		00	100	1100	212
			011	1011	211
			010	1010	210
			001	1001	202
			000	1000	201
				0111	200
				0110	122
				0101	121
				0100	120
				0011	112
				0010	111 ←*
				0001	110 ←
				0000	102
					101 ←
					100 ←
					022
					021
					020
					012
					011 ←
					010 ←
					002
					001 ←
					000 ←

*Arrows indicate where truth table C sequences are contained within truth table E.

to show how the methodology described can be used to draw conclusions concerning contingency relationships in accidents, a small and generalized example will be given using a total of 27 accidents and four variables scaled to 3-valued logic. The nature of the data set is such that data are collected as they become available in time, with the occurrence of each event. Data on selected variables are systematically collected as well as data for any other variable which appears applicable. The data are presented in the format of a matrix of events-versus-variables with the state of the variable indicated at the proper cell in the matrix.

Initially, data may be recorded sequentially for 13 events over four variables scaled into 3-valued logic (2, 1, 0), with "2" assigned the highest value of logic (see Table 13). For each variable, over all events, the numbers (N) of each state of logic are enumerated (N_2, N_1, N_0) (Matrix A, Table 13). The columns (variables) are then rearranged in descending order of the highest level of logic (leftmost column has greatest total of "2's") (Matrix B, Table 13). Each row pattern in Matrix B is traced on the truth table in Table 14 (solid black square = 2, open square with dot = 1, open square = 0) and the rows of Matrix B are rearranged vertically in their order of occurrence in Table 14. Three large clusters of five, three and five events (outlined with lines) are formed, each having subclusters (Matrix C, Table 13).

The reason for applying this clustering methodology is that all clusters and subclusters are logically disjoint. This means that when the next event occurs the pattern of states of the variables may be identified uniquely as belonging to a particular cluster and the same as some event in the cluster. Classification (synonomous here with the formed clusters) and identification are considered inverse mental activities. Clustering or classifying and the clusters and classes so formed are considered a matter of induction because we do not have every possible event and we infer that the classes or clusters are stable and significant. Inversely, identification is considered a matter of deduction. If the next event is not identifiable, however, the values for the variables are added to the matrix and the resulting updated matrix reclustered. This process is shown in Table 13, Matrices D, E, and F. Clusters in Matrices C and F may be summarized. This is sometimes preferable, especially when the number of events becomes very large. These clusters are formed by "relatedness" of states of variables and provide insight for discovering possible new heretofore unsuspected relationships within these events (accidents). An advantage of using clustering is that known data are all considered within one matrix. These clusters demonstrate a structure in the data set and the relationships of patterns of variables to events, with a minimum loss of information. This would not be possible if the data were abstracted further. In addition, as data are accumulated, it is possible to determine the sensitivity and statistical stability of the clusters. This forms a basis for the study of relationships of variables and factors within the events. These are learning matrices, as described by Rypka (18).

TABLE 13

An illustration of data accumulation with time concerning pilot error-related events (E, vertical axix) and four characteristics (C) or variables scaled to 3-valued logic (horizontal axis).
Matrix A represents 13 events. The number of occurrences of values of logic (N_2, N_1, N_0) for each variable are enumerated.
In Matrix B the variables (columns) are rearranged in descending order of the highest N values.
Matrix C shows vertical rearrangement of events (rows) corresponding to the order found in the truth table of Table 14. The data begin to show structure and patterns of clusters.
Data on 14 new events are added and the same procedure of horizontal and vertical rearrangement of data is performed in the expanded new data set (Matrices D, E, F). With time and accumulation of data, the sensitivity and statistical stability of clusters can be determined and may form the basis for action. From these data, the likelihood of the occurrence of a given pattern may also be determined.

