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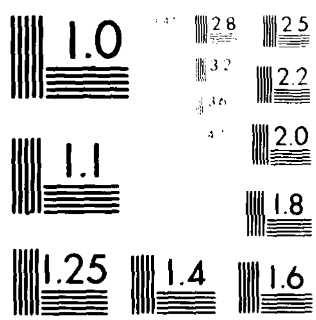

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Report No. ASP 80-2

EVALUATION OF SAFETY PROGRAMS WITH RESPECT TO THE CAUSES OF GENERAL AVIATION ACCIDENTS

VOLUME I: TECHNICAL REPORT

May 1980

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

Prepared for

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
Office of Aviation System Plans
Washington, D.C. 20591

NOTICE

GENERAL AVIATION ACCIDENT CODES USED IN
THE SAFETY PROGRAM ALIGNMENT ANALYSIS

Code	Description
A	Ground-Water Loop-Swerve
B	Dragged Wingtip, Pod, or Float
C	Wheels-up
D	Wheels-Down Landing in Water
E	Gear Collapsed
F	Gear Retracted
G	Hard Landing
H	Nose Over/Down
I	Roll Over
J	Overshoot
K	Undershoot
L0	Collision with Aircraft - Both in Flight
L1	Collision with Aircraft - One Airborne
L2	Collision with Aircraft - Both on Ground
M0	Collision with Ground/Water - Controlled
M1	Collision with Ground/Water - Uncontrolled
N	Collision with Wires, Trees...other
P	Bird Strike (Collision with Birds)
Q	Stall
R	Fire or Explosion
S0	Airframe Failure - In Flight
S1	Airframe Failure - On Ground
T	Engine Tearaway
U	Engine Failure or Malfunction
V	Propeller/Rotor Failure
W	Propeller/Rotor Accident to Person
Y	Propeller/Jet/Rotor Blast
0	Turbulence (Z). Hail Damage to Aircraft (0), Lightning Strike (1)
2	Evasive Maneuver
4	Ditching
5	Missing Aircraft, Not Recovered
6	Miscellaneous/Other
7	Undetermined

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GENERAL AVIATION CAUSE/FACTOR CODES USED IN THE SAFETY PROGRAM ALIGNMENT ANALYSIS

C/F Code	Description
64*1Z	Judgment
64*2Z	Operational decision
64*3Z	Procedures, regulations, etc.
64*4Z	Operation of equipment
64*5Z	Attention/Awareness
64*6Z	Perception
64*7Z	Physical
68*00	Other personnel--random occurrences
68*3Z	Other personnel--procedures, etc.
70*CA	Airframe--main gear--shocks
70*CB	Airframe--landing gear retraction
70*CC	Airframe--landing gear--emergency extension
70*CE	Airframe--landing gear--nosewheel
70*CF	Airframe--landing gear--wheels
70*CJ	Airframe--landing gear--brakes
70*CM	Airframe--landing gear--locking
70*00	Airframe--random occurrences
74*AB	Powerplant--structure crankshaft
74*AC	Powerplant--structure--rods
74*AD	Powerplant--structure--cylinder
74*AE	Powerplant--structure--piston
74*AF	Powerplant--structure--values
74*AY	Powerplant--structure--other
74*BA	Powerplant--ignition mags
74*BC	Powerplant--ignition sparkplugs
74*CG	Powerplant--carburetor
74*CH	Powerplant--fuel pumps
74*CJ	Powerplant--fuel vents
74*DB	Powerplant--fuel lines
74*DB	Powerplant--lubrication lines
74*FA	Powerplant--propeller--blades
74*IO	Powerplant--engine throttle
74*KA	Powerplant--failure undetermined
74*00	Powerplant--random occurrences
75*00	Systems--random occurrences
76*00	Instruments/Equipment--random
78*00	Rotorcraft--random occurrences
80*BC	Airport condition--snow
80*BD	Airport condition--snow windrows
80*BJ	Airport--hidden hazard
80*BY	Airport condition--other
80*00	Airport/Airways--random
82*C	Weather--carburetor icing
82*H	Unfavorable winds
82*J	Sudden windshift
82*M	Downdrafts/Updrafts
82*00	Weather--random occurrences
84*C	Foreign object damage
84*I	Undetermined cause
84*J	Written cause
84*00	Miscellaneous causes
84*1	Vortex turbulence
84*3	Animals on runway
84*7	Evasive maneuver
84*8	Unqualified person--operate aircraft

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
ASP-80-2 ASP-80-2A	AD-A087685	

4. Title and Subtitle	5. Report Date
Evaluation of Safety Programs with Respect to the Causes of General Aviation Accidents. Volume I. Technical Report. ~~Volume II: Appendices~~	May 1980
	6. Performing Organization Code
	8. Performing Organization Report No.

7. Author(s)	
T. M. Connor & C. W. Hamilton	

9. Performing Organization Name and Address	10. Work Unit No. (TRAIS)
Batelle Columbus Laboratories 505 King Avenue Columbus, Ohio 43201	11. Contract or Grant No. DOT-FA78WA-4159
	13. Type of Report and Period Covered

12. Sponsoring Agency Name and Address	14. Sponsoring Agency Code
Federal Aviation Administration Office of Aviation System Plans 800 Independence Ave., S.W. Washington, D.C. 20591	

15. Supplementary Notes

16. Abstract The objective of this study was to determine the extent to which the FAA safety programs were aligned with the causes of general aviation accidents. The data base used in this study consisted of a total of 30,592 general aviation accident records compiled by the National Transportation Safety Board (NTSB) from 1971 through 1977. Analysis of these records was made with respect to NTSB-cited cause/factors. FAA programs implemented during the study time period and pertaining to safety were also included in this study.

Conclusions of this study are:
1. No substantive change is required with respect to mechanical safety programs
2. Operating environmental safety programs have been effective in mitigating hazards.
3. Existing safety programs relating to human error need improvement in mitigating the human error oriented causes of accidents.

Recommendations for further improvement of general aviation safety are:
1. Implementation of new investigative strategies for aircraft accidents, including non-fatal as well as fatal accidents;
2. Definition and development of the requirements for FAA safety related aviation data;
3. Creation of a comprehensive single-source data system;
4. Investigation of participation in safety programs by various system user groups.

17. Key Words	18. Distribution Statement
General aviation; Safety; Accidents National Aviation System (NAS) Human error; Safety Programs National Transportation Safety Board (NTSB)	A-W (AF/AM/AT/EM/FO/RD/WS/SF)-2; A-X (AF/AM/AS/AT/FS)-2; A-Y (AM)-2; A-Z (AM/AF/SA)-2; A-FAT-1 (Ltd); A-FFS-1,2,7 (Ltd).

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

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

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EXECUTIVE SUMMARY

This report provides an assessment of the Federal Aviation Administration (FAA) safety programs with respect to the causes of general aviation accidents. This evaluation has been made in support of FAA planning aimed at improving safety in the National Aviation System (NAS). It follows, and is very similar to, an earlier study focused specifically on air carrier accidents.

In its responsibilities for safety in the NAS, the FAA continually conducts safety research and development, installs facilities and equipment, provides operational procedures, and implements and enforces regulatory standards. These programs, in conjunction with aviation safety activities of other Government agencies and the aviation industry, have contributed to an impressive aviation safety record. Yet, accidents still occur, resulting in loss of life and property damage. Further, the aviation environment is constantly changing, manifested by increasing traffic and congestion, more sophisticated equipment, more complex operational procedures, etc.--all imposing new demands for maintaining safety in future aviation activity. To meet these demands for maintaining safety, the FAA recognizes the need for empirical assessments of the effectiveness of its current safety programs--the extent to which its safety programs are aligned with accident causes, and their effectiveness in mitigating these causes--as a baseline for guiding future safety initiatives.

The purpose of this study was to provide such a safety assessment. Specifically, it was the objective of this study to determine the extent to which the FAA safety programs were aligned against general aviation accidents. This study and the earlier air carrier study extended and refined a preliminary analysis made by FAA's Office of Aviation System Plans in 1976. This earlier study consisted of quantifying and allocating air carrier accident costs for the time period 1966-1975 to the probable causes of the accidents reported in the National Transportation Safety Board (NTSB) accident data base. The results suggested that such an assessment procedure constituted a practical and useful approach for safety program evaluation where both air carrier and general aviation accidents were concerned. However, the existence of several problems made it difficult to establish direct linkages between accident

cause/factors and safety programs. For example, in some instances, accident cause/factor citations used by the NTSB dealt with symptomatic attributes of an accident; accounting for what occurred, but not explaining why the accident occurred. Further, most accident records consisted of citations of multiple, related cause/factors. These multiple citations often contained redundancies and associated, but not causative, circumstances that were only spuriously related to the evaluation of safety program effectiveness.

The foregoing and other findings revealed in FAA's preliminary analysis of air carrier accident causes suggested data base and methodological requirements for the conduct of Battelle's earlier air carrier study. These same requirements were, in the main, applicable to this study. It was necessary to:

a. Modify the NTSB accident cause/factor framework to facilitate proper alignment of accident causes and safety programs

b. Develop a comprehensive listing, description and categorization of FAA's safety programs to be used in the alignment analysis

c. Develop criteria and methodology for aligning safety programs and accident causes

d. Develop criteria and methodology for evaluating FAA's current safety programs and identifying needs for future safety programs and related activities.

However, this study involving general aviation accidents presented a unique problem. Unlike the air carrier sector, general aviation is a very heterogeneous aviation sector with widely differing aircraft, uses, and applicable regulations. Treating it in the aggregate would, it was believed, have offered little chance of developing the necessary insights. Thus, it was necessary to find some basis for disaggregating it into suitably homogeneous subpopulations for the purpose of evaluating the effectiveness of safety programs.

This evaluation is based principally on assessments of the effectiveness of identified safety programs in mitigating the frequency of occurrence and associated costs of general aviation accidents. Toward this end, a study design was established in accord with the following specific objectives:

a. To identify safety programs that, singularly or in combination with other programs, are aligned with accident causes and are effective in mitigating these causes

b. To identify safety program needs including redirection of existing programs and description of program gaps associated with mitigation effectiveness and/or nonaligned accident causes

c. To identify accident safety information needs that would facilitate continuing aviation safety program planning, analysis, and evaluation.

It is important to recognize the limitations imposed by the quantity and quality of the data used in this investigation, especially in making decisions to add or abandon any single safety program. The principal qualifications that should be recognized in interpreting and using the results of this study are as follows:

(1) The infrequent occurrence of most cause/factors prohibits detection of statistically significant trends or shifts in rate of occurrence possibly attributable to safety program effects. Thus, the effectiveness of a given program cannot be evaluated based strictly on statistical analysis of these empirical data.

(2) In the modified cause/factor framework, the human error codes listed in the NTSB Manual of Code Classification (MCC) were aggregated under six more explanatory codes. Assignment of these modified codes is inferential; i.e., these errors are not directly observable. The validity of these inferences, and hence, appropriateness of the substitute code uses, depends on careful reconstruction of pilot/crew actions in the accident event chain. In cases where the accident report contains sketchy or incomplete data (as is typical of many general aviation accident records) it is difficult to support valid assignment of these inferential codes. Thus, caution is required in properly making and interpreting substitute code assignments.

(3) Caution should be exercised in comparing absolute frequencies of individual cause/factor citations. In the modified cause/factor framework, some codes used in this study are aggregations of individual codes (within major categories) that were cited infrequently over the study period. Other codes, especially the human error substitutes codes, are also higher level cause/factors than the invididual codes in the mechanical and environmental categories.

(4) Safety programs have been classified as being directly or indirectly aligned against corresponding cause/factors. It should be noted that an indirectly aligned program should not be necessarily construed as being less effective than a directly aligned program. Sufficient conditions for program effectiveness entail additional criteria concerning relationships to complementary programs and the accumulation of technical knowledge underlying a given program.

(5) Safety programs not aligned or aligned against infrequently cited cause/factors should not be necessarily construed as being unwarranted. Indeed, infrequent cause/factor citation may be a consequence of an effective safety program. A decision to abandon a program should be based on engineering and operational considerations as well as on statistical analysis of accident data.

(6) The effectiveness of a single program depends on its relationship with other programs. That is, there is a synergism among interconnected programs that often results in effective mitigation of hazards in the aviation system. This effect is especially apparent in programs directed toward cause/factors in the mechanical category.

CONCLUSIONS

The primary conclusions of this safety program evaluation concern safety gaps, program balance, and future needs. These conclusions are summarized below for the three major program areas: mechanical safety programs, environmental safety programs, and human error safety programs.

First, no substantive changes in the mechanically-oriented safety programs are needed. The existing programs have been effective in mitigating the associated hazards. This conclusion is also in keeping with the observation that these programs are balanced with respect to their coverage of the major cause/factor categories and include features which provide for effective feedback from the world of day-to-day operations.

Second, the environmentally-oriented safety programs have been effective in mitigating hazards. These programs are of two kinds--those pertaining to the operating system and those relating to meteorological matters. Neither the weather- nor system-oriented cause/factors are frequently cited as accident causes. However, current accident investigation practices are not conducive to revealing the true role played by weather and system factors in inducing accidents. Undoubtedly, this explains why most programs of this type were conceived by deductive reasoning and not predicated on accident data. Thus, the conclusion that environmental safety programs have been effective must be viewed as highly qualified.

Third, the existing safety programs relating to human error are totally ineffective in mitigating the human-error oriented causes of accidents. Human error as a primary accident cause accounts for the majority of all general aviation accidents. The figure ranges from a low of 65 percent in the subpopulation Corporate, Turboprop and Turbojet to a high of 84 percent for Instructional, Single- and Multi-Engine Piston. The observed ineffectiveness and the fact that most such programs are very general in nature are believed to be correlated. However, it should be hastily added that this lack of specificity appears to stem from the current poor grasp of the role of human error in accident causation.

In addition to the above conclusions, other observations were recorded which have a strong bearing on the fundamental problems discussed above.

First, the NTSB accident records used in this study are not well suited to safety analysis purposes. In part, the deficiencies experienced trace to the fact that system safety analysis considerations were not factored into the design of the system. Further, and specific to the case of general aviation accidents, the quality of investigation made of different types of accidents is very nonuniform. This leads to data of questionable statistical significance.

Second, there are serious deficiencies in the generation and handling of general aviation data which could make important contributions to hazard analysis and safety program formulation. Some badly needed data are not collected; other data are collected with no eye to the needs of safety analysis; yet other data, which could be useful, are not retained or used. All of the above derives from the absence of a systematic safety assessment program.

Third, there are some major anomolies in the relationships between degrees of regulation on the one hand and safety performance for different subpopulations of general aviation. This is attributed to the fact that, even though the FAA promulgates many training and educational programs in addition to its regulatory safety programs, infrequent users of the NAS tend also to be infrequent participants in these programs. Thus, independent of improved safety performance directly attributable to pilot skills based on experience, greater attention is warranted in improving safety through incentives aimed at encouraging participation of infrequent users in the available training/educational programs.

RECOMMENDATIONS

Almost without exception, the FAA has done an exceptional job in conceiving and implementing safety programs attuned to the character of system hazards, as such hazards have been identified. These efforts have had a most significant impact in mitigating these system hazards, especially in the mechanical and environmental areas. The remaining primary hazards reside in the area of human error. The lack of substantial progress on this front is not the result of any failure to implement programs for recognized hazards. To the contrary, it is linked to the current lack of insight into the nature of the problems in this regime. A serious need exists to lay into place the ingredients of a system safety assessment process to rectify this problem. The following recommendations are related to this need.

First, the NTSB and FAA should work toward redefining the manner in which accidents are investigated, and accident records developed, to optimize the characterization of safety hazards. The current accident data are not structured for this purpose. Further, the variability in accident investigations undermines the statistical relevance of the data collected. A disproportionate amount of attention is given to fatal accidents and accidents in the Air Taxi and Corporate segments. While in some other segments accidents are so prevalent as to pose serious investigative-cost problems, a thorough investigation of some fraction of accidents in these other segments should be possible and would prove helpful in developing a broader perspective of the general aviation safety problem.

Second, effort should be expended to capture and use a variety of data already available to FAA which would aid the cause of safety. This problem results from the fact that there exists no formal safety analysis process in the human factors area. Were such a program in place, there would be a natural proclivity to generate needed information and use that which is available.

Third, the FAA, NTSB, and other involved/interested parties should work toward the development of a comprehensive single-source data system for safety purposes, especially in the human error area. Such a system would entail a lexicon of safety terminology, a definition of data requirements, an integration of sources, and a plan for multi-year retention of data.

Fourth, the FAA should initiate efforts to better understand the barriers (attitudinal, economic, etc.) that limit the full participation of some persons in the system safety programs already in place. Improved insights here might lead to a way to program innovations which could make for marked improvement in the safety record of a group such as Personal flying.

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CHAPTER 1. INTRODUCTION

This report covers an assessment of Federal Aviation Administration (FAA) safety programs with respect to the causes of general aviation accidents. This study--and an earlier study dealing with air carrier accidents--was conducted in support of FAA planning aimed at improving safety in the National Aviation System (NAS).

In its responsibilities for maintaining and improving safety in the NAS, the FAA conducts safety research and development, installs facilities and equipment, provides operational procedures, and implements and enforces regulatory standards. These programs, in conjunction with aviation safety activities of other Government agencies and the aviation industry, have contributed to continuing improvement in aviation safety. Yet, general aviation accidents still occur at a rate of approximately 13 per 100,000 flight hours resulting in loss of life and property damage valued at a cost of over $500 million annually. Further, the aviation environment is constantly changing, manifested by increasing traffic and congestion, more sophisticated equipment, and more complex operational procedures--all imposing new demands for maintaining safety in future aviation activity. To meet these demands for maintaining aviation safety, the FAA recognizes the need to examine the effectiveness of its current safety programs. Assessing how well-aligned these safety programs are with accident causes is one method of accomplishing this.

The purpose of this study was to provide such a safety assessment. Specifically, it was the objective of this study to determine the extent to which the FAA safety programs were aligned with the causes of general aviation accidents. This study extends and complements an antecedent evaluation concerning air carrier accidents made by Battelle's Columbus Laboratories in 1978.(1) The earlier study involved determining the rates of occurrence and associated costs of the probable causes of 800 air carrier accidents from 1964 through 1977, estimating the extent to which FAA safety programs were directed at and effective in mitigating these causes, and recommending actions aimed at prevailing causes of air carrier accidents. To implement this approach, however, several methodological problems had to be solved to establish linkages between accident cause/factors and safety programs. In particular, the National

Transportation Safety Board (NTSB) accident cause/factor citations in the pilot error category were modified to better explain why an accident occurred rather than simply describing its observable but symptomatic attributes. Further, most accident records consisted of citations of multiple, related cause/factors. These multiple citations often contained redundancies and associated, but not causative, circumstances that are only spuriously related to the evaluation of safety program effectiveness. To correct for such redundancies, selected cause/factors were deleted from the accident records for purposes of the required analysis. Finally, it was found that the effectiveness of a given safety program depended on its connectivity with other related safety programs as well as on its alignment with accident cause/factors. Accordingly, accident cause fault trees were developed as a means for evaluating sets of related safety programs.

The foregoing and other findings of the air carrier accident causes suggested data base and methodological requirements for the conduct of this study. Specifically, to successfully carry out this safety program evaluation, it was necessary to

a. Further modify the NTSB accident cause/factor framework to facilitate proper alignment of accident causes and safety programs

b. Aggregate selected accident type codes used by the NTSB to yield statistically significant frequencies without loss of essential information

c. Disaggregate the general aviation population into subpopulations that are homogeneous in terms of accident behavior and operational characteristics. The criteria and methodology used for aligning and evaluating safety programs with respect to accident causes are common to both the air carrier and general aviation studies. In the latter case, evaluations were made for each of the general aviation subpopulations.

The data base, criteria, and methodology developed in accord with the above cited study requirements are described in Chapter 2 of this report. The analysis of the accident cause/factor data and evaluation of safety programs are given in Chapter 3. This chapter includes descriptive statistics pertaining to accident cause/factor frequencies of occurrence and associated costs for the time period from 1971 through 1977, alignment of frequently cited cause/factors with the objectives of the FAA's safety programs, and evaluation of these safety programs in terms of effectiveness in mitigating the accident causes toward which they were directed. The seven-year period referenced above was selected because it provided for an internally consistent data base containing both accident and activity data. Chapter 4 contains the findings, conclusions and recommendations stemming from the accident cause/factor and safety program analysis and evaluation described in Chapter 3. These study results are concerned with accident investigation data and procedures, general aviation accident histories, successful safety program profiles, and categorical safety program effectiveness and needs with respect to mechanical, weather and human factors cause/factors.

STUDY OBJECTIVES

The overall objective of this study was to provide the FAA with an assessment of its safety programs with respect to the causes of general aviation accidents. The evaluation was based on assessments of the effectiveness of identified safety programs in mitigating the frequency of occurrence and the associated costs of general avaiation accidents. Toward this end, a study design was established in accordance with the following specific objectives:

a. To identify safety programs that, singularly or in combination with other programs, are aligned with accident causes, are effective in mitigating these causes and whose continuation is warranted

b. To identify safety program needs including redirection of existing programs and description of program gaps associated with mitigation effectiveness and/or nonaligned accident causes

c. To determine overall safety program balance in terms of program priorities and resource commitments relative to the frequencies and costs of associated accident costs

d. To identify accident information needs that would facilitate continuing aviation safety program planning, analysis and evaluation.

As stated in the preceding section of this chapter, descriptive information and associated analyses pertinent to these objectives are given in Chapters 2 and 3. Recommendations concerning safety program and information needs are given in Chapter 4.

OVERVIEW OF STUDY SCOPE AND METHODOLOGY

The scope of this study is bounded by the following factors. First, as specified previously in this chapter, accidents documented in the NTSB general aviation accident data base spanning the time period from 1971 through 1977 were examined. This data base consisted of a total of 30,592 accident records. Second, the safety program alignment analysis was made with respect to cause/factors listed in the NTSB Manual of Code Classification (MCC).[2] In some instances, modification of selected codes was determined to be necessary for purposes of the subject study. Third, the study included all FAA programs implemented during the same time period as the accident data base that either listed safety as the primary objective or as an important contributing objective. This program listing was compiled jointly by the FAA and Battelle as part of the earlier air carrier study and consisted of 90 separate safety programs.

To carry out the evaluation of the relationship between the safety programs and accident cause/factors, the sequential study process shown in Figure 1-1 was developed and implemented. As shown in this figure, the study consisted of three principal parts:

a. Data Base Development. The first element of the data base consists of general aviation accident records coded in terms of modified cause/factors and accident types. Those modifications are made in this study. The second element consists of a compilation of FAA safety programs. This listing is the same as that used in the air carrier study. Similarly, accident cost elements, the fourth element, were the same for both studies. Fifth, general aviation activity statistics were compiled for the purpose of calculating accident rates.

b. Methodology Development. The criteria and methodology developed in the air carrier study were carried over to this study in their entirety. These include the accident cost allocation procedure, alignment criteria and program evaluation logic. In addition, methods were developed for disaggregating the general aviation population in homogeneous subpopulations. Also, statistical cross-tabulation methods were adopted as a basis for searching for pairwise empirical associations between causes, causes and accident types, causes and pilot experience, and accident types and pilot experience.