MATRIX A

DATA ACCUMULATION

E/C	1	2	3	4
1	0	0	1	0
2	0	2	1	0
3	1	1	2	1
4	2	0	2	2
5	1	2	0	0
6	1	0	1	1
7	2	1	1	0
8	0	2	2	1
9	1	1	2	1
10	0	2	1	2
11	0	2	0	0
12	2	0	1	0
13	2	0	1	2
N_2	4	5	4	3
N_1	4	3	7	4
N_0	5	5	2	6

MATRIX B

HORIZONTAL REARRANGEMENT

E/C	2	3	1	4
1	0	1	0	0
2	2	1	0	0
3	1	2	1	1
4	0	2	2	2
5	2	0	1	0
6	0	1	1	1
7	1	1	2	0
8	2	2	0	1
9	1	2	1	1
10	2	1	0	2
11	2	0	0	0
12	0	1	2	0
13	0	1	2	2

MATRIX C

VERTICAL REARRANGEMENT

E/C	2	3	1	4
8	2	2	0	1
10	2	1	0	2
2	2	1	0	0
5	2	0	1	0
11	2	0	0	0
3	1	2	1	1
9	1	2	1	1
8	1	1	2	0
4	0	2	2	2
13	0	1	2	2
12	0	1	2	0
6	0	1	1	1
1	0	1	0	0
N_2N_1	15	28	16	12
N_2N_0	25	8	20	18
N_1N_0	15	14	20	24
S =	55	50	56	54

MATRIX D

ADDITIONAL DATA ACCUMULATION

E/C	2	3	1	4
8	2	2	0	1
10	2	1	0	2
2	2	1	0	0
5	2	0	1	0
11	2	0	0	0
3	1	2	1	1
9	1	2	1	1
7	1	1	2	0
4	0	2	2	2
13	0	1	2	2
12	0	1	2	0
6	0	1	1	1
1	0	1	0	0
(Additions)				
14	0	2	2	0
15	1	1	0	1
16	2	2	2	0
17	0	1	1	0
18	0	2	2	2
19	1	0	2	0
20	1	0	2	1
21	0	2	2	1
22	0	2	0	2
23	1	0	1	1
24	0	2	2	0
25	1	1	1	2
26	1	0	2	2
27	2	1	0	1
N_2	7	10	12	7
N_1	9	11	7	9
N_0	11	6	8	11

MATRIX E

HORIZONTAL REARRANGEMENT

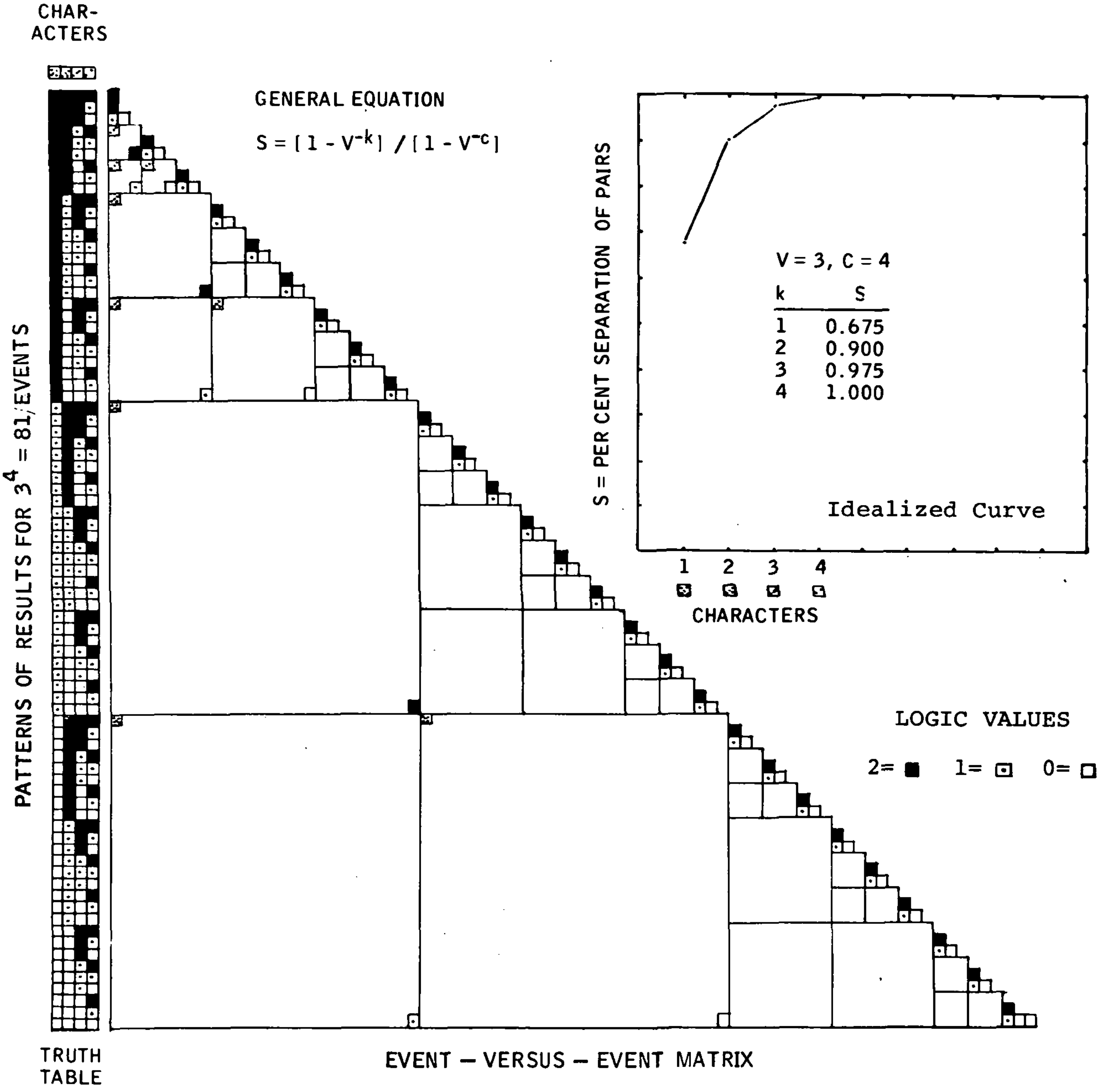
E/C	2	4	1	3
8	2	1	0	2
10	2	2	0	1
2	2	0	0	1
5	2	0	1	0
11	2	0	0	0
3	1	1	1	2
9	1	1	1	2
7	1	0	2	1
4	0	2	2	2
13	0	2	2	1
12	0	0	2	1
6	0	1	1	1
1	0	0	0	1
14	0	0	2	2
15	1	1	0	1
16	2	0	2	2
17	0	0	1	1
18	0	2	2	2
19	1	0	2	0
20	1	1	2	0
21	0	1	2	2
22	0	2	0	2
23	1	1	1	0
24	0	0	2	2
25	1	2	1	1
26	1	2	2	0
27	2	1	0	1