DATA BASE DEVELOPMENT

- Modify NTSB Cause/Factors to Facilitate Safety Program Evaluation
- Aggregate NTSB Accident Codes to Facilitate Safety Program Evaluation
- Compile FAA Safety Program Listing
- Determine Accident Cost Elements

METHODOLOGY DEVELOPMENT

- Dissaggregate General Aviation [illegible]
- Allocate Accident Costs To These Respective Cause/Factor Citations
- Define Criteria for Aligning Accident Causes and Safety Programs
- Develop Accident Cause Fault Trees as a Basis for Overall Safety Program Evaluation

SAFETY PROGRAM ANALYSIS AND EVALUATION

- Tabulate Accident Statistics (frequencies, rates, types, causes and associated costs) by General Aviation Subsegment.
- Align Safety Programs with corresponding Accident Cause/Factors
- Evaluate Safety Programs in Terms of Accident Mitigation Effectiveness, Coverage and Balance.

FIGURE 1-1. DESCRIPTION OF THE PRINCIPAL STUDY ELEMENTS AND INVESTIGATION SEQUENCE

c. Safety Program Analysis and Evaluation. As in the case of methodology development, the analysis and evaluation of safety programs with respect to the causes of general aviation accidents was carried out analogously to that for the causes of air carrier accidents. This process consisted of the logical sequence of tabulating selected accident statistics, aligning safety programs with cause/factors occurring with relatively high frequencies, and evaluating the effectiveness (for each thereof) of the safety programs in mitigating accidents they are designed to prevent. This evaluation was accomplished for each of eight homogeneous general aviation subpopulations.

In the conduct of this research, literature reviews and interviews were used extensively in all phases of the analysis and evaluation effort. In particular, in the course of developing the accident cause/factor and safety program data bases and in carrying out the analyses of these data bases, frequent technical discussions were held with FAA's Office of Aviation Safety, Flight Standards Service, Systems Research and Development Service, and Aeronautical Center at Oklahoma City (in addition to the Office of Aviation System Plans), NTSB's Office of Special Projects; and various general aviation aircraft companies.

QUALIFICATIONS IN INTERPRETING THE STUDY RESULTS

The findings and conclusions presented later in this report are based on the analysis of the general aviation accident data base and supplemental information obtained through literature reviews and interviews with experienced professionals in the field of aviation safety. These findings and conclusions, and the resultant safety program recommendations, are those which can be supported by the available data and information. It is important to recognize the limitations imposed by the quantity and quality of the data used in this investigation, especially in making decisions to add or abandon any single safety program. The principal qualifications that should be recognized in interpreting and using the results of this study are summarized in the following paragraphs.

First, the empirical data used in the aviation accident analysis are the frequencies of citation of cause/factors over the seven year period from 1971 through 1977. In the 30,000-plus accidents that occurred in this period, NTSB investigators cited 723 codes (of a possible list of 798 codes contained in the MCC) as accident causes or factors. The modified cause/factor framework developed in this study (consisting of deletions of some MCC codes and substitution of new codes for selected other MCC codes) contains 495 possible codes. Of these 495 possible codes, only 46 codes were cited as cause at least seven times per year.* Moreover, nine codes (each cited greater than 1,000 times over the seven year period) accounted for 83 percent of all citations as cause. Eight of these leading causes were in the human error category. It follows, then, that these human errors dominate the accident data and, hence, their statistical analysis. The infrequent occurrence of most other cause/factors prohibits detection of statistically significant trends or shifts in rate of occurrence possibly attributable to safety program effects. While statistical estimates of occurrence rates can be made, the large variances associated with such estimates preclude practical interpretations of their meaning. Thus, the effectiveness of a given program cannot be evaluated based strictly on statistical analysis of these empirical data.

Second, in the modified cause/factor framework, the human error codes listed in the MCC were aggregated under six more explanatory codes: judgment, operational decision error, procedures/regulations/instructions/responsibilities, improper operation of equipment, attention and awareness, and perception. Valid use and interpretation of the these substitute codes requires strict adherence to their definitions with respect to the respective MCC codes they subsume. Assignment of these modified codes is inferential; i.e., these errors are not directly observable. The validity of these inferences, and hence, appropriateness of the substitute code uses, depends on careful reconstruction of pilot/crew actions in the accident event chain. In cases where

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*54 cause/factor codes were ultimately used in the accident data analysis. In addition to 46 individual codes that were cited at least seven times per year, eight "collector" codes were defined. A collector code (e.g., powerplant failure or airframe failure) consisted of aggregating individual cause/factor codes within major cause/factor categories that were infrequently cited.

the accident report contains sketchy or incomplete data (as is typical of many general aviation accident records) it is difficult to support valid assignment of these inferential codes. Thus, caution is required in properly making and interpreting substitute code assignments.

Third, caution should be exercised in comparing absolute frequencies of individual cause/factor citations. In the modified cause/factor framework, some codes used in this study are aggregations of individual codes (within major categories) that were cited infrequently over the study period. Other codes, especially the human error substitutes codes, are also higher level cause/factors than the individual codes in the mechanical and environmental categories. These human error codes are, in fact, aggregations of individual cause/factors in the pilot/crew and personnel categories. The accident cause fault trees (described in Chapter 2) are useful guides in interpreting such differences of level among cause/factors.

Fourth, safety programs have been classified as being directly or indirectly aligned against corresponding cause/factors. It should be noted that an indirectly aligned program should not be necessarily construed as being less effective than a directly aligned program. Sufficient conditions for program effectiveness entail additional criteria concerning relationships to complementary programs and the accumulation of technical knowledge underlying a given program.

Fifth, safety programs not aligned or aligned against infrequently cited cause/factors should not be necessarily construed as being unwarranted. Indeed, infrequent cause/factor citation may be a consequence of an effective safety program. A decision to abandon a program should be based on engineering and operational considerations as well as on statistical analysis of accident data.

A sixth caution in interpreting the study results is that the effectiveness of a single program depends on its relationship with other programs. That is, there is a synergism among interconnected programs that often results in effective mitigation of hazards in the aviation system. This effect is especially apparent in programs directed toward cause/factors in the mechanical category. The accident cause fault tree developed as an evaluation tool in this study has been used to display this interconnectivity among sets of safety programs.

CHAPTER 2. DATA BASE AND METHODOLOGY

The data base developed for use in the evaluation of FAA's aviation safety programs consists of four parts

a. The NTSB general aviation accident data base (in particular, assignments of probable causes and contributing factors, accident type classifications)

b. The costs of general aviation accidents including loss of life, injury, and hull damage, as developed by the FAA

c. FAA general aviation activity statistics, partitioned by primary-use and aircraft-type subsegments

d. Descriptions of FAA aviation safety programs partitioned by functional category

A seven-part methodology was developed for purposes of the subject analysis and evaluation. This methodology included:

a. Procedures for modifying the NTSB cause/factor framework to provide for proper alignment of safety programs and accident causes

b. A rationale and algorithm for determining accident costs and for distributing these costs among causes and factors cited in the accident records

c. Formats for tabulating general aviation accident statistics

d. Procedures for combining general aviation subsegments into subpopulations that are homogeneous in their accident behavior and operational attributes

e. Empirical procedures for examining associations among causes, accident types and pilot experience

f. Criteria for determining the degree of alignment between safety programs and related cause/factors

g. Criteria and procedures for evaluating the extent to which FAA's safety programs are effective in mitigating hazards in the National Aviation System.

The data base elements and the first two methodological elements (cause/factor framework and accident cost distribution) are described in the following section. The remaining methodological elements are described in the last section of this chapter.

SECTION 1. DATA BASE

GENERAL AVIATION ACCIDENT DATA BASE

The accident data base used in this study consisted of 30,592 general aviation accidents over the time period 1971 through 1977. The National Transportation Safety Board's (NTSB) original accident records and accident computer file were used as the main source of accident data. These records provided the accident cause/factor citations, administrative information (pilot age, profession, time of day, etc. . .) and other selected operational and accident data. The latter data fields are shown in Table 2-1. These fields represent selections from a larger group of 813 data fields that were included in the computer data base developed for this study. Additional data fields were pertinent to the analysis, but it was found that data in many of these desired fields were missing or were inconsistently recorded. It should be noted that many of the 813 fields were dedicated to administrative record keeping and were not directly pertinent to the subject safety analysis.

The NTSB Accident Cause/Factor Classification System

The NTSB Manual of Code Classifications (MCC) contains 15 major accident cause/factor categories which are subdivided into 70 specific cause/factor categories. These major categories and the number of subdivisions in each of them are listed in Table 2-2. Further, each of these 70 specific categories is subdivided into a varying number of codes describing specific actions, events or conditions associated with an accident. For example, the major cause category Pilot (64) contains 66 individual cause/factors which can be used in coding the probable cause of an accident. Another major cause category, Miscellaneous (84), contains 13 such cause/factors.

TABLE 2-1. LISTING OF SELECTED DATA FIELDS CONTAINED IN THE GENERAL AVIATION COMPUTER DATA BASE

Item Number	Field Code	Definition
1	ACCDATY	Accident Year
2	ACCSTATE	Coded State Location
3	ACTYPE	Type of Aircraft
4	NOENG	Number of Engines
5	TYPPOWER	Type of Power
6	ACDAMAGE	Aircraft Damage
7	GAFLYING	Kind of Flying
8	TYPOPN	Type of Operation
9	ACCTYPE1	Type of Accident 1
10	PHASE1	Operational Phase 1
11	ACCTYPE2	Type of Accident 2
12	PHASE2	Operational Phase 2
13	TYPWEATH	Type of Weather
14	WEABRIEF	Weather Briefing
15	WEAFOST	Weather Forecast
16	FLTFLAN	Type of Flight Plan
17	ARPTROX	Airport Proximity
18	DEPART1	1st Column of Depart
19	ENROUTE1	1st Column of Enroute
20	DESTIN1	1st Column of Destin (L=Local)
21	HRSTOT1	Total Hours First Pilot
22	HRSTOT2	Total Hours Second Pilot
23	HRSTYPE1	Hours in Type for First Pilot
24	HRSTYPE2	Hours in Type for Second Pilot
25	RATED1	First Piloted Rated in Aircraft
26	RATED2	Second Piloted Rated in Aircraft
27	CERTIF1	First Pilot Certificate
28	CERTIF2	Second Pilot Certificate
29	INJURY	Highest Degree of Injury
30	GENWEATH	General Weather
31	PILOT24	Pilot Time-Last 24 Hours
32	PILOT90	Pilot Time-Last 90 Days
33	FIREDETH	Deaths Resulting from Fire
34	SEGMENTS	Segments of Aviation Involved
35	TERMINAL	Terminal Communication Established
36	CONTROLC	Controlling Agency
37	RADARCON	Radar Control/Surveillance
38	TRAFFIC	Traffic Advisory Issued
39	AIRPORTC	Controlled/Uncontrolled Airport
40	ZONE	Control Zone/Area
41	INSTRTN	Instrument Training Operations
42	REPCOST	Replacement Cost at Date of Accident

TABLE 2-2. MAJOR CAUSE/FACTOR CLASSIFICATIONS
(From NTSB Manual of Code Classification)

	Major Code Categories	Number of Major Subdivisions	Number of Individual C/Fs
Pilot	64	0	
Co-Pilot	65	0	66*
Dual Student	66	0	
Check Pilot	67	0	
Personnel	68	15	62
Airframe	70	4	42
Powerplants	74	31	237
Systems	75	10	74
Instruments/Equipment and Accessories	76	3	24
Rotorcraft	78	4	35
Airports/Airways Facilities	80	3	33
Weather	82	0	23
Terrain (other than airport)	83	0	11
Miscellaneous	84	0	13
Miscellaneous Acts, Conditions	88	0	178
Totals	15	70	798

* Individual cause/factors are common to the four Major Code Categories, 64-67.

An example of an accident brief on which this study is based is shown in Figure 2-1. The principal data fields of interest, contained in Table 2-1, are shown in this figure. Codes cited as "probable causes" by accident investigators (for example, "pilot in command-continued VFR flight into adverse weather conditions") are verifiable actions or conditions that were determined to be directly accountable for an accident. Codes cited as "factors" (for example, "weather-other", "miscellaneous acts, conditions-instrument-overload failure"....) are actions or conditions that further explain, supplement or qualify those codes assigned as "probable causes".

In determining the probable cause(s) of an accident, all facts, conditions, and circumstances are considered by investigators. The objective is to ascertain those cause-effect relationships that existed in the accident sequence. In those accidents in which more than one cause was determined to exist, all such causes were recorded. No attempt is made by the accident investigator to establish a primary cause. Thus, there is no weighting of causes that would indicate their relative importance. The assignment of factors is treated in the same manner.

The Modified Cause/Factor Classification System

In the earlier air carrier study, it was necessary that several modifications be made in the existing NTSB cause/factor classification system. These modifications concerned cause/factor citations that often were not sufficiently specific or explanatory for purposes of safety program alignment. This lack of specificity was especially prevelant in the case of cause/factors in the Pilot/Crew categories (Codes 64-67). Further, these modifications involved cause/factor citations that could not be interpreted unambiguously with respect to the chain of events involved in an accident sequence. This problem stemmed principally from the citation of multiple causes and/or factors without any reference to the hierarchical relationships among them. As a prerequisite to the alignment analysis and system program evaluation made in this study, initial effort was focused on ascertaining the appropriateness of these modifications and on defining and resolving other problems in the use of the NTSB general aviation accident data in serving the objectives of this study.

FILE	DATE	LOCATION	AIRCRAFT DATA	INJURIES F S M/N	FLIGHT PURPOSE	PILOT DATA
3-1217	5/5/77 TIME - 0738	HUNTINGTON BCH,CA	BEECH 35 N2826V DAMAGE-DESTROYED	CR- 1 0 0 PX- 3 0 0	NONCOMMERCIAL PLEASURE/PERSONAL TRANSP	PRIVATE, AGE 37, 250 TOTAL HOURS, UNK/NR IN TYPE, NOT INSTRUMENT RATED.

DEPARTURE POINT
CEDAR CITY,UT

INTENDED DESTINATION
FULLERTON,CA

TYPE OF ACCIDENT
AIRFRAME FAILURE IN FLIGHT

PHASE OF OPERATION
IN FLIGHT UNCONTROLLED DESCENT

PROBABLE CAUSE(S)
PILOT IN COMMAND - CONTINUED VFR FLIGHT INTO ADVERSE WEATHER CONDITIONS
PILOT IN COMMAND - SPATIAL DISORIENTATION
PILOT IN COMMAND - EXCEEDED DESIGNED STRESS LIMITS OF AIRCRAFT
FACTOR(S)
WEATHER - OTHER
AIRFRAME - WINGS SKIN AND ATTACHMENTS
MISCELLANEOUS ACTS,CONDITIONS - OVERLOAD FAILURE
MISCELLANEOUS ACTS,CONDITIONS - SEPARATION IN FLIGHT
WEATHER BRIEFING - BRIEFED BY FLIGHT SERVICE PERSONNEL, IN PERSON
WEATHER FORECAST - FORECAST SUBSTANTIALLY CORRECT

SKY CONDITION
OVERCAST
VISIBILITY AT ACCIDENT SITE
5 OR OVER(UNLIMITED)
OBSTRUCTIONS TO VISION AT ACCIDENT SITE
NONE
WIND DIRECTION-DEGREES
210
TYPE OF WEATHER CONDITIONS
IFR
REMARKS- PENETRATED CLOUD LAYER. L WG FAILED.

CEILING AT ACCIDENT SITE
1900
PRECIPITATION AT ACCIDENT SITE
DRIZZLE
TEMPERATURE-F
60
WIND VELOCITY-KNOTS
6
TYPE OF FLIGHT PLAN
VFR

FIGURE 2-1. EXAMPLE OF AN NTSB GENERAL AVIATION ACCIDENT RECORD BRIEF

The resultant modifications made in the NTSB cause/factor classification system relevant to this study are described in the following paragraphs.

Requirements for Cause/Factor Modifications. In the antecedent air carrier study, four modifications were made in the NTSB cause/factor classification system. These modifications consisted of deleting all Terrain (Code 83) and Miscellaneous Acts and Conditions (Code 88) cause/factors, deleting selected Weather (Code 82) cause/factors when cited in conjunction with other redundant cause/factors, and substitution of behavioral cause/factors for descriptive cause/factors in the Pilot/Crew categories (Codes 64-67). These modifications were made to provide a modified cause/factor framework better suited for safety program alignment analysis. Specifically, the following requirements were satisifed:

a. Elimination of noninformative duplications associated with multiple, related cause/factor citations. This requirement stems from the use of additional cause/factor citations to provide supplementary descriptive information and/or to qualify primary cause/factor citations

b. Reduction in redundancy associated with the use of explanatory cause/effect event chains, especially in the mechanical cause/factor categories. Such redundancies constitute double counting of the same accident causes

c. Establishment of more explanatory cause/factor codes in the Pilot/Crew categories (Codes 64-67) as substitutes for existing codes in the MCC that are essentially event descriptors.

Using a sample of 792 general aviation accident briefs and 235 detailed accident dockets, the appropriateness of these modifications was re-examined in this study. Examination of the 792 accident briefs, selected at random from the computerized data file, revealed several prevalent properties of general aviation accident data and investigation procedures. Generally, factual administrative data (e.g., type of aircraft, type of engine, pilot certificate and pilot age) were consistently recorded. However, other factual data desirable for analysis purposes (e.g., pilot duty time, flight time in the last 90 days, or time in type of aircraft) were usually missing or of questionable validity. In particular, these data deficiencies were prevalent in accidents for which there were no witness reports (including pilots or passengers). These findings were qualitatively corroborated by several accident investigators that were interviewed during the course of this accident record examination.

Examination of the 235 original accident dockets at the NTSB's Reference Library and subsequent meetings with FAA and NTSB staff further illuminated specific data problems requiring resolution for purposes of the safety program alignment analysis. Specifically, three significant problems were found in these records. First, non-fatal accidents tended to be superficially investigated. Second, the assignment of cause, especially pilot (human) error, appeared to be highly inferential in the majority of cases. Third, although the quality or detail in the records increased over time most investigations did not measure up to the NTSB standards typically displayed in air carrier accident investigations.

Several factors appear to contribute to these problems, the most prominent factor being the delegation of accident investigation authority to the FAA. As a result of an interagency agreement between the NTSB and FAA, the terms of which dictate the types of accidents to be investigated by the FAA, the FAA handles approximately 75 percent of the general aviation investigations. Table 2-3 shows the general division of these investigation responsibilities.

TABLE 2-3. DIVISION OF ACCIDENT INVESTIGATION RESPONSIBILITIES BETWEEN THE NTSB AND THE FAA

FAA	NTSB
Fatal - Aerial Application	All Air Carrier
Fatal - Home Built	All Cummuter/Air Taxi
Fatal - Restricted	All Large Aircraft (over 12,500 lbs.)
Non-Fatal - Rotorcraft	Fatal - Rotorcraft
Non-Fatal - Airplane	Fatal - Airplane

This delegation of authority shifts the burden of investigation, but not the final assignment of cause, to the FAA. Assignment of cause is still determined by the NTSB based on the reported data. Thus, the accident data is sometimes filtered or handled by three parties (an FAA investigator, an NTSB investigator and the NTSB Encoder) before the citation of cause is assigned in the accident. It is believed that this system of handling the investigation contributes to the first two problem areas: superficial investigation and highly inferential assignment of cause. The third problem, the overall quality or detail in the the investigations, stems mainly from too many accidents being investigated by too few (and to some extent, untrained) accident investigators. It is important to note that these findings concerning data quality do not apply to the sub-group of accident investigations that involve fatalities. Investigation of fatal accidents was found to be substantially more detailed, and validity of assignment of cause paralleled that of the air carrier accidents group.

The inconsistent quality of most of the accident investigations in the non-fatal accident category (and in some fatal accidents) is due to the lack of a sufficient number of skilled investigators that would be required to thoroughly investigate the high frequency of occurrence of general aviation accidents. The highly inferential assignment of pilot (human) error stems from this shortfall coupled with a lack of available pilot data on which to base a clearer assignment of cause. To acquire the requisite pilot information, both behavioral and administrative, would require commitment of significant resources and effort during an investigation. Lacking such commitment, detailed pilot error investigations are not pursued. FAA investigators are also concerned in each accident with the determination or the presence of four factors:

a. Aircraft airworthiness
b. Airmen certification
c. Air navigation aids
d. Violations of FAR's

Many investigations are not carried beyond a determination of facts pertinent to these factors. The last, and perhaps the most important point, concerns the processing of accident investigation data and final determination of the accident cause. Because the NTSB encodes the citation of probable cause based on FAA data, many experts feel that the broad gap that exists in policy, procedures and training between the two agencies might lead to misstatement of the intended findings of the investigator. The true magnitude of such misstatements cannot be quantitatively determined but generally it was felt that disagreement on assignment of cause involves roughly 10 percent of all general aviation accidents.

The foregoing are problems of investigative procedure. No evidence was found that suggested deficiencies in the cause/factor classification system beyond those reported in the air carrier study. Thus, it was concluded that structural changes in the cause/factor framework made in the air carrier study (deletion of redundant and/or qualifying codes) were equally appropriate for this study. These deletions include all Terrain (Code 83) and Miscellaneous Acts and Conditions (Code 88) cause/factors, and selected Weather (Code 82) cause/factors. Also, it was concluded that substitution of new behavioral codes for descriptive codes given in the MCC pilot/crew cause factor category was appropriate. However, because of the lesser level of investigative detail reported in the general aviation accidents, it is necessary to define additional substitute cause factors in the pilot/crew category that can be inferred from the data with reasonable validity. The resultant modified cause/factor framework, including definition of new pilot/crew cause/factors, is described in the following paragraphs.

The Modified Cause/Factor Framework. The cause/factor framework used in the alignment analysis of FAA safety programs in this study is given in Table 2-4. As shown in this table, categories retained as defined in the MCC are as follows:

a. All cause/factors in the Mechanical categories (Codes 70, 74, 75, 76, 78) could be used as defined in the MCC for purposes of alignment analysis. The level of detail represented by mechanical cause/factors provided for establishing direct connections to the objectives of FAA safety programs designed to mitigate mechanical failures.

b. All cause/factors in the Weather category (Code 82) could be used as defined in the MCC for purposes of alignment analysis. Again, strong alignment was found between the weather cause/factors and FAA safety programs designed to mitigate weather-related problems.

c. The major cause/factor categories Airports/Airways (Code 80), and Miscellaneous (Code 84), are well-defined for purposes of logical structuring

TABLE 2-4. MAJOR CAUSE/FACTOR CLASSIFICATIONS IN THE MODIFIED CAUSE/FACTORS FRAMEWORK

	Major Code Category	Number of Individual Cause/Factors	Source of Definitions
Pilot	64	7*	Substitute codes defined in this study in Table 2-5.
Co-Pilot	65	"	
Dual Student	66	"	
Check Pilot	67	"	
Personnel (Human error)	68	"	
Personnel (Events)	68	"	MCC
Airframe	70	42	MCC
Powerplants	74	237	MCC
Systems	75	74	MCC
Instruments/Equipment and Accessories	76	24	MCC
Rotorcraft	78	35	MCC
Airports/Airways Facilities	80	33	MCC
Weather	82	23	MCC
Terrain	83	11	Deleted
Miscellaneous	84	13	MCC
Miscellaneous Acts & Conditions	88	178	Deleted

* Individual C/Fs are common to the five Major Code Categories, 64-67, and 68 (human error)

of accident event sequences with respect to related environmental conditions or facilities. These categories contain desriptors of conditions or facilities present at the time of an accident.