MATRIX F

VERTICAL REARRANGEMENT

E/C	2	4	1	3
10	2	2	0	1
8	2	1	0	2
27	2	1	0	1
16	2	0	2	2
5	2	0	1	0
2	2	0	0	1
11	2	0	0	0
26	1	2	2	0
25	1	2	1	1
20	1	1	2	0
3	1	1	1	2
9	1	1	1	2
23	1	1	1	0
15	1	1	0	1
7	1	0	2	1
19	1	0	2	0
4	0	2	2	2
18	0	2	2	2
13	0	2	2	1
22	0	2	0	2
21	0	1	2	2
6	0	1	1	1
14	0	0	2	2
24	0	0	2	2
12	0	0	2	1
17	0	0	1	1
1	0	0	0	1
N_2N_1	63	110	84	63
N_2N_0	77	60	96	77
N_1N_0	99	66	56	99
S =	239	236	236	239

TABLE 14 *



$$S = [1 - V^{-k}] / [1 - V^{-c}]$$

V = 3, C = 4

k	S
1	0.675
2	0.900
3	0.975
4	1.000

An idealized illustration of multi-valued logic is shown. In this example, four characters having 3-valued logic (3^4=81 patterns) are listed in the truth table at the left. These could represent 81 unique possible patterns of events. The event-versus-event matrix lists the comparison of every pair of patterns. When values for a given variable differ, the two events are separable or disjoint. In this ideal case, all pairs of patterns (events) are separable. The progressively smaller squares within the matrix represent the numbers of pairs separated by each variable conditionally independent of the other variables. The idealized curve for the percent separation of pairs, calculated using the general equation, is shown in the Table. Real data, clustered by the truth table method shown in Table 13, are made to approximate the ideal curve as closely as possible.

*Rypka, E. W. Pattern Recognition as a Method of Studying Host-Parasite Interaction. 1972 International Conference on Cybernetics and Society, Washington, D.C.

APPENDIX B

CLUSTER ANALYSIS AND PATTERN RECOGNITION - DETERMINATIVE AND IDENTIFICATION METHODOLOGY

The theoretical aspects of separation and partitioning of events are shown in Table 14. The truth table shown at the left consists of four 3-state variables (3^4=81 possible patterns of results). Each row is compared with every other row, and the variable(s) that separate(s) a given pair of rows (events) (actually the event's "partitioning variables") is recorded in the "event-versus-event" matrix. In this case there are $e(e-1)/2$ (e=event) or $81(80)/2 = 3240$ pairs of events to separate. We wish to analyze the next event in terms of optimal selection of variables so that an identification can be made in the most accurate, systematic, rapid and economical manner.

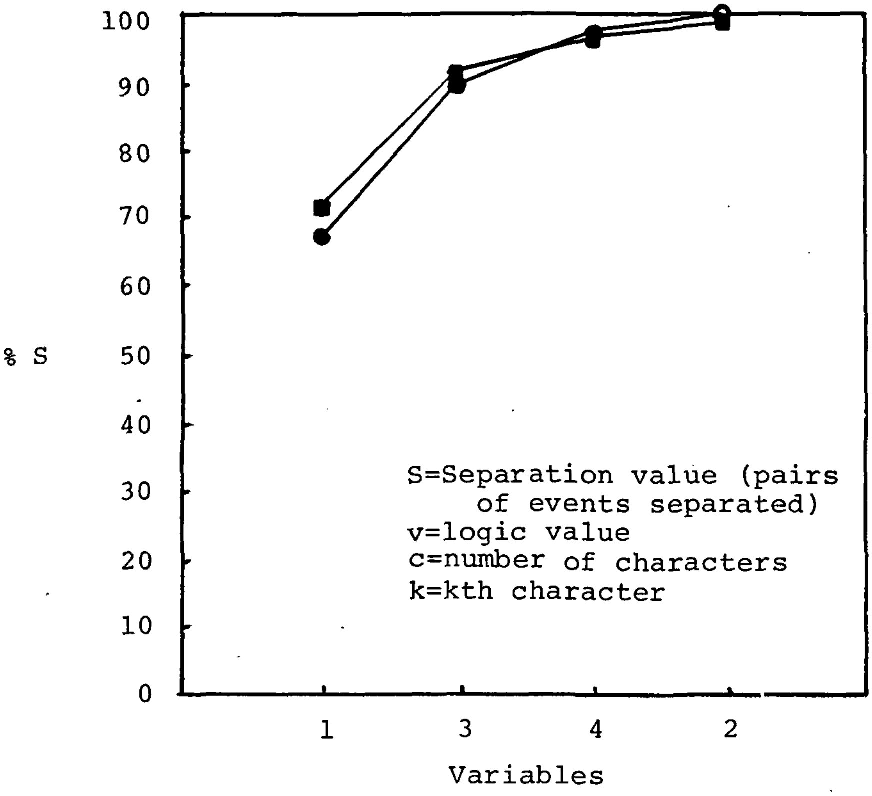
The general identification equation is:

$$S = [1 - v^{-k}]/[1 - v^{-c}]$$

S = separation value for the variable
v = state or value of logic (3 in this case)
k = kth character or variable
c = number of characters or variables

An example of the equation is used in Figure 11. It is necessary next to select variables (for example, from Matrix C and Matrix F, Table 13) so that the pairs of events are separated at a rate that most closely approximates the general case. To do this, variables are selected in sequence so that the first variable separates the most pairs. The second variable separates the most pairs conditionally independent of the first selected variable, etc. Ideally every combination of variable, C^n_r, should be tested but hardware limitations soon become evident because of the large number of combinations to be studied. The empirically determined variable selection and rate of separation of pairs of events for Matrix C of Table 13 are shown in Table 15.

When sufficient data become available, it is then possible to assume that each variable is statistically independent of the others and, with optimal selection of variables as just discussed, to calculate the likelihood for each pattern of variables. This provides a basis for predicting the likelihood of human error-related events for patterns of various states of variables. It



General Identification Equation

$$S = [1-v^{-k}]/[1-v^{-c}]$$

$v=3$, $c=4$

Theoretical●	Matrix C*■
0.675	0.718
0.900	0.910
0.975	0.962
1.000	0.987

*Table 14 illustrates an ideal case.