Major categories that were modified for use in this study were:

a. Cause/factors in the Pilot/Crew categories (Codes 64-67) were judged to be generally too uninformative for use in safety program alignment and evaluation. The principal determinant here was that the cause/factors describe what happened in an accident sequence, but did not reveal why. In general, NTSB air carrier accident investigations are constrained to uncovering those observable facts prevailing at the time of the accident. For most cause/factor categories (mechanical, weather, airport/airways, etc.) such an approach is generally sufficient. However, in the pilot/crew category the investigative detail tends to be lacking in terms of explanatory behavioral information. It is this latter type of information that is required to establish safety programs that address fundamental hazards rather than symptomatic conditions. Substitute cause/factors in this category that are judged to be consistent with the level of detail reported in the general aviation accident records are described in the following paragraphs.

b. Cause/factors in the Personnel category (Code 68) that pertain to human errors are completely analagous to Pilot/crew cause/factors. Accordingly, the same substitutes defined to characterize pilot/error are also used to describe these personnel errors. Other individual cause/factors in this category that describe events are sufficiently well-defined for purposes of alignment analysis and, hence, are retained as specified in the MCC.

Major categories that were deleted from accident records used in this study were:

a. All cause/factors in the category Terrain (Code 33), while well-defined, are not in themselves causes of accidents. Analagously to the use of miscellaneous acts and conditions, these cause/factors are used to describe environmental conditions surrounding an accident.

b. All cause/factors in the category Miscellaneous Acts, Conditions (Code 88) are sufficiently well-defined for purposes of identifying their roles in accident cause-effect relationships. However, these cause/factors are commonly assigned by accident investigators for purposes of qualifying the circumstances in the accident event sequence. Alignment of safety programs with these cause/factors, given this type of usage, would likely lead to inappropriate safety programs.

Substitute Pilot Cause/Factors. It was determined in the air carrier study that the terms "cognition", "decision", and "execution" were valid descriptions of the types of human error being observed in aircraft accidents. The exhaustive investigations performed on air carrier accidents provided the level of detail required to make accurate placements of the originally cited errors into these three categories. However, as described earlier, the general aviation accident records lacked sufficient detail with which to make such assignments. Thus, converting general-aviation-accident, human-error citations into these codes (Cognition, Decision, and Execution) was not practicable. This problem was further amplified by the virtual dominance of human error citations in the general aviation data base. For example, the cause/factor code, Decision Error, would have been cited some 20,000 times. While representing a valid substitution for human behavior, it is apparent that the collection and analysis of such aggregations would yield little discriminatory information pertinent to safety program evaluation.

The solution determined to be the most practicable, was to define a lower level of behavioral cause/factor substitute codes. The new human behavior codes were defined to act as direct links to the previously defined higher-level codes, at the same time, being more compatible with the reported detail in the accident records. As was the case for the air carrier study, it was intended that these human error substitute codes be as widely accepted and generally supported by the current scientific literature as possible. Toward this end, several additional aviation human factor references were drawn upon in their definition.[3-5]

The human error cause/factor substitutes are defined in Table 2-5. The 66 pilot crew error codes listed in the MCC were placed into their respective categories based first on what action they were describing and second, if the description was vague, on how they were used in the record. For example, the citation 64*20 (Failed to Follow Approved Procedures, Etc...) would be placed under the cause citation 64*3Z (Procedures). The results of this substitution process are tabulated in Table 2-6, where the 66 original citations are listed

TABLE 2-5. NEW HUMAN ERROR SUBSTITUTE CAUSE/FACTORS

Code	Title	Definition
64*1Z	Judgment Error	Error in the evaluation of the consequences of the available alternative courses of actions.
64*2Z	Operational Decision Error	The selection of a course of action resulting in an accident. Assumes the information for determining the best alternative, including the option of no action, was available.
64*3Z	Procedures, Regulations Instructions and Responsibilities	Failure to perform according to general or specific procedures, regulations, instructions. Failure to fulfill responsibilities.
64*4Z	Improper Operation of Equipment	The inappropriate use of controls, equipment or systems, including the lack of good operator technique.
64*5Z	Attention and Awareness	Misdirection of mental or perceptual powers in a state of incognizance of the situation or status of the system.
64*6Z	Perception	The failure to obtain and interpret the sensory information necessary for safe operation.
64*7Z	Physiological	Properties or states which negatively affect the operator's normal level of proficiency in any facet of an operational process.

TABLE 2-6. DISTRIBUTION OF 66 PILOT/ERROR CAUSE/FACTOR CITATIONS INTO NEW HUMAN ERROR CODES

Decision Error			Execution Error	Cognition Error		Physiological Error	Deleted
Judgment	Operation Decision	Procedures, Regulations, Instructions	Improper Operation of Equipment	Attention and Awareness	Perception		
64*1Z	64*2Z	64*3Z	64*4Z	64*5Z	64*6Z	64*7Z	
-01	-04	-10	-09	-03	-17	-64	-16
-02	-05	-11	-18	-08	-45	-65	-43
-31	-06	-20	-19	-13	-46	-66	-67
-33	-07	-26	-21	-14	-47		
-37	-12	-29	-22	-15	-48		
-38	-27	-30	-23	-32	-49		
-40	-35	-36	-24	-34	-50		
-74	-44	-39	-25		-51		
-81	-80	-42	-28		-52		
-82		-55	-62		-53		
-37		-56	-71		-54		
			-79				

under their respective, new human error codes. The identification of the 66 codes from the MCC is given in Table 2-7.

It should be noted that these error citations are inferential. That is, the accident data supports these citations only to the extent that an accident investigator can relate the specific behavioral error to observable facts in an investigation. It is evident that classification errors will be made in some unknown fraction of the cases. For example, what might be observed as an Operational Decision Error (64*2Z) could have been based on a Judgment Error (64*1Z) which, in turn, could have been caused by a Perception Error (64*6Z). The investigative detail is not available to determine the original cause. Thus, this analysis was limited to the first citation, or in other words, what the investigator observed about the accident.

Substitute Personnel Cause/Factors. The NTSB classifies Personnel Error (Code 68) as human error committed by someone other than the pilot/crew. Included in this category are flight attendants, air traffic control personnel, maintenance personnel, company management, dispatchers, ground crew, aircraft designers, and passengers. The initial review of the original cause/factors established that this error code was frequently used to describe an event that did not take place such as Maintenance Not Performed (Code 68*D6) rather than citing why the event did not take place. Analyzing these human errors was similar to the problem of identifying the human error in statements such as Pilot Failed to Follow an Approved Procedure (Code 64*20) encountered in the air carrier study. Thus, Personnel Error, as used in the MCC, was separated into two categories: those citations describing a human error and those citations describing events. The Code 68 human error citations were then examined for placement in exactly the same structure as the Code 64 human error assignments made for pilot error as described in the preceding paragraphs and a correspondence was established between these substitute human error codes and the personnel error codes defined in the MCC. The distinction between the two major human error code categories was retained in the analysis by maintaining the Code 64 and 68 identifiers. All other Code 68 errors were treated exactly as the rest of the individual cause/factors in the records.

TABLE 2-7. IDENTIFIERS OF PILOT CAUSE/FACTOR CODES FROM NTSB MANUAL OF CODE CLASSIFICATION*

Code	Cause/Factor Description
01	Attempted operation with known deficiencies in equipment.
02	Attempted operation beyond experience/ability level.
03	Became lost/disoriented.
04	Continued VFR flight into adverse weather conditions.
05	Continued flight into known area of severe turbulence.
06	Delayed action in aborting takeoff. (See code 81)
07	Delayed in initiating go-around. (see code 82)
08	Diverted attention from operation of aircraft.
09	Exceeded designed stress limits of aircraft.
10	Failed to extend landing gear.
11	Failed to retract landing gear.
12	Retracted gear prematurely.
13	Inadvertently retracted gear.
14	Failed to see and avoid other aircraft.
15	Failed to see and avoid objects or obstructions.
16	Failed to obtain/maintain flying speed.
17	Misjudged distance, speed, altitude or clearance.
18	Failed to maintain adequate rotor r.p.m. (helicopters).
19	Failed to use or incorrectly use miscellaneous equipment.
20	Failed to follow approved procedures, directives, instructions, etc.
21	Improper operation of Powerplant controls. (Includes propeller controls.)
22	Improper operation of brakes and/or flight controls.
23	Improper operation of flight controls.
24	Premature lift-off.
25	Improper level off.
26	Improper IFR operation.
27	Improper in-flight decisions or planning.
28	Improper compensation for wind conditions.
29	Inadequate preflight preparation and/or planning.
30	Inadequate supervision of flight.
31	Lack of familiarity with aircraft.
32	Mismanagement of fuel.
33	Exercised poor judgment.
34	Operated carelessly (neglect, forgetfulness).
35	Selected unsuitable terrain.
36	Improper starting procedures.
37	Started engine without proper assistance and/or equipment.
38	Taxied/parked without proper assistance.
39	Failed to assure the gear was down and locked.
40	Initiated flight in adverse weather conditions.
42	Failure to relinquish control.
43	Control interference.
44	Spontaneous - improper action.
45	Misjudged distance, speed and altitude.

TABLE 2-7 - CONTINUED

Code	Cause/Factor Description
46	Misjudged distance and speed.
47	Misjudged distance.
48	Misjudged distance and altitude.
49	Misjudged speed and altitude.
50	Misjudged speed.
51	Misjudged speed and clearance.
52	Misjudged altitude and clearnce.
53	Misjudged altitude.
54	Misjudged clearance.
55	Inadequate training of student (instructor in airplane)
56	Misunderstanding of orders or instructions.
62	Improper recovery from bounced landing.
64	Incapacitation
65	Physical Impairment
66	Spatial disorientation.
67	Psychological condition.
71	Misused or failed to use flaps.
74	Left aircraft unattended, engine running.
79	Failed to maintain directional control.
80	Selected wrong runway relative to existing wind.
81	Failed to abort takeoff. (See code 06)
82	Failed to initiate go-around. (See code 07)

*Major codes categories: 64 pilot in command; 65 copilot; 66 dual student and 67 check pilot.

Accident Type Classification System

The NTSB MCC defines 33 accident type citation codes, seven of which are further subdivided into more detailed codes. For example, the accident type classification, Stall (Code Q), is further detailed as whether the stall was Spin (Code Q1), Spiral (Code Q2) or Mush (Code Q3). These accident type codes and their number of subdivisions are shown in Table 2-8. An accident investigator may cite (and in cases of "undershoot" or "overshoot", is required) a first and second accident type classification. As in the case of cause/factor assignment, the intent is to establish as complete and as factual accounting of an accident as is possible.

Modification of the Accident Type Classification System. Based on a rationale similar to that used in modifying the cause factor classification system, modifications also were made in the classification of accident types. In brief, these modifications consisted of deleting unessential qualifying detail through aggregation of selected codes and deletion of second accident type citations. The specific modifications are described in the following paragraphs.

There were four difficulties associated with the use of the NTSB accident type citations for purposes of safety program evaluation. First, accident type citations in many cases were also cited as the "cause" of the accident. For example, accident Code P (Bird Strike) was also cited in the accident record as the cause, Code 84*0 (Collision with Bird). This accident type might have been more properly cited as Airframe Failure (Code S) with the associated cause citation, 84*0. Second, many accident type citations were simply used as the action descriptors of the events that took place in the accident. Examples of this usage are Roll Over (Code I), Dragged Wing Tip (Code B), Nose Over/Down (Code H) or Evasive Maneuver (Code 2). Third, the citation of two accident types for a single event in some records while adding further factual detail, will generally yield misleading results in statistical tabulations of accident types. For example, the first accident type citation, Engine Failure (Code U), might be followed in the record by a second citation of Collision with Trees (Code N1). This second accident type citation

TABLE 2-8. NTSB ACCIDENT TYPE DESCRIPTIONS

Code	Type of Aircraft
A	Ground-Water Loop-Swerve
B	Dragged Wingtip, Pod, or Float
C	Wheels-Up
D	Wheels-Down Landing in Water
E	Gear Collapsed
F	Gear Retracted
G	Hard Landing
H	Nose Over/Down
I	Roll Over
J	Overshoot
K	Undershoot
L (3)	Collision with Aircraft
M (2)	Collision with Ground/Water
N (17)	Collision with Wires, Trees....Other
P	Bird Strike (Collision with Birds)
Q (3)	Stall
R (2)	Fire or Explosion
S (2)	Airframe Failure
T	Tearaway
U	Engine Failure or Malfunction
V (3)	Propeller/Rotor Failure
W	Propeller/Rotor Accident to Person
X	Jet Intake/Exhaust Accident to Person
Y	Propeller/Jet/Rotor Blast
Z	Turbulence
Ø	Hail Damage to Aircraft
1	Lightning Strike
2	Evasive Maneuver
3	Uncontrolled Altitude Deviation
4	Ditching
5	Missing Aircraft, Not Recovered
6	Miscellaenous/Other
7	Undetermined

( ) indicates number of accident type subcategories essentially describes a post-accident event or the consequence of the first accident type occurrence. Fourth, in some instances, accident type citations are too specific for safety program evaluations. This was especially true of Code N (collision with) which has seventeen different descriptive citations associated with it, each representing a collision with a different object.

It is readily acknowledged that the NTSB computerized accident records were not specifically designed for the type of analysis performed in this study; rather, it was intended as an information storage system to maintain as much data about a specific accident as feasible. As such, the difficulties discussed above are understandable. Still it is believed that these accident citations do offer some basis for measuring safety program effectiveness, even if only of a general nature. To utilize these accident type citations, two modifications were made in the accident type classification system. The first modification consisted of eliminating the second accident type citation from the accident records. These modifications treat the third and fourth difficulties cited above. The first two difficulties would require essentially reinvestigation and reclassification of the involved accident types. Since it was not the intent of this study to carry out reinvestigations, no modifications are made.

Aggregation of Accident Types. As noted above, several of the accident type codes used to identify the event in which an aircraft has been involved were too specific in nature. This level of detail tended to scatter the frequency of the occurrences over several accident types that are nominally identical. For example, the accident category "collision with" (code N in the NTSB's MCC) has seventeen separate assignments, each simply denoting whatever the aircraft struck first (trees, house, pole, car, etc...) before hitting the ground. Thus, without loss of significant information associated with aircraft collisions, these citations (N-1 through N-17) were aggregated into a single category (N). Similarly, the accident types Stall (Q1 through Q3) and Propeller/Rotor Failure (V1 through V3) were each aggregated into the single categories Q and V, respectively. In addition, the three types, Turbulence (Z), Hail Damage to Aircraft (Ø), and Lightening Strike (1) were combined into a single category (designated Ø). These aggregations are shown in Table 2-9.

TABLE 2-9. ACCIDENT TYPE CODES AGGREGATED FOR PURPOSES OF SAFETY PROGRAM EVALUATION

MCC Accident Code	Description	Aggregate Code
N-1 through N-17	Collisions	N
Q-1 through Q-3	Stalls	Q
V-1 through V-3	Propeller/Rotor Failure	V
Z, Ø, and 1	Turbulence, Hail Damage and Lightening Strike	Ø

These aggregations of the four accident types reduced the number of total accident type codes (including their subdivisions) from 58 to 35. The resultant 35 accident type codes and their identification that are used in this study are shown in Table 2-10.

Redefinition of Accident Types. In addition to the above modifications, the 35 accident type citations and their usage in the accident records were further examined to determine the extent to which they could be related to pilot error. This examination resulted in two general classifications of accident types. The first category encompassed those citations that involved the pilot or his control over the accident events. The second category included those events which were beyond the pilot's control. Classifying the accident type citations in accord with their MCC definitions resulted in the following categories:

a. Within Pilot Control. Codes: A, B, D, G, H, I, J, K, L_0, L_1, L_2, M_0, M_1, N, Q, 2.

b. Beyond Pilot Control. Codes: E, P, R_0, R_1, S_0, S_1, T, V, W, X, Y, 0.

TABLE 2-10. MODIFIED ACCIDENT TYPE CLASSIFICATIONS

Code	Type of Accident
A	Ground-Water Loop-Swerve
B	Dragged Wingtip, Pod, or Float
C	Wheels-Up
D	Wheels-Down Landing in Water
E	Gear Collapsed
F	Gear Retracted
G	Hard Landing
H	Nose Over/Down
I	Roll Over
J	Overshoot
K	Undershoot
LØ	Collision with Aircraft - Both in Flight
L1	Collision with Aircraft - One Airborne
L2	Collision with Aircraft - Both on Ground
MØ	Collision with Ground/Water - Controlled
M1	Collision with Ground/Water - Uncontrolled
N	Collision with Wires, Trees...Other
P	Bird Strike (Collision with Birds)
Q	Stall
R	Fire or Explosion
SØ	Airframe Failure - In Flight
S1	Airframe Failure - On Ground
T	Engine Tearaway
U	Engine Failure or Malfunction
V	Propeller/Rotor Failure
W	Propeller/Rotor Accident to Person
X	Jet Intake/Exhaust Accident to Person
Y	Propeller/Jet/Rotor Blast
Ø	Turbulence (Z), Hail Damage to Aircraft (Ø), Lightening Strike (1)
2	Evasive Maneuver
3	Uncontrolled Altitude Deviation
4	Ditching
5	Missing Aircraft, Not Recovered
6	Miscellaneous/Other
7	Undetermined

There are several accident types that were not classified. These were codes 3, 4, 5, 6 and 7. These were dropped because they either did not define an accident type or covered miscellaneous areas. In addition, three other codes were not classified, but rather were retained as they were cited for the analysis. These codes were:

a. Code C (Wheels-Up Landing)
b. Code F (Gear Retracted)
c. Code U (Engine Failure/Malfunction).

These three codes could not be placed in one category or the other because their definition of use included both mechanical and human failures as a basis for their citation. For example, the definition of Code C (Wheels-Up) not only the mechanical inability to lower the landing gear (beyond pilot control) but also the pilots intentional retraction of the gear (within pilot control). Thus, because these three codes were ambiguous as to their correct classification, they were used without redefinition in the analysis. Thus, five new summary accident types were created for this analysis. These are: Within pilot control, wheels-up, gear retracted, engine failure, beyond pilot control. These categories permitted accident types generally associated with pilot error to be examined separately from other types of accidents and provided a clearer basis for determining statistical associations with human error cause citations.

ACCIDENT COSTS

In the air carrier study accident costs were determined for:

a. value of loss of life
b. personal injury
c. aircraft hull loss and damage

These cost elements and the bases for their determination are summarized in the following paragraphs. The following section describes the procedure that has been used in distributing an accident cost among the cause/factors associated with the accident. This procedure, originally developed by the FAA, is the same as that used in the air carrier study.

Determination of Accident Cost Elements

Value of Loss of Life. Several theoretical and empirical methods have been used in estimating the value of human life. Methods referenced in the air carrier study include the present value of a typical passenger's expected future earnings; maximization of the present value of a passenger's future lifetime utility stream; passenger utility maximization plus value to family, community, employer, government and airlines; average judicial settlements over the 1964 to 1974 time period; and CAB data based on non-Warsaw Pact payments during the 1966-1970 period (extrapolated) to 1974. The values of life for a typical airline passenger (in 1974 dollars) obtained by applying the respective methods ranged from $195,000 to $1,000,000.

Given the relatively small difference in the estimated annual income of an airline passenger ($24,000) and a general aviation pilot ($26,000), the value of human life used as a cost element in this study, as in the antecedent study, is assumed to be $300,000. As stated in the antecedent study, "this figure was chosen because it reaches a compromise between the theoretical constructs...and the actual cost figure of $195,000 derived from the Civil Aeronautics board (CAB) data on non-Warsaw Settlements."

Cost of Personal Injury. Costs of personal injury, both major and minor, have been determined based on CAB data on non-Warsaw average settlements. Extrapolating these average settlement payments to 1974, it is estimated that the cost of a major injury is $45,000 and the cost of a minor injury is $6,000.

Cost of Hull Loss and Damage. The cost estimates used for destroyed aircraft were developed by grouping the aircraft into categories based on numbers of seats, engines, weight and types of engines and then deriving the replacement cost from data developed by Aviation Data Services, Inc. No adjustments have been made to account for special electronics or other equipment.

With respect to "substantial hull damage", repair costs are estimated to be one-third of the cost of a replacement aircraft. As stated in the antecedent study, this value is generally accepted in the aviation industry. The industry also generally supports the assumption that repair costs for "minor damage" are negligible.

The accident cost elements described above, and used in this study, are summarized in Table 2-11. All costs are expressed in 1974 dollars using the implicit price deflator values given in Table 2-12.

Distribution of Accident Costs Among Cause/Factors.

The cost elements described in the preceding section have been used in accident valuations of the approximately 30,000 accidents in the general aviation data base. As one means of measuring the relative severity of individual cause/factors, each total accident cost was apportioned among the causes and factors contributing to the accident. In making the apportionment, the relative valuation of causes and factors were weighted in a ratio of 4-to-1. That is, for example, in an accident involving citation of one cause and one factor, 80 percent of the accident cost would be attributed to the cause, and 20 percent attributed to the factor. In general, the accident cost apportionment among causes and factors is, respectively:

$$\text{Cost of Each Cause} = \frac{4 \times \text{total accident cost}}{4 \times \text{number of causes} + \text{number of factors}}$$

$$\text{Cost of Each Factor} = \frac{\text{Total Accident Cost}}{4 \times \text{number of causes} + \text{number of factors}}$$

This ratio formula was initially developed in a preliminary study of the costs of air carier accidents made by the FAA in 1976, and is based on discussions with NTSB and FAA experts.

Redistribution of Accident Costs for the Modified Accident Records. The general aviation accident data base encoded in accord with the modified cause/factor framework entails substitution of new cause/factors for those listed in the MCC for the Pilot/Crew and Personnel categories (Codes 64-68), and deletion of cause/factors in the Terrain (Code 83) and Miscellaneous Acts, Conditions category (Code 88) where they are cited in each accident record. These substitutions and deletions require redistribution of the total cost of

TABLE 2-11. COST ELEMENTS USED IN THE VALUATION OF GENERAL AVIATION ACCIDENTS

Cost Element	Valuation (1974 dollars)
Loss of Life	$300,000
Personal Injury	
Major	45,000
Minor	6,000
Loss of Hull	Identical Used Aircraft Average Selling Price at Time of Accident
Hull Damage	
Substantial	One-Third of Replacement Cost
Minor	Negligible

TABLE 2-12. IMPLICIT PRICE DEFLATION FOR 1974 BASE YEAR

Year	Implicit Price Deflator*
1971	0.82762
1972	0.86192
1973	0.91191
1974	1.00000
1975	1.09619
1976	1.15393
1977	1.21807

* Source: "1978 Economic Report of the President"

an accident among the cause/factor citations as modified. This redistribution is made in accord with the procedure described in the preceding paragraph. In so doing, the total dollar loss for each accident remains unchanged. Where a cause/factor is deleted from an accident, its apportioned share of the accident cost is redistributed among the remaining cause/factors in that specific record. Analagously, where a cause/factor substitution is made, the substitute cause/factor code automatically assumes that cost apportioned to the cause/factor for which the substitution was made. It is noted that one substitute cause/factor may be substituted more than once in a single record. For example, in an accident record, the original citations of Improper Operation of Flight Controls (64*23) and Exceeded Design Limits (64*09) would be substituted twice by the modified cause/factor Improper Operation of Equipment (64*2Z). In this instance, the substitute cause/factor Improper Operation of Equipment would assume the costs apportioned to both of the originally cited cause/factors. An illustration displaying a typical redistribution of accident costs, is given in Table 2-13.

GENERAL AVIATION ACTIVITY DATA

The general aviation population is heterogeneous with respect to its types of aircraft and equipment, use of airspace and airport facilities and services, regulation, insurance, and pilot skills and experience. It was expected, a priori, that these differences within the general aviation population will be manifested in terms of varying safety records among its constituent segments. Moreover, these differences also influenced the extent to which the various general aviation segments participate in or take advantage of FAA safety programs.

To better account for these potential differences in safety performance and response to FAA safety programs, the general aviation population was disaggregated into primary use and aircraft type categories. This disaggregation yielded 36 general aviation subsegments as shown in Figure 2-2. Corresponding definitions of primary uses and aircraft types are given in Tables 2-14 and 2-15, respectively. These subsegments are judged to be reasonably homogeneous in terms of their physical and operational attributes described above.

TABLE 2-13. DISTRIBUTION OF ACCIDENT COST AMONG CITED CAUSES AND FACTORS AS ENCODED ACCORDING TO THE MCC AND THE MODIFIED FRAMEWORK

Original MCC Encoding			General Aviation Study Modified Encoding	
Associated Cost	Cause/Factor		Cause/Factor	Associated Cost
Cited a Cause				
69,655.17	70ACJ	-	70ACJ	101,000
69,655.17	88A38	-	deleted	--
69,655.17	88A33	-	deleted	--
69,655.17	75AAY	-	75AAY	101,000
69,655.17	64A19	-	64*4Z	101,000
69,655.17	64A44	-	64*4Z	101,000
69,655.17	64A31	-	64*5Z	101,000
Cited as Factor				
17,513	88J05	-	deleted	--
505,000	Total Accident Cost			505,000

TYPE OF AIRCRAFT

PRIMARY USE	Single-Engine Piston	Multi-Engine Piston	Turboprop	Turbojet	Rotor Piston	Rotor Turbine
Business						
Corporate						
Personal						
Aerial Application						
Instructional						
Air Taxi						

FIGURE 2-2. DISAGGREGATION OF THE GENERAL AVIATION POPULATION BY PRIMARY USE AND AIRCRAFT TYPE

TABLE 2-14. PRIMARY USE DEFINITIONS

Primary Use	Definition
BUSINESS (BUS) -	Any use of an aircraft not for compensation or hire by an individual for the purposes of transportation required by a business in which they are engaged.
CORPORATE (CORP) -	(previously Executive) - Any use of an aircraft by a corporation, company or other organization for the purposes of transporting its employees and/or property not for compensation or hire and employing professional pilots for the operation of the aircraft.
PERSONAL (PER) -	Any use of an aircraft for personal purposes not associated with a business or profession, and not for hire. This includes maintenance of pilot proficiency.
AERIAL APPLICATION (AA) -	Aerial application in agriculture consists of those activities that involve the discharge of materials from aircraft in flight and a miscellaneous collection of minor activities that do not require the distribution of any materials.
INSTRUCTIONAL (INST) -	Any use of an aircraft for the purposes of formal instruction with the flight instructor aboard, or with the maneuvers on the particular flight(s) specified by the flight instructor.
AIR TAXI (AT) -	Any use of an aircraft by the holder of an Air Taxi Operating Certificate which is authorized by that certificate.

TABLE 2-15. AIRCRAFT TYPE DEFINITIONS

Aircraft Type	Predominant Aircraft Class
SINGLE-ENGINE PISTON (SEP)	Single-engine piston (any type)
MULTI-ENGINE PISTON (MEP)	Twin-engine piston under 12,500 lb TOGW
TURBOPROP (T/P)	Twin engine turboprop under 12,500 lb TOGW
TURBOJET (T/J)	Twin-engine turbojet/fan under 12,500 lb TOGW
ROTOR PISTON (RP)	All aircraft in class
ROTOR TURBINE(RT)	All aircraft in class

Moreover, activity data (active aircraft, operations, hours flown, etc.) for these subsegments are available from the FAA Statistical Handbook of Aviation(6). For 1976 and prior years, these data are extracted from the Aircraft Registration File. Based on the reporting procedures, number of aircraft by type represent census counts. However, reporting of hours flown is optimal; and, hence, are estimated. After 1976, both types of data are obtained through statistical sampling.

Hours flown and number of active aircraft by general aviation subsegment for each of the years 1971 through 1977 are given in Figure 2-3. These data are used in the calculation of accident rates in the accident data analysis section of Chapter 3.

FAA SAFETY PROGRAMS

A list of 90 active safety programs was compiled based on information in several FAA source documents at the onset of the air carrier study.(7-15) These sources included fiscal year reviews of FAA activities, national aviation system plans, engineering and development program plans, safety related engineering and development activities and program overview and highlight reports. Drawing on statements of objectives and related descriptive information, a program was included in the safety program list if:

a. Its primary objective was safety related

b. The program was listed under a safety related category in its reference document

c. The program represented an effort to improve safety in an existing operational program

d. The primary objective of the program served some other purpose (e.g., increase in capacity), but also contained elements which contributed significantly to safety.

An initial listing of 104 programs was compiled. This listing was subsequently compressed to 90 programs through merging of several partially redundant program elements. For purposes of the alignment analysis, these programs were Classified into six functional categories as follows:

PRIMARY USE

(a) 1971

	TYPE OF AIRCRAFT					
	Single-Engine Piston	Multi-Engine Piston	Turboprop	Turbojet	Rotor Piston	Rotor Turbine
Business	3,129 20,084	1,231 6,124	--	--	67 244	--
Corporate	225 910	1,350 3,700	587 1,121	434 863	--	94 211
Personal	6,040 64,696	340 2,273	--	--	7 256	--
Aerial Application	1,273 4,742	30 150	--	--	100 367	--
Instructional	4,287 9,635	139 528	--	--	35 139	--
Air Taxi	643 1,536	745 1,709	327 239	26 53	127 246	102 274

(b) 1972

	TYPE OF AIRCRAFT					
	Single-Engine Piston	Multi-Engine Piston	Turboprop	Turbojet	Rotor Piston	Rotor Turbine
Business	3,115 21,540	1,293 6,632	--	--	64 288	--
Corporate	231 1,130	1,369 3,264	568 1,170	454 934	--	95 239
Personal	7,180 71,469	376 2,781	--	--	9 290	--
Aerial Application	1,434 5,312	40 248	--	--	140 290	--
Instructional	4,395 10,461	144 563	--	--	51 165	--
Air Taxi	672 1,774	941 2,052	347 241	49 77	99 213	240 329

(c) 1973

	Single-Engine Piston	Multi-Engine Piston	Turboprop	Turbojet	Rotor Piston	Rotor Turbine
Business	3,806 25,369	1,481 7,335	--	--	67 317	--
Corporate	260 1,169	1,521 4,256	633 1,434	589 1,133	--	111 267
Personal	7,144 70,312	349 2,486	--	--	8 312	--
Aerial Application	1,653 5,538	54 318	--	--	130 415	--
Instructional	4,932 11,622	174 602	--	--	62 209	--
Air Taxi	849 1,990	1,173 2,566	377 292	81 117	91 224	264 416

(d) 1974

	Single-Engine Piston	Multi-Engine Piston	Turboprop	Turbojet	Rotor Piston	Rotor Turbine
Business	4,182 26,012	1,518 7,733	--	--	90 393	--
Corporate	299 1,284	1,485 4,253	777 1,636	652 1,279	--	130 335
Personal	7,812 73,878	452 2,732	--	--	20 347	--
Aerial Application	1,692 5,712	48 260	--	--	138 465	-
Instructional	4,512 11,793	193 636	--	--	77 213	--
Air Taxi	977 2,134	1,348 2,342	414 338	117 168	89 192	378 553

FIGURE 2-3. GENERAL AVIATION ACTIVITY STATISTICS BY PRIMARY USE AND AIRCRAFT CATEGORIES FOR THE YEARS 1971-1977 (The upper number is hours flown and the lower number is active aircraft. A dash indicates negligible activity).

TYPE OF AIRCRAFT

PRIMARY USE	Single-Engine Piston	Multi-Engine Piston	Turboprop	Turbojet	Rotor Piston	Rotor Turbine
Business	4,379 26,780	1,537 7,926	--	--	100 420	--
Corporate	329 1,434	1,498 4,373	844 1,891	667 1,431	--	183 499
Personal	8,574 77,839	489	--	--	25 166	--
Aerial Application	1,785 6,338	47 291	--	--	137 507	--
Instructional	4,754 11,510	182 652	--	--	68 225	--
Air Taxi	877 2,056	1,384 2,833	412 402	147 155	65 175	462 710

(e) 1975

TYPE OF AIRCRAFT

PRIMARY USE	Single-Engine Piston	Multi-Engine Piston	Turboprop	Turbojet	Rotor Piston	Rotor Turbine
Business	4,464 28,484	1,664 8,441	--	--	90 424	--
Corporate	337 1,612	1,518 4,570	858 1,975	735 1,582	--	215 544
Personal	9,074 81,462	516 3,188	--	--	32 460	--
Aerial Application	2,002 6,842	64 354	--	--	161 579	--
Instructional	4,805 12,177	165 568	--	--	72 281	--
Air Taxi	945 2,327	1,384 2,964	425 347	174 177	77 182	561 792

(f) 1976

PRIMARY USE						
Business	4,687 31,542	1,793 8,587	--	--	108 424	--
Corporate	436 1,161	1,413 3,856	916 2,243	765 1,763	--	170 425
Personal	7,812 81,740	480 3,378	--	--	23 539	--
Aerial Application	1,802 6,221	47 235	--	--	175 869	--
Instructional	5,965 14,544	239 768	--	--	37 139	--
Air Taxi	1,044 2,057	1,555 3,165	454 434	222 217	38 86	660 875

(g) 1977

FIGURE 2-3. (Continued)

a. Facilities and Equipment
b. Safety Research and Development
c. Operations Safety
d. Regulatory Programs
e. Capacity Programs with Safety Contributions
f. Management and Administrative Programs with Safety Contributions.

The programs within each of the above categories are listed in Tables 2-16 through 2-21, respectively. These program listings, originally reviewed with respect to completeness and accuracy by several FAA offices as a part of the earlier air carrier study, were subsequently reexamined for their appropriateness relative to the purposes of this study.

SECTION 2. ANALYSIS AND EVALUATION METHODOLOGY

The analysis and evaluation methodology consists of three parts:

a. Cause/factor and accident type data analysis
b. Cause/factor and safety program alignment analysis
c. Safety program effectiveness evaluation

The respective methods used for the above cited analyses and evaluations are described in the following paragraphs.

CAUSE/FACTOR AND ACCIDENT TYPE DATA ANALYSIS

Analysis of the general aviation accident data serves three purposes. First, prevailing causes and accident types occurring in the respective general aviation subsegments are documented in terms of selected descriptive statistics. Second, individual general aviation subsegments are combined into larger subpopulations based on the degree of similarity (homogeneity) in accident behavior and operational attributes. The subsequent safety program evaluations are made with respect to these combined subpopulations. Third, empirical associations are sought among cause/factors, accident types, and selected pilot experience parameters. Such associations, to the extent to which they

TABLE 2-16. FAA SAFETY PROGRAMS: FACILITY AND EQUIPMENT*

Code	Program Description
101	ATCT- CS/T - Air Traffic Control Tower - Combined Station/Tower (1964)
102	Automation of Flight Assistance and Weather Information Service (1975)
103	Automation of Preflight Briefing Services (1977)
104	D. F. Equipment Improvements (1964)
105	Equip Remaining VOR's with DME (1973)
106	Add DME to ILS (1972)
107	REIL - Runway End Identification Lights (1964)
108	VASI - Visual Approach Slope Indicator (1964)
109	LDIN - Lead in Lighting System (1965)
110	Frangible Approach Light Mounting Retrofit (1975)
111	OMNI - Directional REIL/RAIL (Runway Alignment Indicator Lights) (1976)
112	BRITE - (Bright Radar Indicator Tower Equipment) (1967)
113	ARTS II (1972)
114	ASR - 8 (1964)
115	Revised Approach Lighting System (MALS, MALSR, SSALS) (1967)
116	Simplex Radar Digitizer Replacement Program (1978)
117	Runway Grooving Program (1972)
118	EARTS/DARC - Enroute Automated Radar Tracking System/Discrete Access Radar Channel (1979)

* The year the program started is given at the end of each program description.

TABLE 2-17. FAA SAFETY PROGRAMS: SAFETY RESEARCH AND DEVELOPMENT*

Code	Program Description
201	Radar Tracking of Nonbeacon Equipped A/C - ARTS III (1970)
202	Conflict Alert - ARTS III - (Software) (1975)
203	Weather Radar Display System (ASR - 57)
204	ATARS - Automated Terminal Area Radar Service (1974)
205	Instrument Landing Approach Aids (1961)
206	BCAS/APWI - Collision Avoidance System/Proximity Warning Indicator (1975)
207	Fog Dispersal Research (1970)
208	New Equipment Development for Crash and Fire Rescue (1960 continuous)
209	Snow/Ice/Slush Removal Methods (1964)
210	Hazardous Materials Transport and Handling System Investigations
211	Fire Safety Research - Inflight/Post Crash/Ground (1964)
212	New Bomb and Weapon Detection Systems (1976)
213	Crashworthiness Programs - Air Carriers/GA (1972)
214	MLS - Microwave Landing System (1971)
215	ASTC-ASDE-Airport Surface Traffic Control - Airport Surface Detection Equipment (1966)
216	WVAS - Wake Vortex Avoidance System (1970)
217	DABS - Discrete Address Beacon System (1972)
218	Cockpit Human Factors Research (Hardware) (1977)
219	Wind Shear Program (1972)
220	All Weather Landing System (1961 Approx.)
221	Pilot Training Research Program (1965)
222	Experiments on Preventing Disorientation (Date Unknown)
223	Biomedical Experiments on Visual Collision Avoidance (Date Unknown)
224	Studies on Controller Stress (Date Unknown)
225	AV-AWOS - Automatic Weather Observation System (1973)

* The year the program started is given at the end of each program description.

TABLE 2-18. FAA SAFETY PROGRAMS: OPERATIONS SAFETY*

Code	Program Description
301	Increased Emphasis on Detecting/Sensing/Tracking Hazardous Weather (1977)
302	Organization and Participation in Clinics/Meetings/Group Discussions to Increase Pilot and Crew Member Knowledge/Techniques/Skills and Safety Awareness (1968)
303	Airport Security Programs (1970-Skymarshalls and 1972 Airports)
304	Screening of Surplus Military Aircraft Prior to Dispersal (1973)
305	QASAR - Quality Assurance Systems Analysis Review (1971)
306	Hazardous Material Inspections (1974)
307	New Cabin Safety Rules (1961)
308	MAC - Maintenance Analysis Center (MRRS/MISRS/MDRS) (1963)
309	MSAW (ARTS III Improvement) Minimum Safe Altitude Warning System (1976)
310	SWAP - Systemworthiness Analysis Program (1966)
311	Review and Revision of Pilot/Controller Glossary (1977)
312	TAP - Technical Appraisal Program for ATC (1976)

* The year the program started is given at the end of each program description.

TABLE 2-19. FAA SAFETY PROGRAMS: REGULATORY PROGRAMS (FAR's)*

Code		Program Description
401	FAR Part 13	Enforcement Procedures (11/1962)
402	FAR Part 21	Certification Procedures Product and Parts (2/1965)
403	FAR Part 23	Air Worthiness Standards - Normal, Utility, Acrobatic Airplanes (1/1965)
404	FAR Part 25	Air Worthiness Standards - Transport Category Airplanes (2/1965)
405	FAR Part 27	Air Worthiness Standards - Normal Certified Rotorcraft (2/1965)
406	FAR Part 29	Air Worthiness Standards - Transport Category Aircraft (2/1965)
407	FAR Part 33	Air Worthiness Standards - Aircraft Engines (2/1965)
408	FAR Part 35	Air Worthiness Standards - Propellers (2/1965)
409	FAR Part 37	Technical Standard Order Authorization (1/1965)
410	FAR Part 39	Air Worthiness Standards - Procedures (11/1964)
411	FAR Part 43	Maintenance, Preventive Maintenance, Rebuilding Alterations (7/1964)
412	FAR Part 61	Certification: Pilot and Flight Instructors (11/1962)
413	FAR Part 63	Certification: Crew Members (Other than above) (11/1962)
414	FAR Part 65	Certification: Airmen (Other Than 61 and 63) (11/1962)
415	FAR Part 67	Medical Standards and Certification (11/1962)
416	FAR Part 91	General Operating and Flight Rules (9/1963)
417	FAR Part 93	Air Traffic Rules and Airport Traffic Patterns (9/1963)
418	FAR Part 107	Airport Security (3/1972)
419	FAR Part 121	Certification and Operation: Air Carrier and Commercial Operators Using Large Airplanes (4/1965)
420	FAR Part 123	Certification and Operation: Air Travel and Clubs (10/1968)
421	FAR Part 135	Air-Taxi and Commercial Operators of Small Aircraft (9/1964)
422	FAR Part 139	Certification and Operation: Land Airports Serving Air Carriers (Other Than Helicopters) (7/1972)

* Date of implementation is given at the end of each program description, but it is noted that most FAR's have undergone general revisions since implementation.

TABLE 2-20. FAA SAFETY PROGRAMS: CAPACITY PROGRAMS WITH SAFETY CONTRIBUTIONS

Code	Program Description
501	National ATCSCC - To Enhance Safety and Efficient Operation of Aircraft Throughout 20 ARTCC System
502	Airways Facilities System Checking
503	Full ILS Program Installation
504	Establish Localizer/Marker/Approach Lights at Airports Not Qualifying for Full ILS
505	Establish TVOR's at Qualifying Airports
506	Area Navigation System (RNAV)
507	Aircraft Separation/Navigation Standards Program

TABLE 2-21. FAA SAFETY PROGRAMS: MANAGEMENT AND ADMINISTRATIVE PROGRAMS WITH SAFETY CONTRIBUTIONS

Code	Program Description
601	Biennial Review of Airworthiness and Operations Regulations
602	Increasing the Effectiveness of Delegation Option Authorization (DOA) Program
603	Examining the Use of a Random Sampling Program for Management and Enforcement for General Aviation
604	Automation of the Process of Developing New Instrument Flight Procedures
605	Review of TCA Establishment Requirements
606	Review of TRSA Establishment Requirements
607	Advisory Information Services Regarding Compliance and Standards for ADAP, Part 139 and Part 121

exist, are used in the interpretations of effectiveness of interrelated safety programs. As implied by the foregoing, the first purpose constitutes part of the final findings and conclusions of this study. The latter purposes yield intermediate results that are used in organizing the safety program evaluations.

Accident Descriptive Statistics

Using the accident base described in the preceding section of this chapter, general aviation descriptive statistics are tabulated that portray:

a. Summary statistics on number of accidents, fatalities, injuries and costs by general aviation subsegment for the seven year period from 1971 through 1977.

b. Rank orderings of leading cause/factors and accident types by individual general aviation subsegment and by combined general aviation subpopulation.

c. Time series histories of the leading cause/factors and associated accident costs by combined general aviation subpopulations for the years 1971 through 1977.

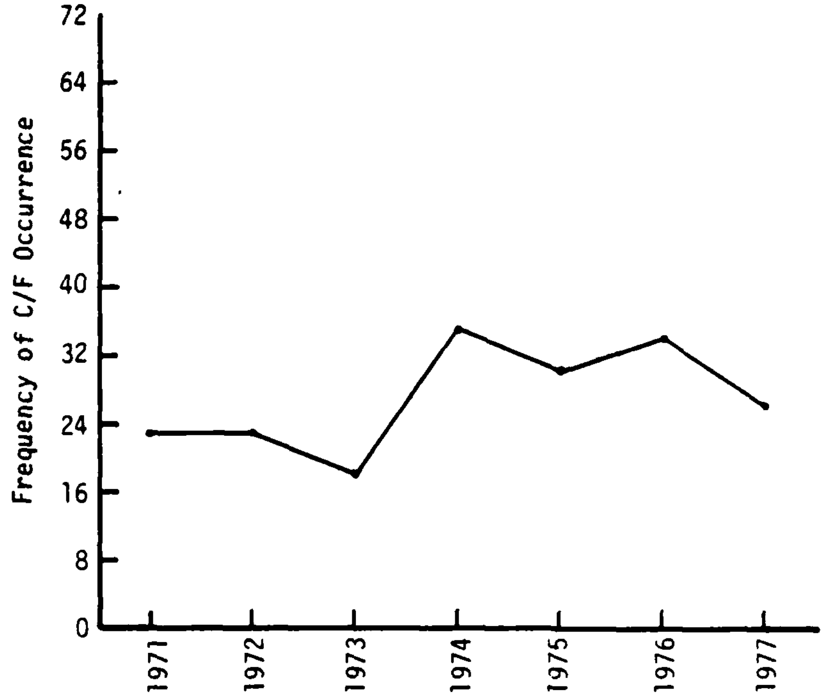
The formats adopted for displaying these summary statistics are illustrated in Figures 2-4 and 2-5 (the actual statistics are described later, in Chapter 3). In the format shown in Figure 2-4, the top ten cause/factors and accident types are ranked by frequency of citation. In addition, other summary statistics are also shown including accidents, injuries, costs, hours flown, and active aircraft. The format illustrated in Figure 2-5 was adopted for purposes of examining the year-to-year changes in cause/factor frequencies and their corresponding relationships with FAA safety programs. These relationships pertain to the entire general aviation population, not its individual subsegments. In reporting these descriptive statistics, it should be noted that some cause/factors used in the analysis represent aggregations of individual cause/factors as described in the following section of the report.

TOTAL ACCIDENTS	16,287	TOTAL COST (1000) (1974 DOLLARS)	$2,097,710
FATAL INJURIES	6,094		
SERIOUS INJURIES	3,049		
MINOR INJURIES	4,614		

CAUSE FACTORS	FREQUENCY	%	ACCIDENT TYPE	FREQUENCY	%
64*4Z	5895	22	U	3710	23
64*2Z	3622	14	N	2281	14
64*3Z	2691	10	A	2146	13
64*1Z	2666	10	Q	1744	11
64*6Z	2520	10	G	992	6
64*5Z	2515	10	J	959	6
64*7Z	830	3	M1	751	5
68*3Z	760	3	MØ	653	4
74*KA	739	3	H	592	4
74*00	352	.1	K	527	3

TOTAL FLIGHT HOURS	57,438,000
AVERAGE ACTIVE AIRCRAFT	77,328

FIGURE 2-4. SAMPLE OF GENERAL AVIATION SUBSEGMENT DATA PRESENTATION FORMAT



Total Yearly C/F Cost (1974 Dollars X 1000)

	1971	1972	1973	1974	1975	1976	1977
$	3,285	3,339	4,172	5,946	4,265	2,071	3,877

TOTAL ASSOCIATED FATALITIES 173

TOTAL ACCIDENTS ASSOCIATED AS CAUSE . . 846
TOTAL ACCIDENTS ASSOCIATED AS FACTOR . 34
TOTAL ACCIDENTS ASSOCIATED AS BOTH. . . 880

TOTAL ASSOCIATED COST AS CAUSE. $26,359
TOTAL ASSOCIATED COST AS FACTOR . . . . $ 596
TOTAL ASSOCIATED COST AS BOTH $26,955

DIRECTLY ALIGNED SAFETY PROGRAMS. . . . None
INDIRECTLY ALIGNED SAFETY PROGRAMS. . . 104, 106, 107, 108, 109, 111
115, 214, 218, 220, 221
503, 504

FIGURE 2-5. SAMPLE OF GENERAL AVIATION CAUSE/FACTOR AND ACCIDENT COST DATA PRESENTATION FORMAT

Cause/Factor Aggregation

Relatively few cause/factors were cited by accident investigators with sufficient frequency to permit detection of statistically significant changes in their rates of occurrence. The majority of cause/factors listed in the MCC and in the modified framework were cited at a rate of less than twice a year, if at all. Accordingly, these rarely occurring cause/factors have been aggregated within major cause/factor categories to provide partial, lower resolution data to be used in detecting trends that might be attributable to safety program effects.