Figure 11. The theoretical rate of separation or partitioning of events and separation based upon data in Matrix C of Table 13. Variables selected to separate events that most closely fit the theoretical curve means identification of future events is being done at the fastest rate.

TABLE 15

EVENT-VERSUS-EVENT MATRIX

	8	10	2	5	11	3	9	7	4	13	12	6	1
8													
10	3 4												
2	3 4	4											
5	1 3 4	1 3 4	1 3										
11	3 4	3 4	3	1									
3	1 2	1 2 3 4	1 2 3 4	2 3 4	1 2 3 4								
9	1 2	1 2 3 4	1 2 3 4	2 3 4	1 2 3 4								
7	1 2 3 4	1 2 4	1 2	1 2 3	1 2 3	1 3 4	1 3 4						
4	1 2 4	1 2 3	1 2 3 4	1 2 3 4	1 2 3 4	1 2 4	1 2 4	2 3 4					
13	1 2 3 4	1 2	1 2 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	2 4	3				
12	1 2 3 4	1 2 4	1 2	1 2 3	1 2 3	1 2 3 4	1 2 3 4	2	3 4	4			
6	1 2 3	1 2 4	1 2 4	2 3 4	1 2 3 4	2 3	2 3	1 2 4	1 3 4	1 4	1 4		
1	2 3 4	2 4	2	1 2 3	2 3	1 2 3 4	1 2 3 4	1 2	1 3 4	1 4	1	1 4	

Variable selection in an event-versus-event matrix. Data are from Matrix C, Table 13. Each event in the matrix is compared with every other event. Variable states that separate events are entered in the squares in this table. Variable selection for identification is done so that the first best variable is the one separating the most pairs of events. The second variable is the one separating the most pairs of events conditionally independent of the first variable, etc. This optimal partitioning is shown in Figure 11.

also allows for avoiding and for correcting against combinations of variable states, based upon previous experience, that were present in accidents and have a high likelihood of occurrence. To illustrate this method, using variables from our data set, four variables were selected from the matrix of the 56 non-training/non-midair accidents found in Figure 4. (The method is also illustrated elsewhere in this report on critical element data.)

Table 16 summarizes the steps taken in computing separation or partitioning information on the 49 variables. The number of logic states for each variable in Table 16, over the 56 events, is listed. Five-valued logic (1 through 5, in descending value of logic) was used. Logic states "8" ("not applicable") and "9" ("no data") were omitted from the calculation of the S value for each variable. The value S represents the number of pairs of events a given variable will separate. The lower two lines in the table list the variables rearranged in descending order of their S values. Arbitrarily, the first four variables (numbers 03, 16, 17 and 18), in 3-valued logic, are selected to illustrate the capability of predicting "likely and unlikely" combinations of variable states (patterns), based on accumulated data. The variables selected are listed below:

	Variable		Logic Value
03	Phase of operation	Landing	1
		Approach	2
		Departure	3*
16	Total flight time	Under 3500	1
		3500 - 10,000	2
		Over 10,000	3
17	Hours in type (Captain)	0 - 500	1
		501 - 2000	2
		Over 2000	3
18	Hours in type (First Officer)	0 - 500	1
		501 - 2000	2
		Over 2000	3

*In this example, "3" includes inflight, departure, takeoff to first power reduction and static/ramp.

From the summary of the data set in Table 16, the frequency of occurrence of the states for the variable are:

Logic State	Variable			
	03	16	17	18
1	0.429*	0.250	0.327	0.473
2	0.250	0.339	0.454	0.400
3	0.321	0.411	0.218	0.127

*$N_1/N_1 + N_2 + N_3$

TABLE 16

COMPUTATION OF S-VALUES[1]