The procedures used for cause/factor aggregation were as follows:

a. An individual cause/factor cited at a rate of no greater than seven times in one year, and not cited more than ten times in the years 1976 and 1977, was listed for aggregation.

b. These individual cause/factors were then aggregated under their respective major cause/factor category codes.

For example, if cause/factor 76*AA (Flight Altimeter) was cited, say seven times in one year as a cause of an accident (and not in 1976 or 1977), its frequency of occurrence and associated costs were transferred to the collecting code 76*00 (Instruments/Equipment). This process was repeated for all code 76*XX individual cause/factors that met the aggregation test. Thus, the cumulation code (76*00) represented all of the infrequently cited individual cause/factors in that major category. This same process was repeated for all major code categories. Based on a total of over 68,000 cause/factor citations as a cause over the seven year period, any single cause cited less than 55 times represented less than 0.1 percent of the total cause citations. Collectively, all cause citations aggregated in these cumulation codes represented less than 5 percent of all cause citations.

This accumulation of infrequent events into intermediate cause/factor categories was of particular value in the case of mechanical cause/factors, where individual cause/factors were often at too low a level of disaggregation to align with a safety program. For example, the cause/factor code 74*SK denoted not only a power plant failure, but a failure of the fuel system, and more specifically, the malfunctioning of the fuel system's pressurizing and dump valve. While this information might be vital to an engineer in determining why an engine caught fire, for purposes such as creating a more general program for maintenance procedures or post crash fire safety, it was sufficient to this study's purposes to know that a fuel system or power plant failure occurred. Thus, because alternative safety programs are aimed at different levels of a system hazard, this conversion of "rare events" to a higher level of aggregation facilitated their use in evaluating corresponding safety programs.

Determination of Homogeneous General Aviation Subpopulations

As described in the data base section of this chapter, general accident statistics have been disaggregated by primary use and aircraft type subsegments. These subsegments were chosen for the purpose of examining potential differences in accident behavior among commonly recognized categories of general aviation. Based on this examination, those categories found to be similar in their accident behavior (and selected other operational attributes) were combined into larger subpopulations. Because these subpopulations are homogeneous, no essential information is lost in the evaluation at this subpopulation level. Therefore, the FAA safety programs are evaluated with respect to the causes of accidents in each of these subpopulations. The steps used in determining these subpopulations consist of:

a. Classifying subsegment pairs as being similar in accident behavior based on rank order correlations between their respective accident cause orderings

b. Combining subsegments into subpopulations that have high rank order correlations, and also are similar in other operational attributes (aircraft types, degree of regulation, etc.).

Further, some subsegments are deleted from the analysis because they represent a negligible fraction of general aviation activity.

The Spearman rank correlation coefficient[16] was used to test for statistically significant correlations of accident cause orderings among general aviation subsegments. This test is nonparametric and, as such, does not carry strong assumptions regarding the sample population distribution. Using this test, general aviation subsegment pairs having rank correlations equal to or greater than 0.90 at the 10 percent significance level were judged as being similar (homogeneous in accident cause behavior). This test was based on the ten causes cited most frequently in the subsegment accident records.

The second step in the specification of general aviation subpopulations consisted of identifying operational differences that preclude a specific combination of subsegments (even though their accident cause rank orderings are similar) or suggest an alternative combination of subsegments better suited to safety program evaluation. Mainly, this step entailed qualitative judgments concerning the safety implications of different aircraft types and regulatory environments. Finally, general aviation subsegments in which there was insignificant activity (number of aircraft and hours flown) and few accidents reported in the data base (less than 0.1 percent of total accidents) were deleted.

Cross-Tabulations of Accident Statistics

Determinations of safety program effectiveness requires that sets of interrelated safety programs and cause/factors be judged collectively. That is, it is not sufficient to make singular judgments concerning mitigation of one cause/factor by one program. To facilitate accomplishment of this collective evaluation requirement, cross-tabulations of selected accident statistics were generated. The cross-tabulations were used for purposes of identifying:

a. Frequently occurring pairwise cause/factor combinations

b. Frequently occurring cause/factor and accident type combinations, and

c. Accident type and pilot experience relationships.

Three accident statistic cross-tabulations were generated for each of the general aviation subpopulations (described in the preceding section). Examples of these cross-tabulations are given in Tables 2-22, 2-23 and 2-24. It can be seen, for example, from Table 2-22 that in 846 accidents in which 64*4Z was cited as a cause, 64*2Z was also cited as a cause 115 times (pairwise cause occurrence), and accident type A was cited 230 times (cause and accident type association). In addition, the cause 64*2Z was cited 30 times in conjunction with 64*4Z as the cause of accident type A. Similarly, the statistics illustrated in Table 2-23 portray accident frequencies as a function of "total

TABLE 2-22. SAMPLE CROSS-TABULATION OF NUMBER OF ACCIDENTS BY CAUSE, FACTOR, AND ACCIDENT TYPE: FOR CASE WHERE 64*4Z WAS ONE OF THE CAUSES

Cause/ Factors*	Accident Type										
	Any	U	N	A	Q	MI	C	G	J	MO	H
CAUSES:											
64*4Z	846	102	40	230	70	11	0	140	19	11	10
64*2Z	115	16	14	30	8	1	0	10	7	1	2
64*3Z	50	17	1	10	6	2	0	3	2	3	2
64*5Z	27	13	1	3	1	0	0	2	0	2	1
64*1Z	64	5	8	12	8	1	0	10	10	1	1
64*6Z	50	3	4	6	2	0	0	4	18	3	0
68*3Z	13	5	0	6	0	0	0	0	0	0	0
64*7Z	19	0	0	0	0	3	0	0	0	1	0
74*KA	9	9	0	0	0	0	0	0	0	0	0
74*00	8	7	0	0	0	0	0	0	0	0	0
FACTORS:											
64*4Z	11	0	0	0	0	0	0	0	0	0	0
64*2Z	12	2	0	5	1	0	0	2	0	0	0
64*3Z	19	3	2	6	5	1	0	1	0	0	0
64*5Z	6	0	0	1	3	0	0	1	0	0	0
64*1Z	40	2	2	20	2	0	0	4	1	1	1
64*6Z	4	2	0	1	0	0	0	0	0	0	0
68*3Z	6	1	0	3	0	0	0	0	0	1	0
64*7Z	5	1	0	1	1	0	0	1	0	0	0
74*KA	0	0	0	0	0	0	0	0	0	0	0
74*00	3	2	0	0	0	0	0	0	0	0	0

* See Page 2-11 for cause/factor classifications

TABLE 2-23. SAMPLE CROSS-TABULATION OF NUMBER OF ACCIDENTS BY TOTAL PILOT HOURS AND TOTAL PILOT HOURS IN TYPE*

Total Pilot Hours	Total Pilot Hours in Type							
	Unknown	0-5	6-10	11-25	26-50	51-75	76-100	Above 100
Unknown	2	--	--	--	--	--	--	--
0 - 25	--	79	2	14	3	1	1	6
26 - 50	--	5	1	3	24	--	--	--
51 - 75	--	11	15	13	6	23	--	--
76 - 100	--	5	6	13	14	8	26	--
101 - 200	--	23	14	34	57	30	29	53
201 - 500	--	55	24	52	70	50	34	241
Above 500	--	189	64	126	142	106	86	1,151

* These data are given here as contained in the accident data base. Some errors are present in these data as evidenced by cases where Total Pilot Hours in Type exceeds Total Pilot Hours.

TABLE 2-24. SAMPLE CROSS-TABULATION OF NUMBER OF ACCIDENTS BY ACCIDENT TYPE AND TOTAL PILOT HOURS IN TYPE FOR PILOTS WITH TOTAL PILOT TIME

Accident* Type	Total Pilot Hours in Type: Unknown	0-5	6-10	11-25	26-50	51-75	76-100	Above 100
A	--	13	9	15	15	8	8	110
B	--	--	--	--	--	--	--	2
C	--	1	3	5	8	3	7	101
D	--	--	--	--	--	--	--	6
E	--	1	4	4	5	--	4	43
F	--	--	2	5	7	4	5	37
G	--	2	3	8	4	3	4	31
H	--	3	3	4	2	5	6	41
I	--	--	--	--	--	--	--	1
J	--	4	2	3	3	5	1	44
K	--	5	1	5	1	4	7	26
LO	--	6	2	2	--	1	--	15
L1	--	--	--	1	--	--	--	1
L2	--	--	--	1	1	1	2	11
MO	--	16	3	4	9	4	3	38
M1	--	19	1	2	6	7	1	61
N	--	37	3	12	22	16	13	158
P	--	--	--	--	--	--	--	5
Q	--	20	10	12	13	9	5	80
RO	--	1	--	2	--	--	1	11
R1	--	--	--	--	--	--	--	7
SO	--	6	2	2	4	--	2	12
S1	--	--	--	--	1	--	1	--
T	--	--	--	--	--	--	1	--
U	--	42	16	37	37	32	14	273
V	--	2	--	2	1	1	--	13
W	--	--	--	--	--	2	--	6
Y	--	--	--	--	1	--	--	1
0	--	2	--	--	1	--	--	8
2	--	--	--	--	--	--	--	--
4	--	--	--	--	--	--	--	2
5	--	7	--	--	--	--	--	2
6	--	1	--	--	1	1	1	4
7	--	1	--	--	--	--	--	1

* See Page 2-21 for accident type descriptions

pilot time" and "pilot time in type of aircraft", and the statistics in Table 2-24 extend this functional relationship to include accident type.

CAUSE/FACTOR AND SAFETY PROGRAM ALIGNMENT ANALYSIS

The alignment analysis addresses two questions. First, are there one or more safety programs directed toward mitigating hazards implied by the citation of significant cause/factors? In short, this analysis concerns the completeness of the mapping between programs and significant cause/factors.

The primary component of the alignment analysis consists of comparing cause/factor descriptions against the objectives of the 90 FAA safety programs listed in Tables 2-16 through 2-21. Specifically, this procedure consists of the following sequence:

a. High frequency individual or aggregated cause/factors are determined to be aligned with safety programs where there exists a direct or indirect correspondence between the cause/factor definition and the safety program objective. This step yields three results: aligned cause/factors and safety programs, unaligned cause/factors, and unaligned safety programs.

b. Those safety programs not aligned with the cause/factors cited in the data base are further examined for alignment with cause/factors in the MCC, but not used by accident investigators over the seven year study period. The alignment criteria and result categories are the same as in the first step.

c. Those cause/factors not aligned with safety programs in the first safety analysis step are reviewed in the context of the potential hazards they represent. Associated hazards judged to be potentially significant in the present aviation environment are subsequently considered in the safety program effectiveness evaluation. Similarly, safety programs not aligned with cause/factors were reconsidered with respect to the hazards they addressed in the effectiveness evaluation.

CAUSE/FACTOR AND SAFETY PROGRAM ALIGNMENT CRITERIA

The criteria used in aligning safety programs and cause/factors are qualitative indicators of the congruence between program objectives and hazards implied in the cause/factor definitions. Specifically, alignments are determined to be direct, indirect, or nonexistent in accord with the following definitions:

a. Direct Alignment. The mitigation of the hazard implied in the cause/factor definition is stated as a specific objective of the aligned safety program. That is, there exists one-to-one congruency between hazard and objective.

b. Indirect Alignment. The mitigation of the hazard implied in the cause/factor definition may be partially stated or subsumed in the objective of a safety program. That is, there exists a partial congruency between hazard and objective. For example, FAR Part 29, Airworthiness Standards for Transport Category Aircraft (Program Code 406) includes, among other things, standards for all airframe components (major cause/factor code 70) which subsumes several individual cause/factors such as Main Shock Assembly Structures (Code 70*CA), Nosewheel Assembly (Code 70*CE), etc.

c. No Alignment. Safety programs and cause/factors that fail the above defined congruency criteria are determined to be nonaligned. Nonaligned safety programs should not necessarily be construed as being unwarranted, nor should nonaligned cause/factors be construed as being unattended hazards. The interpretation of such nonalignments is dealt with in the safety program effectiveness evaluation.

SAFETY PROGRAM EFFECTIVENESS EVALUATION

The purpose of this evaluation was to determine the extent to which the FAA safety programs mitigate general aviation accident causes and, based on these findings and the attributes of the overall safety program structure, to make recommendations for program improvements. The criteria and methods used in this evaluation are described in the following paragraphs.

Evaluation Criteria

The effectiveness of FAA's safety programs is evaluated in this study in accord with four principal considerations:

a. Changes in frequencies of cause/factor citations that can be attributed to safety program impacts.

b. The effectiveness of the means by which programs addressed safety problems at various accident cause hierarchical levels.

c. The extent to which related safety programs addressed safety problems at various accident cause hierarchial levels.

d. The extent to which related safety programs contributed to overall general aviation system safety, especially within major cause/factor categories.

The first consideration is a direct measure of empirical improvements in aviation results. The latter three considerations pertain mainly to how effectively single and multiple, related programs are designed and implemented.

Evaluation Procedures

The FAA safety programs listed in Tables 2-16 through 2-21 were evaluated in three steps with respect to the considerations described.

a. Association of cause/factor frequency changes with corresponding implementation of aligned safety programs.

b. Use of an accident cause fault tree for assessing safety program interdependencies and their respective points of implementation in the accident cause hierarchy.

c. Classification of safety programs in terms of the types of action taken toward improving systems safety performance. These procedures are separately described in the following paragraphs.

Cause/Factor and Safety Program Associations

Apart from other influencing variables, an effective safety program should be empirically demonstrable through observation of a decreasing citation rate or downward shift in level of cause/factor(s) corresponding to the implementation of the aligned program(s). This evaluation step is directed toward identifying such empirical associations based on the cause/factor citation frequency histories (given in the descriptive statistics part of the cause/factors data analysis) and on the safety program implementation dates (given in the safety program data base section of this report).

In seeking these associations, it is apparent, a priori, that several factors exist that tend to mask such empirical cause-effect relationships. First, many individual cause/factor frequency rates are too low to detect statistically significant changes (the rare event problem). As discussed earlier, cause/factors have been aggregated at higher levels to partially offset this problem. Second, most safety programs are indirectly aligned with cause/factors in general aviation accidents. This is generally true of monitoring, regulatory and educational programs and, also, generally characteristic of programs aligned at higher levels in the accident cause hierarchies. Third, changes over time in the aviation environment alter relative exposure rates to aviation hazards which, of course, also influence cause/factor frequency rates. These factors are dealt with qualitatively to the extent practicable in this step of the evaluation procedure. The subsequent evaluation steps are designed in the main to provide further insights on program effectiveness that are not masked by the above factors.

The Accident Cause Fault Tree

The fault tree used in this study is a conceptual model used for portraying the logical cause-effect relationships leading to an aircraft accident. This method is widely used in systems safety investigations (for example, nuclear plants and automated control systems). In simple terms, a fault tree consists of event chains leading to system failure and are specified in terms of hierarchical "and/or" relationships among all possible factors affecting system performance.

Three interconnected fault trees have been developed in this study for safety program evaluation. These fault trees portray, respectively

a. Human error accident causes (Figure 2-6)

b. Mechanical accident causes (Figure 2-7)

c. Environmental accident causes (Figure 2-8).

The logic symbols used in these fault trees are defined in Figure 2-9. A detailed treatment of fault tree construction and use will be found in

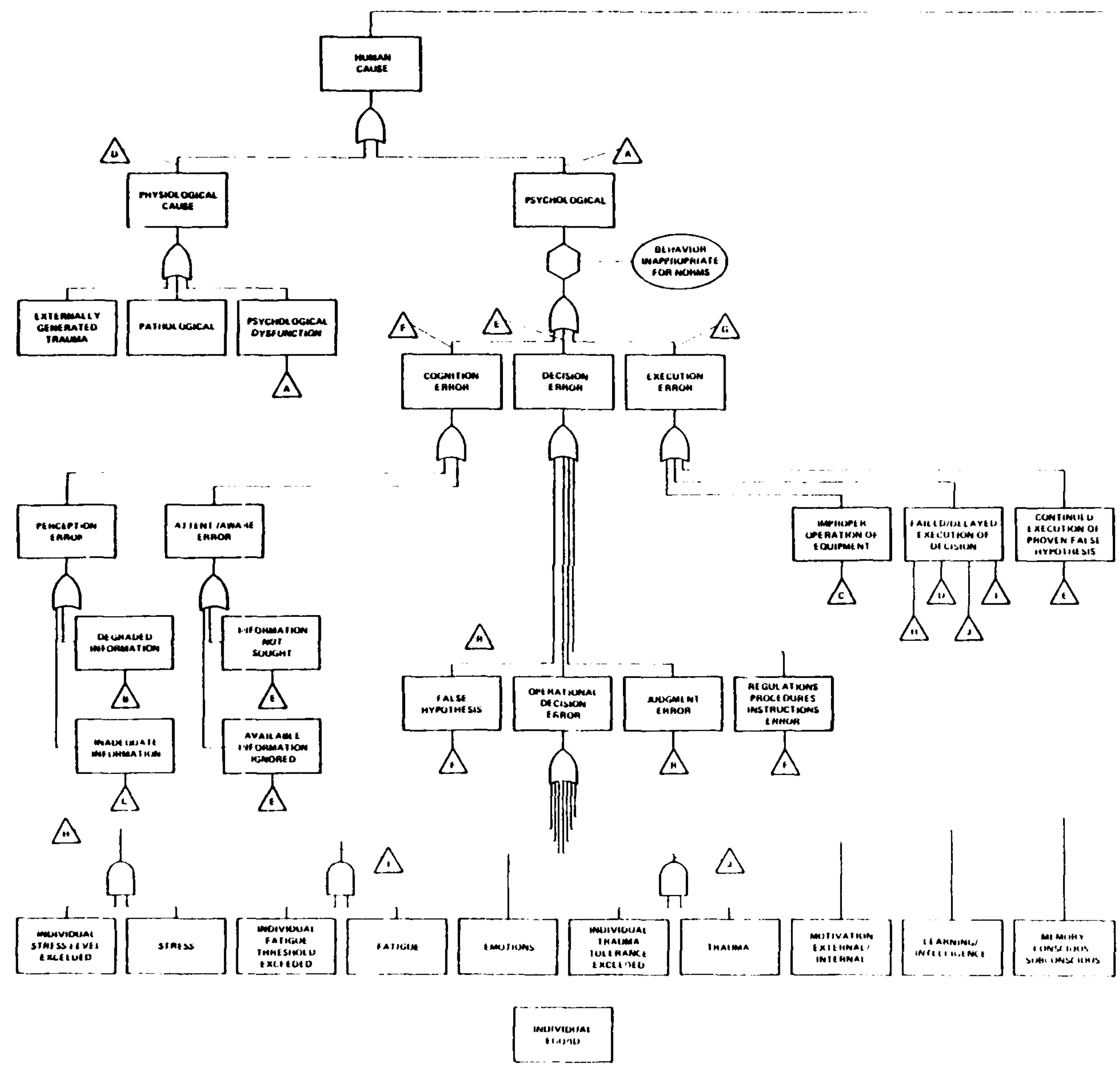


FIGURE 2-6. HUMAN ERROR FAULT TREE DIAGRAM

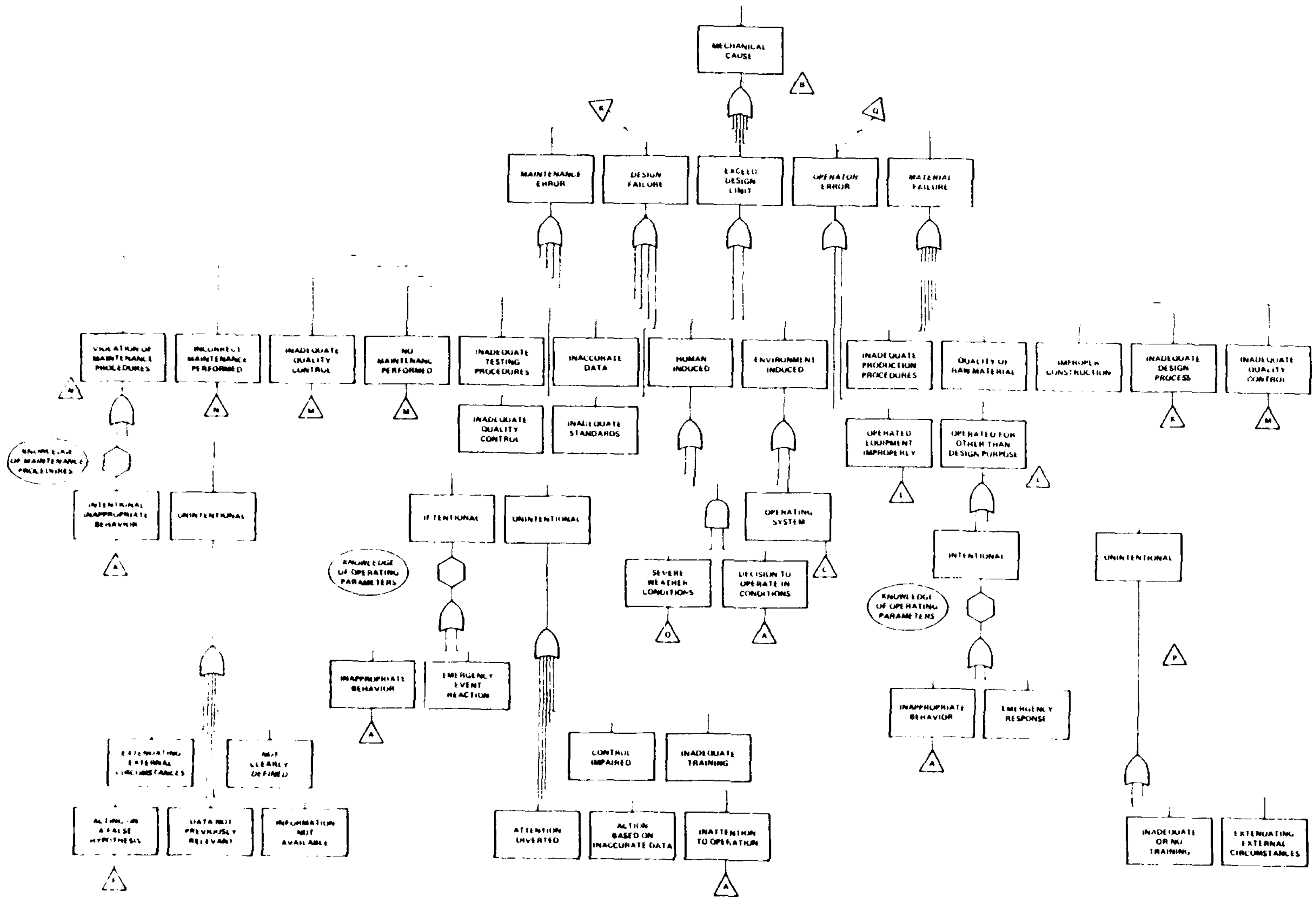


FIGURE 2-7. MECHANICAL ERROR FAULT TREE DIAGRAM

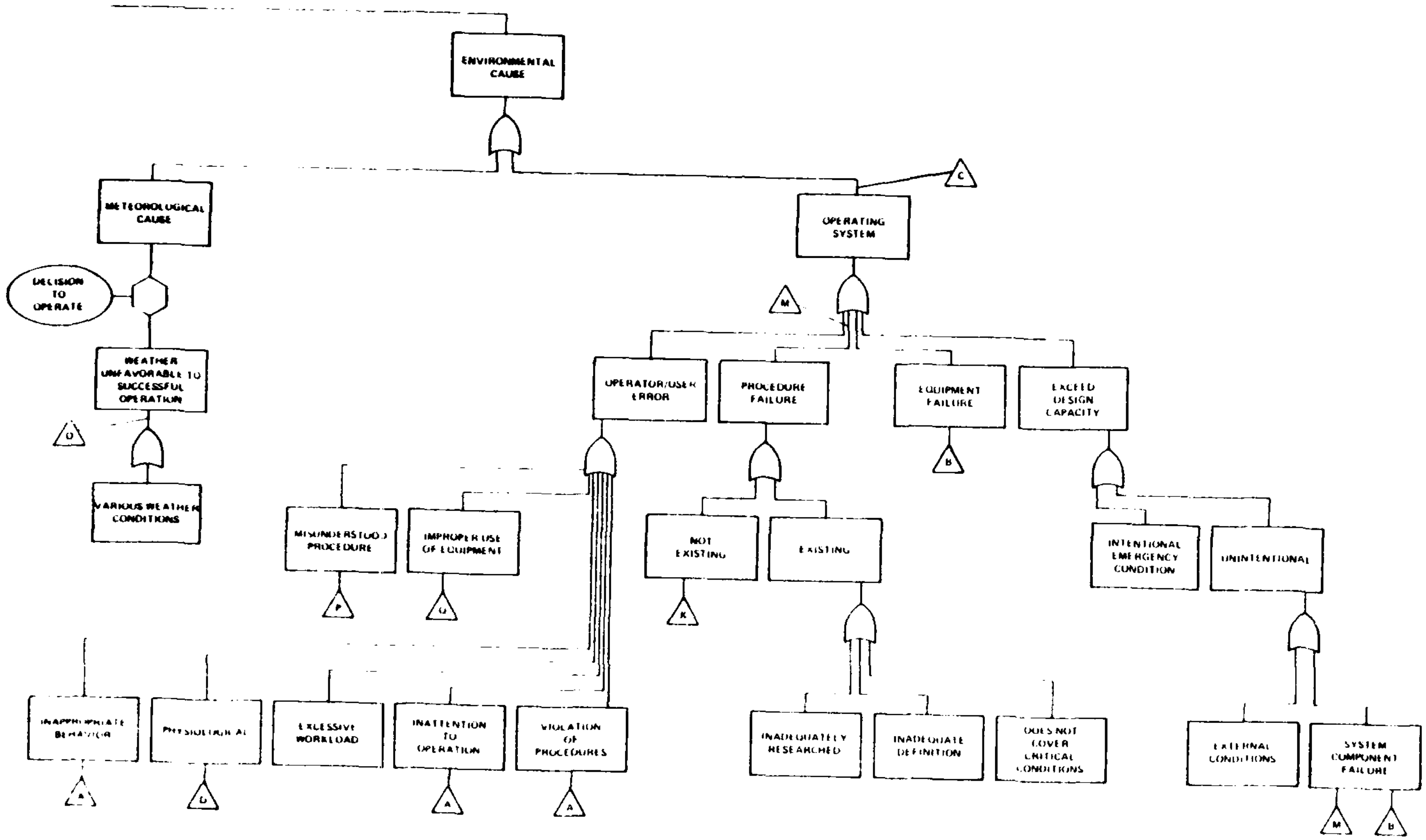
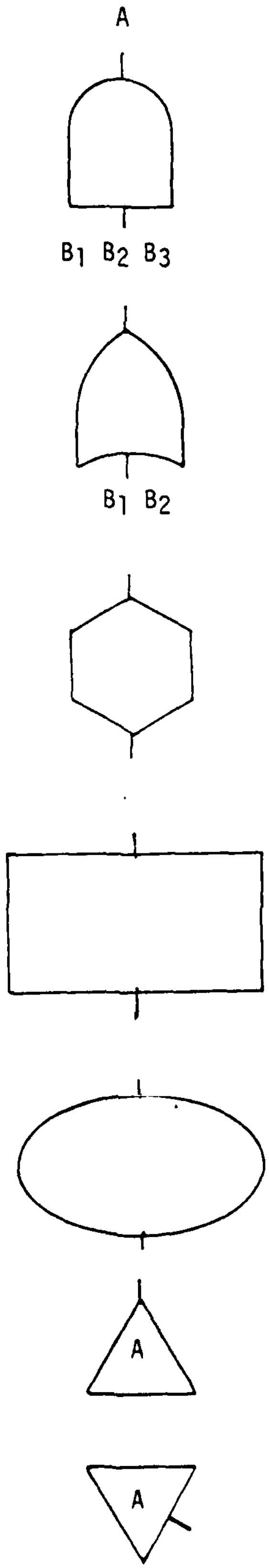


FIGURE 2-8. ENVIRONMENTAL ERROR FAULT TREE DIAGRAM



AND Gate. An AND gate is used to denote an event that can only occur if all of the input events also occur. For example, Output A cannot occur unless inputs B_1, B_2 and B_3 occur.

OR Gate. An OR gate is used to denote an event that can occur if any one (or combinations thereof) input event occurs. For example, event A can occur if either or both B_1 or B_2 occurs.

INHIBIT Gate. An INHIBIT gate permits applying a condition or restriction to the sequence that must be satisfied for an output to be generated.

EVENT IDENTIFICATION. Usually describes the output or input of an AND or an Or gate.

RESTRICTION IDENTIFICATION Usually indicates a restriction or stipulation when used with an INHIBIT gate.

INPUT SYMBOL A connecting symbol to another part of the fault tree within the same or another major branch and has a matching OUTPUT symbol.

OUTPUT SYMBOL A connecting symbol to another part of the fault tree to show continuation of the error path(s).

FIGURE 2-9. FAULT TREE SYMBOLS

Reference 17. For their intended use in this study, these fault trees are strictly qualitative. That is, they portray the logical structure of accident cause-event chains, but no attempt has been made to estimate event probabilities.

The use of these fault trees is predicated on conditions present in all aircraft accidents: a precipitating (or first) cause, and the logic relationships through which this first cause may result in an accident or incident. Given a clear picture of an accident's cause-effect chain, it is possible to determine at what levels in the chain remedial safety actions can be taken and what their potential effectiveness might be. The fault tree is used here to provide such an assessment of existing programs in terms of the hierarchy of alignments between interdependent programs and aligned accident cause/factors. The results of this fault tree application provide an overall systems safety basis for making recommendations that address gaps in existing safety program coverage.

It should be noted that fault trees presented in this report are not highly detailed. Fault trees that traced all the cause-event chains to their lowest logical level would add several hierarchical levels. They would also eventually lead to a common cause: human error. Such detailed information is clearly impractical as a working tool given the boundaries of factual (observable) human error data recoverable from accident investigations. Further, factual data necessary to corroborate alternative human behavior concepts are limited and subject to controversy among experts. Thus, the fault trees used here stop short of attempting to capture basic human behavior. Rather, these fault trees deal with observable facts about accidents and present the possibilities for their cause. Based on such findings, directions for further research are recommended.

Classification of Safety Programs by Type of Activity

FAA safety programs examined in this study are classified in four categories as follows:

a. Programs that are directed at assisting system operators (pilots, air traffic controllers, etc.) in the performance of their work. These programs can have the dual purpose of increasing system capacity while enhancing safety (e.g., ILS, VASI, DME, ARTS III, etc.)

b. Programs which form an active monitoring system of checks and balances on the aviation industry's equipment, manufacturing, maintenance, and operational procedures (i.e., SWAP, MAC, QASAR, etc.). Also classified within this category are other operational phase monitoring systems such as conflict prediction, MSAW, detection/tracking of hazardous weather and the tracking of non-beacon equipped aircraft (an ARTS III improvement)

c. Programs which are remedial in nature and are designed to counter new or increasingly troublesome safety threats in the system (i.e., wind shear detection, crashworthiness, hazardous material handling, frangible approach light systems, etc.)

d. Regulations, procedures, education and enforcement programs directed at maintaining an overall minimum safety level in the aviation system (i.e., FAR's, safety seminars, spot checks cabin safety, etc.).

This classification of safety programs in conjunction with the fault tree evaluations previously described provided another means of determining safety program effectiveness based on the "approach" to the safety problem they address. Thus, for example, even though different safety programs might have the same objective, their effectiveness (or lack thereof) might depend on their approach.

CHAPTER 3. SAFETY PROGRAM ANALYSIS AND EVALUATION

In this chapter, analyses and evaluations of FAA safety programs with respect to the causes of general aviation accidents for the time period from 1971 through 1977 are described. Using the data base and methodology described in the preceding chapter, these analyses and evaluations are presented in three parts:

a. General aviation accident data analysis
b. Safety program and cause/factor alignment analysis
c. Safety program evaluations.

SECTION 1. GENERAL AVIATION ACCIDENT DATA ANALYSIS

The study results presented in this section consist of descriptive statistics of general aviation accidents, determinations of homogeneous general aviation subpopulations and analyses of cause/factor and accident type patterns within these subpopulations. Descriptive statistics include number of accidents, fatalities, injuries, cost, cause/factors and accident types. These statistics are given for each of the 36 general aviation subsegments described in Chapter 2, and for combinations (subpopulations) of these subsegments that were determined to be similar in their accident behavior.

DESCRIPTIVE STATISTICS OF GENERAL AVIATION ACCIDENTS

Accident Frequencies and Costs

Over the 1971-77 time period, there were 30,592 general aviation accidents. The frequency distribution of these accidents over this period is shown in Figure 3-1. It is seen from this figure that there is no apparent trend in accident frequency over the seven year period. Apart from peaks of about 4,711 accidents in 1971 and 4,500 accidents in 1974, general aviation accidents occur at a constant annual rate of about 4,300. Adjusting these

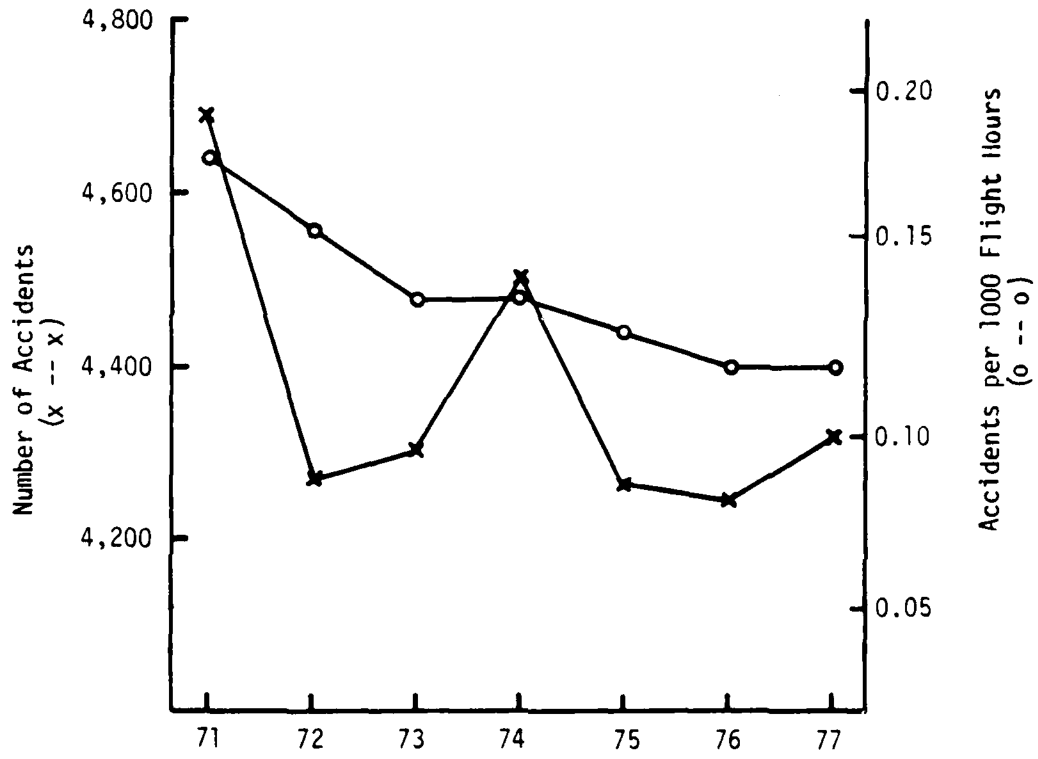


FIGURE 3-1. GENERAL AVIATION ACCIDENT HISTORY (1971-1977)

frequencies to an annual rate, expressed in terms of the number of accidents per 1,000 flight hours, shows a modest decline of about five percent (less than one percent per year) over the seven year period. This decline in rate contrasts sharply with the nearly 50-percent decline in air carrier accidents over the same time period.

These accidents and corresponding accident rates are broken down by primary use and aircraft type category in Tables 3-1 and 3-2. These tables show, for example that the Personal, Single-Engine Piston subsegment accounts for approximately 50 percent of all general aviation accidents. Moreover, the accident rate for this subsegment (0.28 accidents per 1,000 flight hours) is approximately double the mean rate of 0.14 accidents per 1,000 flight hours for the entire general aviation population. Similarly, aerial application use and rotorcraft also exhibit relatively high accident rates. In contrast, corporate, business and air taxi uses exhibit accident rates significantly below the population mean rate.

Fatalities, and serious and minor injuries are shown in Tables 3-3 through 3-5. The personal use general aviation category clearly dominates these statistics. For example, the Personal, Single-Engine Piston subsegment accounts for 53 percent of fatalities, 55 percent of serious injuries and 57 percent of minor injuries. These percentages are somewhat higher than the corresponding percentage of general aviation accidents (49 percent) suggesting that accidents are relatively more serious in this subsegment than in the remainder of the general aviation population.

Accident costs for the seven year period by primary use and aircraft type subsegment are given in Table 3-6. All costs are given in 1974 dollars based on implicit price deflation values given in Table 2-13. These costs have been estimated based on the cost factors described in Chapter 2. That is, fatalities, major, and minor injuries were valued at $300,000, $45,000 and $6,000, respectively. Destroyed aircraft were valued at replacement cost at the time of the accident, and substantial damage was valued at one-third of replacement cost. Using these cost factors, it was estimated the cost of general aviation accidents over the 1971-1977 time period totalled $3.6 billion. The distribution of this cost over the 36 general aviation subsegments is approximately proportional to the corresponding distribution of 30,000 plus accidents. As

TABLE 3-1. NUMBER OF ACCIDENTS FOR EACH GENERAL AVIATION PRIMARY USE AND AIRCRAFT TYPE SEGMENT (1971-1977)

	SEP	MEP	T/P	T/J	ROTOR PIST.	ROTOR TURB.	OTHER	TOTAL
BUSINESS	2,259	652	23	5	231	69	15	3,254
CORPORATE	178	335	95	51	47	31	5	742
PERSONAL	15,059	1,228	20	10	222	26	491	17,056
AER. APPL.	2,660	29	4	--	456	18	--	3,167
INSTR.	3,873	176	7	5	168	23	112	4,364
AIR TAXI	482	517	67	17	97	161	1	1,342
OTHER	328	77	15	6	149	79	13	667
TOTAL ACCIDENTS								30,592

TABLE 3-2. ACCIDENT RATES FOR EACH GENERAL AVIATION PRIMARY USE AND AIRCRAFT TYPE SEGMENT (Number of Accidents per 1,000 Flight Hours)

	SEP	MEP	T/P	T/J	ROTOR PIST.	ROTOR TURB.	OTHER
BUSINESS	.08	.06	NA	NA	.39	NA	NA
CORPORATE	.08	.04	.02	.01	NA	.03	NA
PERSONAL	.28	.41	NA	NA	1.79	NA	NA
AERIAL APPL.	.23	.09	NA	0	.46	NA	NA
INSTR.	.11	.14	NA	NA	.42	NA	NA
AIR TAXI	.08	.06	.02	.02	.13	.06	NA
OTHER	NA	NA	NA	NA	NA	NA	NA

NA = Not Applicable

TABLE 3-3. TOTAL FATALITIES FOR EACH PRIMARY USE AND AIRCRAFT TYPE GENERAL AVIATION SUBSEGMENT (1971-1977)

	SEP	MEP	T/P	T/J	ROTOR PIST.	ROTOR TURB.	OTHER	TOTAL
BUSINESS	712	365	9	22	43	17	2	1,170
CORPORATE	45	187	80	57	7	9	2	387
PERSONAL	5,158	936	42	5	24	10	91	6,266
AER. APPL.	273	28	3	--	21	1	--	326
INSTR.	533	72	5	10	6	--	12	638
AIR TAXI	191	394	107	23	27	116	5	863
OTHER	102	91	22	2	33	32	1	33
TOTAL FATALITIES								9,683

TABLE 3-4. SERIOUS INJURIES FOR EACH PRIMARY USE AND AIRCRAFT TYPE SUBSEGMENT (1971-1977)

	SEP	MEP	T/P	T/J	ROTOR PIST.	ROTOR TURB.	OTHER	TOTAL
BUSINESS	338	77	1	8	46	16	3	486
CORPORATE	28	47	21	26	10	4	--	136
PERSONAL	2,784	265	6	1	42	4	114	3,102
AER. APPL.	317	3	1	--	54	3	--	378
INSTR.	395	18	1	--	13	4	28	431
AIR TAXI	99	126	42	3	12	61	--	343
OTHER	62	21	6	1	45	28	2	163
TOTAL								5,039

TABLE 3-5. MINOR INJURIES FOR EACH PRIMARY USE AND AIRCRAFT TYPE SUBSEGMENT (1971-1977)

	SEP	MEP	T/P	T/J	ROTOR PIST.	ROTOR TURB.	OTHER	TOTAL
BUSINESS	516	115	5	3	106	32	4	777
CORPORATE	33	75	16	27	21	7	--	179
PERSONAL	4,331	283	7	1	77	5	87	4,704
AER. APPL.	353	2	--	--	77	4	--	436
INSTR.	696	36	2	--	34	7	23	775
AIR TAXI	130	168	24	--	50	94	--	466
OTHER	76	21	17	--	59	43	3	216
TOTAL								7,553

TABLE 3-6. TOTAL COSTS FOR EACH PRIMARY USE AND AIRCRAFT TYPE SUBSEGMENT (Thousands of 1974 Dollars)

	SEP	MEP	T/P	T/J	ROTOR PIST.	ROTOR TURB.	OTHER	TOTAL
BUSINESS	244,545	127,332	4,510	8,034	18,359	8,412	863	412,055
CORPORATE	15,859	64,738	38,032	41,159	3,146	4,139	642	232,453
PERSONAL	1,776,607	321,[illegible]03	16,771	3,054	12,097	4,261	32,019	2,167,912
AER. APPL.	109,263	9,965	948	--	14,439	1,160	--	135,775
INSTR.	196,662	26,097	2,534	5,800	4,232	862	5,104	236,187
AIR TAXI	65,362	135,972	40,363	13,926	10,173	45,687	1,586	313,069
OTHER	35,402	29,473	8,566	867	14,100	14,401	415	103,224
TOTAL								3,600,675

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EVALUATION OF SAFETY PROGRAMS WITH RESPECT TO THE CAUSES OF GEN--ETC(U)
MAY 80 T M CONNOR, C W HAMILTON DOT-FA78WA-4159
UNCLASSIFIED FAA-ASP-80-2 NL

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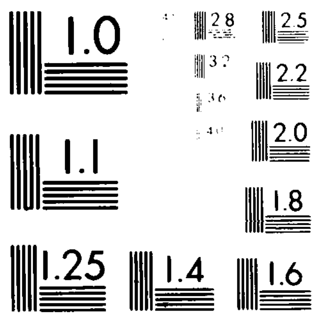
1.0
2.8
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3.2
2.2
3.6
4.0
2.0
1.1
1.8
1.25
1.4
1.6

is evident from Table 3-6, accidents in the personal use category account for $2.1 billion (60 percent) of total general aviation accident costs.

Cause/Factor and Accident Type Statistics

Table 3-7 summarizes general aviation accident cause/factor frequency citations based on the NTSB cause/factor code listing given in the MCC. It is seen from this table that approximately 723 of the possible 798 codes (80 percent) were cited over the seven year period (this contrasts with the 50 percent of codes cited in air carrier accidents over the 1964 to 1976 period). These 723 codes were cited a total of 102,964 times as causes or factors in the 30,592 accidents reported in the data base. However, about 50 percent of these cause/factors were cited at a rate of once per year, and only 20 percent were cited at a rate of more than seven times per year.

TABLE 3-7. SUMMARY OF CAUSE/FACTOR CITATIONS (cause/factor codes listed in the NTSB MCC)

Total Number of Cause/Factors	798	
Number of Cause/Factors Cited	723	
Frequency of Citation as Cause		
Cited 7 or fewer times/year	575	(80 percent)
Cited 4 or fewer times/year	512	(71 percent)
Cited 2 or fewer times/year	440	(61 percent)
Cited one time/year	352	(49 percent)
Total Citations as Cause	68,655	
Total Citations as Factor	34,309	

These original NTSB cause/factor codes were modified as described in Chapter 2; i.e., Terrain (Code 83) and Miscellaneous Acts and Conditions (Code 88) cause/factors were deleted, and substitute codes were used in the Pilot/Crew (Codes 64-67) and Personnel cause/factor categories (Code 68). Further, the modified cause/factors were screened and aggregated where required in accord with the methodology described in Chapter 2. Specifically, individual cause/factors occurring at a rate of seven or fewer times per year were aggregated into a corresponding collection code (XX*00) with each major cause/factor category. These modifications and aggregations resulted in a final set of 55 cause/factors that are subsequently aligned with FAA safety programs. These cause/factors, rank ordered by frequency of citation as cause, are given in Table 3-8. The designated collection codes resulting from the aggregation tests are given in Table 3-9. Analagous to the corresponding results in the earlier air carrier study, human error citations dominate their cause/factor statistics. Eight of the most frequently cited cause/factors are in the human error category. Collectively, these eight cause/factors account for 39,099 (80 percent) of the 48,783 citations as cause.

Corresponding summary statistics for general aviation accident types over the 1971 to 1977 time period are given in Table 3-10. As for cause/factors, accident types are rank ordered by frequency of citation.

These statistics are further detailed for each of 36 primary use and aircraft type subsegments in Appendix A. Specifically, using the format shown in Figure 2-4, the following statistics (and their sources) are tabulated:

a. Number of accidents
b. Number of fatalities
c. Number of major injuries
d. Number of minor injuries
e. Estimated accident cost
f. Ten most frequently cited cause/factors
g. Ten most frequently cited accident types
h. Total hours flown
i. Average active aircraft fleet size.