	Variable Number:	07	00	22	04	02	25	29	11	18	09	03	21	10	20	17	26	45	35	16	13	46	28	32	30
Logic State Frequency Count	n_1	40	36	31	30	28	27	26	27	26	25	24	22	19	19	18	16	15	14	14	13	11	11	10	9
	n_2	9	10	15	26	24	27	18	11	22	18	14	3	17	28	25	1	26	26	19	7	17	13	9	16
	n_3	6	10	8	0	3	0	0	0	7	0	5	29	6	6	12	35	12	13	23	4	10	9	8	0
	n_4	0	0	0	0	1	0	0	0	0	0	11	0	0	0	0	0	0	0	0	1	0	0	0	0
	n_5	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
	n_8	1	0	0	0	0	0	4	5	0	6	0	0	7	0	0	0	0	0	0	30	0	4	0	18
	n_9	0	0	2	0	0	2	8	12	1	7	0	2	7	3	1	4	3	3	0	1	18	19	29	13
	$n_1 \times n_2 =$	360	360	465	780	672	729	468	297	572	450	336	66	323	532	450	16	390	364	266	91	187	143	90	144
	$n_1 \times n_3 =$	240	360	248		84				182		120	638	114	114	216	560	180	182	322	52	110	99	80	
	$n_1 \times n_4 =$					28						264									13				
	$n_1 \times n_5 =$											48													
	$n_2 \times n_3 =$	54	100	120		72				154		70	87	102	168	300	35	312	338	437	28	170	117	72	
	$n_2 \times n_4 =$					24						154									7				
	$n_2 \times n_5 =$											28													
	$n_3 \times n_4 =$											55									4				
	$n_3 \times n_5 =$											10													
	$n_4 \times n_5 =$											22													
Separation (Partitioning) Value	S =	654	820	833	780	880	729	468	297	908	450	1107	791	539	814	966	611	882	884	1025	195	467	359	242	144

Variable Number[2]:	03	16	17	18	01	35	45	02	23	31	22	24	00	20	06	05	15	21	37	4	34	19	43	25
S-Value:	1107	1025	966	908	898	884	882	880	879	839	833	822	820	814	813	809	799	791	785	780	773	743	731	729

[1] S=the number of pairs of accidents a given variable partitions.

[2] Variables rearranged in descending order of S-value

24	27	1	23	41	39	19	31	37	33	38	12	47	35	48	8	34	43	44	40	42	5	15	6	14
9	8	8	7	7	7	6	5	5	5	5	4	4	4	4	3	2	2	2	2	2	1	1	1	0
12	11	18	22	12	8	35	22	22	15	13	17	11	9	7	10	19	19	15	10	10	26	24	15	1
34	3	29	25	11	7	13	27	25	16	20	26	37	41	27	34	35	33	23	1	2	29	31	18	55
0	21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	6	0	0	0	0	0	0	0	0	0	6	0	0	0	6	0	0	0	2	0	0	0	3	0
1	7	1	2	26	34	2	2	4	20	18	3	4	2	18	3	0	2	16	41	42	0	0	4	0
																				20	26	24	15	
108	88	144	154	84	56	210	110	110	75	65	68	44	36	28	30	38	38	30	20	4	29	31	18	
306	24	232	175	77	49	78	135	125	80	100	104	148	164	108	102	70	66	46	2				15	
	168																							
																				20	754	744	270	55
408	33	522	550	132	56	455	594	550	240	260	442	407	369	189	340	665	627	345	10				225	
	121																							
																							270	
	63																							
822	547	898	879	293	161	743	839	785	395	425	614	599	569	325	472	773	731	421	32	44	809	799	813	55
7	12	26	47	36	27	10	8	29	46	9	38	44	35	28	48	11	41	32	13	39	30	14	42	40
654	614	611	599	569	547	539	472	468	467	450	425	421	395	359	325	297	293	242	195	161	144	55	44	32

Then, the likelihood of the following patterns of variable states would be:

	Variable					Likelihood	Normalized*
	03	16	17	18			
Logic State Pattern	3	1	3	3			
Frequency	(0.321)x(0.250)x(0.218)x(0.127)				=	0.0022218	0.0554274
Logic State Pattern	1	3	2	1			
Frequency	(0.429)x(0.411)x(0.454)x(0.473)				=	0.0378630	0.9445725
					Sum	0.0400848	

*By dividing the likelihood by the sum of likelihoods.

From the preceding normalized likelihoods the inference would be made that variable states pattern 1, 3, 2, 1 for the four variables 03, 16, 17 and 18 has a high likelihood of occurrence and that the information in this pattern should be further investigated.

In summary, by clustering, optimally selecting variables, and calculating likelihood, it is possible, using real data sets to gain insight into combination of variable states, to determine likely and unlikely combinations thus providing some degree of predictability to pilot error-related aircraft accidents.

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