The first four statistics (accidents, fatalities, and major and minor injuries) were taken directly from the NTSB accident data base. Accident costs were estimated using the cost factors described previously in this section. Cause/factors and accident types are those contained in the respective modified classification systems. The top ten cause/factors and accident types shown in these tables account for a subsegment average of 86 percent of all

TABLE 3-8. MODIFIED CAUSE/FACTORS AND THEIR RESPECTIVE FREQUENCIES USED IN THE SAFETY PROGRAM ALIGNMENT ANALYSIS

Cause/Factor Code	Description	Frequency	
		Causes	Factors
64*4Z	Operation of equipment	11,294	434
64*2Z	Operational decision	5,725	462
64*3Z	Procedures, regulations, etc.	5,613	973
64*5Z	Attention/Awareness	4,942	458
64*6Z	Perception	4,576	150
64*1Z	Judgment	4,080	1,278
68*3Z	Other personnel--procedures, etc.	1,772	520
74*KA	Powerplant failure undetermined	1,438	2
64*7Z	Physical	1,097	181
74*00	Powerplant--random occurrences	836	217
82*H	Unfavorable winds	594	1,691
84*I	Undetermined cause	523	--
84*7	Evasive maneuver	442	137
70*00	Airframe--random occurrences	399	283
82*00	Weather-random occurrences	389	5,435
84*G	Foreign object damage	304	25
75*00	Systems--random occurrences	289	149
80*00	Airport/Airways--random	289	1,257
70*CJ	Airframe--landing gear--brakes	262	98
80*BY	Airport condition--other	251	1,050
78*00	Rotorcraft--random occurrence	244	23
70*CB	Airframe--landing gear retraction	243	30
74*AC	Powerplant--structure--rods	200	1
74*AF	Powerplant--structure-values	182	3
70*CA	Airframe--main gear-shocks	154	5
74*CG	Powerplant--carburetor	147	4
82*M	Downdrafts/Updrafts	138	396
74*AD	Powerplant--structure--cylinder	121	3
82*G	Weather--carburetor icing	114	356
74*DB	Powerplant--fuel lines	114	3
70*CF	Airframe--landing gear--wheels	113	37
74*IO	Powerplant--engine throttle	113	6
84*00	Miscellaneous causes	111	26
74*AB	Powerplant--structure crankshaft	107	--
74*BA	Powerplant--ignition mags	107	7
84*J	Written cause	101	3
74*AE	Powerplant--structure--piston	98	2
74*FA	Powerplant--propeller--blades	91	5
70*CE	Airframe--landing gear--nosewheel	87	8
84*1	Vortex turbulence	87	7
74*BC	Powerplant--ignition sparkplugs	87	15
70*CM	Airframe--landing gear--locking	84	2
74*AY	Powerplant--structure--other	80	1
82*J	Sudden windshift	78	112
74*CH	Powerplant--fuel pumps	75	8
74*CJ	Powerplant--fuel vents	75	9
74*DB	Powerplant--lubrication lines	72	4
70*CC	Airframe--landing gear--emergency extension	71	1
84*8	Unqualified person--operate aircraft	67	33
80*BJ	Airport--hidden hazard	66	52
84*3	Animals on runway	59	7
80*BD	Airport condition--snow windrows	58	221
76*00	Instruments/Equipment--random	55	112
80*BC	Airport condition--snow	55	257
68*00	Other personnel--random occurrences	12	15
TOTAL CITATIONS		48,783	16,583

TABLE 3-9. CODE DESIGNATIONS FOR AGGREGATION OF INDIVIDUAL CAUSE/FACTOR CODES

Category Description	Aggregated Cause/Factor Codes
All Personnel	68*00
" Airframe	70*00
" Powerplants	74*00
" Systems	75*00
" Instruments/Equipment	76*00
" Rotorcraft	78*00
" Airports/Airways	80*00
" Weather	82*00
" Other Miscellaneous	84*00

TABLE 3-10. NUMBER OF GENERAL AVIATION ACCIDENTS RANK ORDERED BY ACCIDENT TYPE

Code	Description	Number of Accidents
A	Ground-Water Loop-Swerve	3,747
B	Dragged Wingtip, Pod, or Float	25
C	Wheels-up	658
D	Wheels-Down Landing in Water	26
E	Gear Collapsed	496
F	Gear Retracted	369
G	Hard Landing	1,987
H	Nose Over/Down	959
I	Roll Over	80
J	Overshoot	1,343
K	Undershoot	814
LØ	Collision with Aircraft - Both in Flight	370
L1	Collision with Aircraft - One Airborne	45
L2	Collision with Aircraft - Both on Ground	220
MØ	Collision with Ground/Water - Controlled	1,155
M1	Collision with Ground/Water - Uncontrolled	1,175
N	Collision with Wires, Trees...other	4,292
P	Bird Strike (Collision with Birds)	13
Q	Stall	2,981
R	Fire or Explosion	146
SØ	Airframe Failure - In Flight	408
S1	Airframe Failure - On Ground	59
T	Engine Tearaway	1
U	Engine Failure or Malfunction	6,753
V	Propeller/Rotor Failure	277
W	Propeller/Rotor Accident to Person	129
Y	Propeller/Jet/Rotor Blast	30
Ø	Turbulence (Z), Hail Damage to Aircraft (Ø), Lightening Strike (1)	152
2	Evasive Maneuver	11
4	Ditching	12
5	Missing Aircraft, Not Recovered	101
6	Miscellaneous/Other	112
7	Undetermined	96
TOTAL		29,042

* The total excludes 1,550 of the 30,592 accidents studied. The "Other" categories shown in Table 3-1 account for 1,291 of this number. The remainder represent the subsegments eliminated in forming the subpopulations.

citations as cause and 84 percent of accident type citations. The remaining 15 percent of citations as cause were distributed among 44 other cause/factors, and the remaining 16 percent of accident citations were distributed among 26 accident types. The hours flown are extracted from FAA activity statistics covering the study period (Table 2-3). Active aircraft is taken to be the unweighted average of the number of active aircraft for the years 1971 through 1977 (Table 2-3).

DETERMINATION OF HOMOGENEOUS SUBPOPULATIONS

The accident statistics described above were tabulated for widely recognized general aviation subsegments for which activity data are regularly collected. For purposes of evaluating safety programs, it was desirable to combine those segments that are judged to be similar in their accident behavior. As described in the methodology section of Chapter 2, subsegments were combined if:

a. Their cause/factor rank orderings did not differ significantly, and

b. Their operating attributes were judged to be similar (at least to the extent to which such attributes could influence accident behavior).

The Spearman rank correlation test was used to test for statistically significant correlations between subsegment cause/factor citations. This statistical test was chosen because it is a nonparametric test and therefore does not require strong distribution assumptions. Moreover, due to the nature of nonparameteric tests, they tend to reflect conservative estimates of the true (but unknown) correlations between cause/factor rank orderings for different subsegments or pairs. In using this test, two subsegments were judged to be similar if the probability that a rank order correlation of at least 0.90 occurring by chance was less than 0.10. An example of this rank correlation test is shown in Table 3-11 using the subsegments Instructional, Single-Engine Piston and Instructional, Multi-Engine Piston. The sample calculations indicated that the probability that the calculated rank order correlation ($R = .930$) occurred by chance alone, was less than 0.0025. Thus, the test hypothesis that these two subsegments differ in the cause/factor rank orderings is

TABLE 3-11. AN EXAMPLE OF A SPEARMAN RANK ORDER CORRELATION TEST OF CAUSE/FACTOR SIMILARITY BETWEEN GENERAL AVIATION SUBSEGMENTS

	Instructional Primary Use		
	Rank		
Cause	Single Engine Piston Aircraft	Multi-Engine Piston Aircraft	$(Rank_S - Rank_M)^2$
64*4Z	1	2	1
64*3Z	2	1	1
64*5Z	3	3	0
64*2Z	4	5	1
64*6Z	5	6	1
64*1Z	6	4	4
74*KA	7	7	0
82*H	8	9.5	2.25
68*3Z	9	8	1
74*00	10	9.5	0.25
			SUM = 11.5

D = SUM = 11.5

N = Number of ranks = 10

$R = 1 - 60/n^3 - n = 1 - 6(11.5)/1000 - 10 = .930$

P = probability = 0.0025

rejected. This correlation test was repeated for all aircraft type pairs within each of the six primary use categories. The resultant rank order correlations were significant at the .025 level on the average, with many pairwise tests yielding rank order correlations significant at the 0.0005 level. These results were interpreted to mean that with respect to cause/factor rank order there were no variations in accident behavior among the aircraft types within a specific primary use category. In making these inferences, however, it is noted that such correlations may stem solely from peculiarities in the data base structure or investigative biases. Subsequent interpretation of these correlations took this possibility into consideration.

As a result of these correlation tests, the data associated with aircraft types within primary use categories were combined. However, those subsegments that lacked any supporting general aviation activity data were not combined, but rather deleted from the analysis. These deletions were determined to be appropriate because it was believed that additions of accidents to the analysis record that could not be accounted for in operational terms (Flight hours, etc...) would confound the results. Those subsegments deleted as a result of this step are shown in Figure 3-2. These subsegments accounted for less than one percent of the accidents being used in the analysis and, hence, should not affect the study findings.

The final step of determination of similar general aviation subpopulation was the identification of significant operational characteristics that might have either precluded a specific combination or warranted a different combination.

Only two changes to the subsegment combinations resulted from this review. The first change was to separate the Corporate population into two subpopulations: Corporate, Single- and Multi-Engine Piston and Corporate, Turboprop and Turbojet. This change was made for the following reasons:

a. While the rank order correlation of accident causes for these two groups was significant at the 0.1 level, some difference in relative frequencies of accident causes was indicated.

b. This separation into two subpopulations permitted comparisons of the same aircraft types across primary use categories.

TYPE OF AIRCRAFT

PRIMARY USE	Single-Engine Piston	Multi-Engine Piston	Turboprop	Turbojet	Rotor Piston	Rotor Turbine
Business			X	X		X
Corporate					X	
Personal			X	X		X
Aerial Application			X	X		X
Instructional			X	X		X
Air Taxi						

X = Eliminated

FIGURE 3-2. GENERAL AVIATION SUBSEGMENTS DELETED FROM THE SUBPOPULATION COMBINATIONS

The second change resulting from this subsegment examination consisted of combining all helicopter subsegments into one rotorcraft category (ROTOR). This combination included (excluded) the subsegments shown in Table 3-12.

TABLE 3-12. SUBSEGMENTS COMBINED IN THE GENERAL AVIATION SUBPOPULATION: ROTOR

Included Subsegments	Excluded Subsegments
BUS - RP	BUS - RT
CORP - RT	CORP - RP
PER - RP	PER - RT
AA - RP	AA - RT
INST - RP	INST - RT
AT - RP + RT	

The reasons for this change were:

a. All rank order correlations between these subsegment pairs were significant ($p < 0.0025$), indicating similar accident behavior.

b. Helicopters have unique operating characteristics and applications significantly different from airplanes.

c. Helicopters, regardless of primary category, are exempt from many of the regulations regarding airplane operations

Homogeneous General Aviation Subpopulations

The final combinations of the general aviation subsegments selected for the analysis and evaluation of the safety programs are shown in Figure 3-3. These eight subpopulations represent a total of 29,044 accidents, or 95 percent of the 30,592 accidents occurring during the study period. The data contained in each of these subpopulations consist of a pooling of the data associated with the subsumed individual subsegments. For example, the subpopulation Business, Single- and Multi-Engine Piston (Table 3-13) contains the data from the subsegments Business, Single-Engine Piston and Business, Multi-Engine Piston (Appendix A, Tables A-1 and A-2). Tables 3-13 through 3-20 display the summary data for the eight subpopulations subsequently used in the analysis.

TYPE OF AIRCRAFT

PRIMARY USE	Single-Engine Piston	Multi-Engine Piston	Turboprop	Turbojet	Rotor Piston	Rotor Turbine
Business	SUBPOPULATION #1		X	X	#8	X
Corporate	#2		#7		X	#8
Personal	#3		X	X	#8	X
Aerial Application	#4		X	X	#8	X
Instructional	#5		X	X	#8	X
Air Taxi	#6				#8	#8

X = Excluded Subsegment

1. BUS-SEP and MEP
2. CORP-SEP and MEP
3. PER-SEP and MEP
4. AA-SEP and MEP
5. INST-SEP and MEP
6. AT-SEP, MEP, T/P and T/J
7. CORP-T/P and T/J
8. ROTOR-RP and RT

FIGURE 3-3. GENERAL AVIATION SUBPOPULATIONS DETERMINED AS HOMOGENEOUS WITH RESPECT TO ACCIDENT BEHAVIOR

TABLE 3-13. GENERAL AVIATION SUBPOPULATION STATISTICS: BUSINESS, SINGLE- AND MULTI-ENGINE PISTON

TOTAL ACCIDENTS	2911
FATAL INJURIES	1077
SERIOUS INJURIES	415
MINOR INJURIES	631

TOTAL COST (1000) $371,877 (1974 DOLLARS)

CAUSE FACTORS*	FREQUENCY	%	ACCIDENT TYPE**	FREQUENCY	%
64*4Z	846	18	U	656	23
64*2Z	641	14	N	411	14
64*3Z	612	13	A	301	10
64*5Z	512	11	Q	244	8
64*1Z	373	8	M1	162	6
64*6Z	360	8	C	152	5
68*3Z	177	4	G	146	5
64*7Z	142	3	J	127	4
74*KA	127	3	MØ	125	4
74*00	92	2	H	101	3

TOTAL FLIGHT HOURS	38,479,000
AVERAGE ACTIVE AIRCRAFT	33,227

* See Page 2-11 for cause/factor classifications
** See Page 2-21 for accident type classifications

TABLE 3-14. GENERAL AVIATION SUBPOPULATION STATISTICS: CORPORATE, SINGLE- AND MULTI-ENGINE PISTON

TOTAL ACCIDENTS	513	TOTAL COST (1000) (1974 DOLLARS)	$80,597
FATAL INJURIES	232		
SERIOUS INJURIES	75		
MINOR INJURIES	108		

CAUSE FACTORS*	FREQUENCY	%	ACCIDENT TYPE**	FREQUENCY	%
64*3Z	126	16	U	100	19
64*4Z	104	13	N	63	12
64*2Z	82	10	A	63	10
64*5Z	79	10	C	37	7
64*1Z	57	7	Q	37	7
64*6Z	54	7	F	35	7
63*3Z	53	7	G	28	5
74*00	26	3	J	21	4
74*KA	23	3	MØ	20	4
70*CB	22	3	M1	15	3

TOTAL FLIGHT HOURS	10,858,000
AVERAGE ACTIVE AIRCRAFT	5,368

* See Page 2-11 for cause/factor classifications

** See Page 2-21 for accident type classifications

TABLE 3-15. GENERAL AVIATION SUBPOPULATION STATISTICS:
PERSONAL, SINGLE- AND MULTI-ENGINE PISTON

TOTAL ACCIDENTS	16,287	TOTAL COST (1000) (1974 DOLLARS)	$2,097,710
FATAL INJURIES	6,094		
SERIOUS INJURIES	3,049		
MINOR INJURIES	4,614		

CAUSE FACTORS*	FREQUENCY	%	ACCIDENT TYPE **	FREQUENCY	%
64*4Z	5895	22	U	3710	23
64*2Z	3622	14	N	2281	14
64*3Z	2691	10	A	2146	13
64*1Z	2666	10	Q	1744	11
64*6Z	2520	10	G	992	6
64*5Z	2515	10	J	959	6
64*7Z	830	3	M1	751	5
68*3Z	760	3	MØ	653	4
74*KA	739	3	H	592	4
74*00	352	1	K	527	3

TOTAL FLIGHT HOURS	57,438,000
AVERAGE ACTIVE AIRCRAFT	77,328

* See Page 2-11 for cause/factor classifications
** See Page 2-21 for accident type classifications

TABLE 3-16. GENERAL AVIATION SUBPOPULATION STATISTICS: AERIAL APPLICATION, SINGLE- AND MULTI-ENGINE PISTON

TOTAL ACCIDENTS	2,689
FATAL INJURIES	301
SERIOUS INJURIES	320
MINOR INJURIES	355

TOTAL COST (1000) $119,228
(1974 DOLLARS)

CAUSE FACTORS*	FREQUENCY	%	ACCIDENT TYPE**	FREQUENCY	%
64*5Z	569	17	U	808	30
64*6Z	429	13	N	706	26
64*4Z	381	12	Q	520	19
64*3Z	349	11	A	221	8
64*2Z	215	7	MØ	96	4
68*3Z	183	6	H	72	3
74*KA	182	6	M1	38	1
64*1Z	157	5	O	33	1
74*00	134	4	LØ	30	1
84*7	59	2	E	28	1

TOTAL FLIGHT HOURS	11,972,000
AVERAGE ACTIVE AIRCRAFT	6,077

* See Page 2-11 for cause/factor classifications
** See Page 2-21 for accident type classifications

TABLE 3-17. GENERAL AVIATION SUBPOPULATION STATISTICS: INSTRUCTIONAL, SINGLE- AND MULTI-ENGINE PISTON

TOTAL ACCIDENTS	4,049	TOTAL COST (1000) (1974 DOLLARS)	$222,759
FATAL INJURIES	605		
SERIOUS INJURIES	413		
MINOR INJURIES	732		

CAUSE FACTORS*	FREQUENCY	%	ACCIDENT TYPE**	FREQUENCY	%
64*4Z	2723	38	A	886	22
64*3Z	1025	14	U	840	21
64*5Z	595	8	G	650	16
64*2Z	529	7	Q	352	9
64*6Z	515	7	N	329	8
64*1Z	474	7	J	169	4
68*3Z	247	3	K	151	4
74*KA	160	2	H	141	3
82*H	104	1	LØ	112	3
74*00	68	1	MØ	69	2

TOTAL FLIGHT HOURS 35,066,000
AVERAGE ACTIVE AIRCRAFT 12,295

* See Page 2-11 for cause/factor classifications
** See Page 2-21 for accident type classifications

TABLE 3-18. GENERAL AVIATION SUBPOPULATION STATISTICS: AIR TAXI, SINGLE- AND MULTI-ENGINE PISTON, AND TURBOPROP AND TURBOJET

TOTAL ACCIDENTS	1,033	TOTAL COST (1000)	$255,623
FATAL INJURIES	715	(1974 DOLLARS)	
SERIOUS INJURIES	270		
MINOR INJURIES	322		

CAUSE FACTORS*	FREQUENCY	%	ACCIDENT TYPE**	FREQUENCY	%
64*3Z	261	15	U	200	18
64*2Z	253	14	N	192	18
64*4Z	246	14	A	117	11
64*5Z	171	10	MØ	78	7
64*1Z	124	7	Q	76	7
64*6Z	119	7	E	41	4
68*3Z	116	7	C	40	4
74*00	45	3	J	38	4
74*KA	32	2	M1	36	3
70*CB	32	2	H	32	3

TOTAL FLIGHT HOURS 18,189,000
AVERAGE ACTIVE AIRCRAFT 5,038

* See Page 2-11 for cause/factor classifications
** See Page 2-21 for accident type classifications

TABLE 3-19. GENERAL AVIATION SUBPOPULATION STATISTICS: CORPORATE, TURBOPROP AND TURBOJET

TOTAL ACCIDENTS	146	TOTAL COST (1000) (1974 DOLLARS)	$79,191
FATAL INJURIES	137		
SERIOUS INJURIES	47		
MINOR INJURIES	18		

CAUSE FACTORS*	FREQUENCY	%	ACCIDENT TYPE**	FREQUENCY	%
64*3Z	56	24	N	24	16
64*4Z	30	13	U	19	13
64*2Z	20	9	A	15	10
64*5Z	14	6	C	15	10
68*3Z	14	6	MØ	11	8
64*6Z	10	4	F	10	7
64*1Z	8	3	G	9	6
74*00	8	3	J	7	5
75*00	8	3	M1	7	5
80*00	8	3	K	5	3

TOTAL FLIGHT HOURS	9,529,000
AVERAGE ACTIVE AIRCRAFT	2,923

* See Page 2-11 for cause/factor classifications
** See Page 2-21 for accident type classifications

TABLE 3-20. GENERAL AVIATION SUBPOPULATION STATISTICS: ROTOR (ALL CATEGORIES)

TOTAL ACCIDENTS	1,366	TOTAL COST (1000) (1974 DOLLARS)	$109,126
FATAL INJURIES	246		
SERIOUS INJURIES	232		
MINOR INJURIES	445		

CAUSE FACTORS *	FREQUENCY	%	ACCIDENT TYPE **	FREQUENCY	%
64*4Z	569	25	U	420	31
64*5Z	288	12	N	286	21
64*6Z	274	12	G	121	9
64*3Z	263	11	M1	116	8.5
78*00	176	8	V	110	8
68*3Z	125	5	MØ	103	7.5
64*2Z	107	5	I	80	6
74*KA	105	5	SØ	32	2
64*1Z	67	3	6	22	2
74*00	55	2	H	11	1

TOTAL FLIGHT HOURS 6,396,000
AVERAGE ACTIVE AIRCRAFT 2,502

* See Page 2-11 for cause/factor classifications
** See Page 2-21 for accident type classifications

Data for the respective individual subsegments making up each subpopulations are documented in Appendix A.

A caveat that should be noted is that this selection process should not be construed as downplaying safety problems associated with the less active subsegments of general aviation. The selection process was intended to focus research attention on those areas that would have the most significant impact on the majority of general aviation population. Certainly later efforts should be extended to cover the areas not directly evaluated in this study.

ANALYSIS OF SUBPOPULATION ACCIDENT DATA

Within each general aviation subpopulation (defined in Figure 3-3) patterns in the accident data were sought that might explain why some safety programs appear to be mitigating a particular accident cause in one general aviation subpopulation, but not in others.

Specifically, two approaches were used in identifying patterns:

a. The identification of patterns through cross-tabulation of the accident data fields, viz:

- common cause/factor combinations
- cause/factor and accident type associations
- accident type and pilot flight experience relationships

b. The identification of time-series trends in accident data fields, viz:

- cause/factor occurrence rates
- accident rates by accident type
- annual accident costs by cause/factor.

Cross-Tabulations

Seven different types of cross-tabulations were made. These cross-tabulations cover all eight subpopulations and are presented in detail in Appendices B through I. The seven different types of cross-tabulations performed were as follows:

a. Pairwise Cause Frequencies. The ten most frequent accident causes were selected for each general aviation subpopulation. The cross-tabulations show the number of times a given cause is cited in combination with the other top ten causes in that subpopulation. For example, Table 3-21 (also Table B-11 in Appendix B) shows that for the Business, Single- and Multi-Engine Piston subpopulation, cause/factor 64*4Z is cited 64 times in combination with cause/factor 64*1Z.

b. Joint Cause and Factor Frequencies. These top ten causes were also cross-tabulated with respect to the frequency of citations with each of the same causes cited as a factor. This was done to determine if a cause/factor was being used more often as contributing "factor" rather than as a cause.

c. Cause and Accident Type Frequencies. In order to evaluate the accident with which the top ten causes were associated, a cross-tabulation of these causes with the top ten accident types was generated. In this instance, only the first accident type listed in an accident record was used. The second accident type, when cited, usually described a post-accident event. For example, a first accident type Undershoot (Code K) was sometimes followed by the second accident type Collision with Crops (Code N).

d. Pairwise Causes and Accident Type Frequencies. The top ten causes were cross-tabulated with themselves (as in cause by cause discussed above) and then by the top ten accident types for each general aviation subpopulation. This three dimensional tabulation further dissected both the cause-cause frequencies and cause-cause-accident type frequencies. Going beyond two dimensional joint frequencies (cause by cause, or cause by accident) gave indications of any compounding effects that might have been present.

e. Cause, Factor, and Accident Type Frequencies. The same three-dimensional frequency tabulation as that discussed above was generated using the factor citation as the variable.

f. Pilot Time in Type, and Pilot Total Time Frequencies. The predominance of human error as accident causes suggested that a close look at pilot flight time might hold some potential for detecting safety problems. For example, a high frequency of accidents involving a pilot with only 6 to 10 hours time in type and total flight hours, might be associated with accidents in a certain subpopulation. These data could be tested further to find what

TABLE 3-21. CROSS-TABULATION OF THE NUMBER OF ACCIDENTS BY CAUSE, FACTOR, AND ACCIDENT TYPE WHERE THE CODE 64*4Z IS CITED: BUS, SEP & MEP

Cause/ Factors*	Accident Type**										
	Any	U	N	A	Q	MI	C	G	J	MO	H
CAUSES:											
64*4Z	846	102	40	230	70	11	0	140	19	11	10
64*2Z	115	16	14	30	8	1	0	10	7	1	2
64*3Z	50	17	1	10	6	2	0	3	2	3	2
64*5Z	27	13	1	3	1	0	0	2	0	2	1
64*1Z	64	5	8	12	8	1	0	10	10	1	1
64*6Z	50	3	4	6	2	0	0	4	18	3	0
68*3Z	13	5	0	6	0	0	0	0	0	0	0
64*7Z	19	0	0	0	0	3	0	0	0	1	0
74*KA	9	9	0	0	0	0	0	0	0	0	0
74*00	8	7	0	0	0	0	0	0	0	0	0
FACTORS:											
64*4Z	11	0	0	0	0	0	0	0	0	0	0
64*2Z	12	2	0	5	1	0	0	2	0	0	0
64*3Z	19	3	2	6	5	1	0	1	0	0	0
64*5Z	6	0	0	1	3	0	0	1	0	0	0
64*1Z	40	2	2	20	2	0	0	4	1	1	1
64*6Z	4	2	0	1	0	0	0	0	0	0	0
68*3Z	6	1	0	3	0	0	0	0	0	0	0
64*7Z	5	1	0	1	1	0	0	1	0	1	0
74*KA	0	0	0	0	0	0	0	1	0	0	0
74*00	3	2	0	0	0	0	0	0	0	0	0

* See Page 2-11 for cause/factor classifications
** See Page 2-21 for accident type classifications

other factors were present during the event (e.g., weather, mechanical problems, etc...). Accordingly a range of pilot times by type and total were specified for purposes of the subject cross-tabulation. The ranges used to examine the pilot time data both in this case and in the case described below are shown in Table 3-22 (also see Table C-11, in Appendix C). The pilot flight time in type is displayed in the uppermost rows and the total pilot flight time is shown in the left hand column. The matrix entries are the number of accidents associated with the respective combinations of flight time.

g. Pilot Time in Type, Pilot Total Time, and Accident Type. This three dimensional tabulation was generated to further relate pilot experience to accident data. By introducing the accident type into the segment, associations of pilot times can be developed for those cases where a high frequency was identified.

Time-Series Trends

The number of accidents, the top ten cause/factor citations and their associated costs were distributed across the seven-year study period. Specifically, these time series plots portray

a. Annual accident cost by general aviation subpopulation and cause/factor.

b. Accident rates by year and general aviation subpopulation

c. Cause/factor frequency by year and general aviation subpopulation.

The total yearly costs of the accidents in each general aviation subpopulation were distributed by cause/factor across the seven-year study period. These annual costs are based on the cost elements given in Chapter 2 (Table 2-12). These costs and their temporal variabilities, are one indication of the relative severity among cause/factors within and between general aviation subpopulations. The distributions of the number of accidents per year, and their corresponding accident rates, in each general aviation subpopulation portrays variations in trends among the various subpopulations. Determinations of accident rates are based on the flight hours within the respective subpopulations for each year. These rates provided a measure of the

TABLE 3-22. CROSS-TABULATION OF THE NUMBER OF ACCIDENTS BY TOTAL PILOT HOURS IN TYPE AND TOTAL PILOT HOURS: CORP, SEP & MEP

Total Pilot Hours	Total Pilot Hours in Type: Unknown	0-5	6-10	11-25	26-50	51-75	76-100	Above 100
Unknown	--	--	--	--	--	--	--	--
0 - 25	--	10	--	1	--	--	--	3
26 - 50	--	1	--	1	1	--	--	--
51 - 75	--	--	--	--	2	--	--	--
76 - 100	--	--	--	--	--	--	--	--
101 - 200	--	1	--	1	1	2	--	3
201 - 500	--	4	4	5	6	1	--	8
Above 500	--	38	9	19	35	28	14	315

over-all impact of the various safety program clusters as they pertain to the respective subpopulations. The top ten cause/factor citations were normalized by the rate of occurrence per 100 accidents for each subpopulation. The commonalities and differences in these rates were then used to examine the relative severities of the top ten causes both within and between segments. These time series statistics are grouped by general aviation subpopulation in Appendices B through I, respectively. Summaries of the essential statistics are discussed in the following paragraphs.

Cause/Factors. Table 3-23 shows the 17 cause/factors that were cited in at least one subpopulation's top ten list. The cause/factor having the highest overall percentage of citation was 64*4Z (Improper Operation of Equipment). This cause was ranked first in four of the eight subpopulation. Cause/factor 64*5Z (Attention/Awareness) ranked first in one segment and, along with cause/factor 64*2Z (Operational Decision Error), displayed strong secondary contributions in the accident rates of all eight subpopulations. Cause/factor 64*3Z (Procedures, Regulations, etc.) was also very prominent in all subpopulations. Collectively, these four cause/factors represented over 50 percent of the citations in very general aviation subpopulation except aerial application, where they comprise 47 percent of the citations. These facts mean that almost one half of all general aviation accidents in the study period (approximately 15,296) were consequencies of only four cause/factors. This finding and its implication for safety program effectiveness is discussed in the safety program evaluations section later in this report.

The balance of the cause/factor findings were less significant than that stated above. Essentially the cause/factors fell into previously hypothesized patterns. For example, a high degree of association was found between cause 64*1Z (Judgment Error) 64*2Z (Operational Decision Error) and 64*3Z (Procedures, Regulations Error) in the subpopulation Personal, Single-and Multi-Engine Piston. In general, most of the subpopulation cause/factor associations were used to confirm existing conditions and only in specific cases did they offer any insight in other safety problems. These specific cases are discussed in the subpopulation "safety program evaluations" later in the report.

TABLE 3-23. CITATION RATE SUMMARY FOR ALL CAUSE/FACTORS RANKED AMONG THE TOP TEN CAUSE/FACTORS IN AT LEAST ONE GENERAL AVIATION SUBPOPULATION (in percent of total citations within subpopulations)

Cause/Factor Codes	& Descriptions	Subpopulation							
		BUS	CORP	PER	AA	INST	AT	CORP-T	ROTOR
64*1Z	Judgement Error	8	7	10	5	7	7	3	3
64*2Z	Operational Decision Error	14	10	14	7	7	14	9	5
64*3Z	Procedures, Regulations, Etc.	13	16	10	11	14	15	24	11
64*4Z	Improper Operation of Equipment	18	13	22	12	38	14	13	25
64*5Z	Attention and Awareness	11	10	10	17	8	10	6	12
64*6Z	Perception	8	7	10	13	7	7	4	12
64*7Z	Physiological	3	--	3	--	--	--	--	--
68*3Z	Other Personnel -- Procedures, Etc.	4	7	3	6	3	7	6	5
70*CB	Airframe -- Landing Gear Retraction	--	3	--	--	--	2	--	--
70*00	Airframe -- Random Occurrences	--	--	--	--	--	--	--	--
74*00	Powerplant -- Random Occurrences	2	3	1	4	1	3	3	2
74*KA	Powerplant Failure -- Undetermined	3	3	3	6	2	2	--	5
75*00	Systems -- Random Occurrences	--	--	--	--	--	--	3	--
78*00	Rotorcraft -- Random Occurrences	--	--	--	--	--	--	--	8
80*00	Airport/Airways -- Random Occurrences	--	--	--	--	--	--	3	--
82*H	Unfavorable Winds	--	--	--	--	1	--	--	--
84*7	Evasive Maneuver	--	--	--	2	--	--	--	--

Accident Rates. The annual accident rates for each general aviation subpopulation are displayed in Tables 3-24 to 3-25. Several facts were evident from the rates given in this table. First, all subpopulations reflected the general historical trend for the population as a whole (Figure 3-1)--a slowly increasing, or decreasing, in the rates and in the last three years of the study. Third, the subpopulation with the lowest accident rate was Corporate, Turboprop and Turbojet and the subpopulation with the highest accident rate was Personal, Single- and Multi-Engine Piston.

The subpopulation's accident rates were examined in relation to safety program implementation dates to determine if any relationship could be inferred between the safety programs and accident mitigation. The results were inconclusive. There were no significant changes in the accident rates, and the few moderate decreases that do occur (1971-1973) could not be linked to safety program implementation. Generally, the subpopulation accident rates appear to have reached a static level in the final year (1977) of the study. In fact, two subpopulations actually show an increase in accident rate.

Accident Types. The top five accident types in each of the eight general aviation subpopulations are shown in Table 3-26. There are nine different accident types cited in at least one of the subpopulations. The accident type that dominates every segment except Corporate, Turboprop and Turbojet, is Code U (Engine Failure or Malfunction). The next highest overall citation of accident type is Code N (Collision with Object) which ranks first in the Corporate, Turboprop and Turbojet subpopulation and is cited in most subpopulations as second only to Code U. In general, these top five accident types represent at least 55 percent of all accidents and, in some subpopulations, as high as 87 percent (Aerial Application) of the citations.

The high rate of Code U (Engine Failure or Malfunction), which totals 23 percent of the entire accident history, was further examined with respect to corresponding cause/factors. It was found that the high rate of citation of Code U was inconsistent with the low citation rates of cause/factors 74*KA (Engine Failure-Undetermined Cause) and 74*00 (Powerplant-Random). In other words a high rate of engine failure would normally be associated with mechanical problems; yet, the corresponding mechanical cause/factors 74*00 and 74*KA comprise no more than an average of three percent of the occurrences in any

TABLE 3-24. TEMPORAL TRENDS IN CITATION RATES OF THE TOP TEN CAUSE/FACTORS IN EACH GENERAL AVIATION SUBPOPULATION

Cause/Factor Codes & Descriptions		Subpopulation							
		BUS	CORP	PER	AA	INST	AT	CORP-T	ROTOR
64*1Z	Judgement Error	I	C	C	C	C	C	C	C
64*2Z	Operational Decision Error	I	C	C	C	I	I	D	I
64*3Z	Procedures, Regulations, Etc.	C	C	C	C	C	C	I	C
64*4Z	Improper Operation of Equipment	I	D	I	D	D	C	C	C
64*5Z	Attention and Awareness	C	I	C	C	C	C	D	C
64*6Z	Perception	C	I	C	C	C	I	D	D
64*7Z	Physiological	C	--	C	--	--	--	--	--
68*3Z	Other Personnel, Procedures, Etc.	C	C	C	C	C	C	D	C
70*00	Airframe -- Random Occurrences	--	--	--	--	--	--	--	--
70*CB	Airframe -- Landing Gear Retraction	--	D	--	--	--	C	--	--
74*00	Powerplant -- Random Occurrences	C	D	C	C	D	I	D	C
74*KA	Powerplant Failure -- Undetermined	C	C	C	C	C	C	--	C
75*00	Systems -- Random Occurrences	--	--	--	--	--	--	D	--
78*00	Rotorcraft -- Random Occurrences	--	--	--	--	--	--	--	C
80*00	Airport/Airways -- Random	--	--	--	--	--	--	D	--
82*H	Unfavorable Winds	--	--	--	--	D	--	--	--
84*7	Evasive Maneuver	--	--	--	D	--	--	--	--

Frequency of Cause/Factor
I = Increasing Trend
C = Constant Trend
D = Decreasing Trend

TABLE 3-25. ANNUAL ACCIDENT RATE BY GENERAL AVIATION SUBPOPULATION (number of accidents per 1,000 flight hours; number of accidents is shown in parenthesis)

Calendar Year	Subpopulations								
	BUS	CORP	PER	AA	INST	AT	CORP-T	ROTOR	TOTALS
1971	.11 (493)	.05 (87)	.35(2525)	.28 (365)	.15 (685)	.08 (135)	.02 (19)	.26 (163)	.20 (4472)
1972	.10 (459)	.05 (76)	.30(2271)	.22 (329)	.14 (641)	.06 (119)	.02 (24)	.22 (151)	.17 (4070)
1973	.07 (396)	.05 (89)	.31(2305)	.21 (359)	.11 (546)	.06 (149)	.02 (25)	.28 (204)	.16 (4073)
1974	.07 (414)	.04 (79)	.28(2350)	.25 (431)	.12 (604)	.06 (167)	.01 (21)	.23 (209)	.15 (4275)
1975	.07 (390)	.04 (71)	.28(2350)	.22 (399)	.11 (536)	.06 (162)	.01 (21)	.21 (222)	.14 (4053)
1976	.06 (366)	.03 (59)	.24(2311)	.19 (396)	.10 (505)	.06 (164)	.01 (16)	.17 (207)	.13 (4024)
1977	.06 (393)	.03 (52)	.27(2273)	.22 (410)	.09 (532)	.05 (187)	.01 (20)	.17 (210)	.13 (4077)
TOTALS	.08 (2911)	.05 (513)	.28(16,287)	.22 (2689)	.11 (4049)	.06 (1083)	.01 (146)	.21 (1366)	.15 (29,044)

TABLE 3-26. ACCIDENT TYPE SUMMARY FOR THE TOP FIVE ACCIDENT TYPES IN AT LEAST ONE SUBPOPULATION (in percent of total subpopulation citations)

	Accident Type Code & Description	Subpopulation							
		BUS	CORP	PER	AA	INST	AT	CORP-T	ROTOR
A	Ground-Water Loop Swerve	10	10	13	8	21	11	10	--
C	Wheels-up	--	7	--	--	--	--	10	--
G	Hard Landing	--	--	6	--	16	--	--	9
M_0	Collision with Ground/Water-Controlled	--	--	--	4	--	7	8	--
M_1	Collision with Ground/Water-Uncontrolled	6	--	--	--	--	--	--	9
N	Collision with Wires, Trees, Etc.	14	12	14	26	8	18	16	21
Q	Stall	8	7	11	19	9	7	--	--
U	Engine Failure or Malfunction	23	19	23	30	22	18	13	31
V	Propeller/Rotor Failure	--	--	--	--	--	--	--	8
	TOTALS	61	55	67	87	76	61	57	78

subpopulation. A check of this accident type in the cause-accident type cross-tabulations revealed that this accident type was cited an average of 60 percent of the time with cause/factor codes 64*5Z (Awareness/Attention) and 64*6Z (Perception). The balance of the citations were distributed between 64*3Z (Procedures, Regulations, etc...) and 64*4Z (Improper Operation of Equipment). These pairwise associations indicate that an apparent mechanical problem (powerplant failure) was in fact a human error problem. That is, the mechanical failure was induced by some type of pilot error.

The other eight accident codes in Table 3-26 were not as significant as that described above. Generally, they reflected prior expectations. For example, the high rate of accident type A (Ground/Water Loop-Swerve) in instructional flying was anticipated as well as the high rate of code N (Collision with Object) shown for Aerial Application.

SECTION 2. CAUSE/FACTOR AND SAFETY PROGRAM ALIGNMENT ANALYSIS

As described in Chapter 2, this analysis consists of aligning cause/factors with FAA programs. The results of this alignment analysis are described in the following paragraphs.

ALIGNED FAA SAFETY PROGRAMS AND CAUSE/FACTORS

This analysis consists of aligning the 55 cause/factors listed in Table 3-8 with the objectives of the 90 FAA safety programs listed in Tables 2-16 through 2-21 in accord with the direct/indirect alignment criteria defined in Chapter 2. As described earlier in Chapters 2 and 3, these cause/factors include six substitute behavioral codes (Table 2-5) in the Pilot/Crew and other Personnel major cause/factor categories, exclude the Terrain (Code 83) and Miscellaneous Acts and Conditions (Code 88) cause/factors used qualifiers, and, where required, represent aggregation of low frequency cause/ factors within major categories. The 90 FAA safety programs are categorized by type as described in the data base section of Chapter 2. These program categories are: Facilities and Equipment (100), Safety Research and Development (200), Operations Safety (300), Regulatory (400), Capacity Programs with Safety Contributions (500), and Management and Administrative Programs with Safety Contributions(600).

The alignment criteria address the question, is there a one-to-one correspondence between the specific objective of a safety program and the hazard associated with a cause/factor definition (direct alignment), or is there a more general correspondence in which the hazard associated with a cause/factor is subsumed within the context of a broader safety program objective (indirect alignment)? In short, the alignments given in this section are qualitative statements of the degree of congruence between program objectives and cause/factor hazards.

Application of these criteria yielded the cause/factor and safety program alignments shown in Table 3-27 (and the general aviation subpopulation cause/factor statistical summaries in Appendices B through I). Examination of the direct and indirect alignments shown in Table 3-27 reveal the following summary observations:

a. 60 of the 90 FAA safety programs were aligned against 52 of the 55 cause/factors. Almost all of these alignments were determined to be indirect. Specifically, only three safety programs were directly aligned against 3 cause/factors and 57 safety programs were indirectly aligned against 52 cause/factors (some programs were aligned both directly and indirectly).

b. The three direct safety program and cause/factor alignments are: Wake Vortex Avoidance System (Program 216) and Vortex Turbulence (Cause/Factor 84*1); FAR Part 43, Maintenance, Preventive Maintenance and Rebuilding Alterations (Program 211) and Procedures, Regulations, Instructions and Responsibilities (Cause/Factor 64*3Z); FAR Part 67, Medical Standards and Certification (Program 415) and Physical Incapacitation (Cause/Factor 64*7Z).

c. 28 of the 57 indirectly aligned safety programs are in the regulatory (400) program category and another 80 indirect alignments are in the Operations Safety (300) category. These alignments reflect the general nature and broad scope of programs in these categories. The remaining 21 indirect alignments are distributed among the Facilities/Equipment (100), Safety R&D

TABLE 3-27. SAFETY PROGRAM AND CAUSE/FACTOR ALIGNMENTS

Cause/Factor[1] Code	Aligned Safety Programs[2] Direct Alignment	Indirect Alignment
64*1Z	None	302,412
*2Z	None	101,221,302,412
*3Z	None	101,221,302,412
*4Z	None	104,106,107,108, 109,111,218,221, 214,220,504
*5Z	None	104,202,206
*6Z	None	101,106,107,108, 109,111,202,206, 218,223
*7Z	415	None
68*00	None	414,417,507,102, 118,204,224,309, 311,413
68*3Z	411	204,309,311,417, 507,118,422,607, 224,413,414,102, 103,310,601,421, 602,305,308
70*00	None	411,305,308,403,
70*CA,CB,CC,CE,CF,CJ,CH	None	305
74*00	None	308,402, 407-411
*AB,AC,AD,AE,AF,AY,BA	None	407
*BC,CB,CG,CH,CJ,DB,IO,KA	None	407
*FA	None	408
75*00	None	308,411,402,409, 410
76*00	None	411,308,402,409, 410
78*00	None	411,308,402,405, 409,410
80*00	None	115,117,209,310, 422,502
*BC,BD,BJ,BY	None	310,209,422
82*00	None	102,103,203,207, 219,225,301
*H,J,M,G	None	102,103,203,219, 225,301
84*00	None	None
84*1	216	None
*3,8	None	201,202
	None	303,418

(1) Cause/Factor code descriptions are given in Table 3-8.

(2) Program descriptions are given in Tables 2-17 through 2-22.

(200), Capacity with Safety Contributions (500) and Management with Safety Contributions (600) safety program categories. Further, as implied by the indirect alignment criterion definition, such programs are typically aligned with several cause/factors. For example, FAR Part 33, Airworthiness Standards-Aircraft Engines (407), and the Maintenance Analysis Center Program (308) are aligned with 16 cause/factors in the Powerplant category (Code 74). Similarly, Automation of Flight Assistance and Weather Information Service (102) is aligned with seven cause/factors in the Other Personnel (Code 68) and Weather (Code 82) categories. These multiple alignments are examined further in the evaluation of interconnected sets of safety programs against associated cause/factor combinations.

UNALIGNED SAFETY PROGRAMS AND CAUSE/FACTORS

There were 30 safety programs not aligned with any of the 55 cause/factors cited in the accident records. These programs are shown in Table 3-28. Five safety programs were not considered in the alignment analysis because they were air carrier specific. The finding that 25 other programs did not align with any cause/factor does not mean the program is not effective in mitigating accidents. Non-alignment could mean:

a. Cause/factors related to these safety programs were not cited in any accident during the 1971-1977 time period. Such programs might have been instrumental in eliminating the occurrence of these cause/factors.

b. The scope of the safety program was too broad to align with an accident cause. For example, FAR Part 13, Enforcement Procedures (401) impacts many cause/factors, but does so through other programs (Standards, Certification, etc.) that are aligned with specific cause/factors.

c. The program dealt with cause/factors associated with post crash events. Generally, these cause/factors are in the Miscellaneous Acts and Conditions category which was deleted in the modified framework.

It is also important to note that Safety R&D programs (200 series) were programs that had not been implemented during the accident study period (1971-1977) and, thus, had no past mitigating effect on the accidents.

Nonetheless, these 200-series programs were aligned where appropriate as an indication that they were designed to eventually combat identified safety problems.

In addition to the non-aligned safety programs there were three cause/factors not aligned with any of the 90 safety programs. These cause/factors are also shown in Table 3-28. Cause/factors 84*J (Written Cause) and 84*I (Undetermined Cause) could not be aligned because specific accident data required to accurately place them into a cause category was not provided. The cause/factor 84*J was cited in 101 accidents and 84*I was cited in 523 accidents. Cause/factor 84*G (foreign matter damage) was not sufficiently specific as to cause to align with a safety program. The cause/factor 84*G was cited in 304 accidents.

SECTION 3. SAFETY PROGRAM EVALUATION

The evaluations of FAA safety programs described in this section were accomplished for each of the eight general aviation subpopulations:

a. Business, Single- and Multi-engine Piston
b. Corporate, Single- and Multi-engine Piston
c. Personal, Single- and Multi-engine Piston
d. Aerial Application, Single- and Multi-engine
e. Instructional, Single- and Multi-engine Piston
f. Air Taxi, Single- and Multi-engine Piston, and Turboprop and Turbojet
g. Corporate, Turboprop and Turbojet
h. Rotorcraft, All Primary Use Categories.

These evaluations consist of summary observations concerning subpopulation characteristics, delineation of leading cause/factor citations and findings concerning the effectiveness of programs in the human, mechanical, and environmental areas.

Collective evaluation of safety programs at these three major category levels is predicated on the finding that virtually all programs are indirectly aligned with associated cause/factors reported in general aviation accidents.

TABLE 3-28. UNALIGNED SAFETY PROGRAMS AND CAUSE/FACTORS

	Facilities/ Equipment (100)	Safety R&D (200)	Operations Safety (300)	Regulatory (FARS) (400)	Capacity with Safety Contributions (500)	Management/ Administration with Safety Contributions (600)
Safety Programs Not Aligned	105 110 112 113 114 116	205 208 210 211 213 215 217	304 306 312	401	501 503 505 506	603 604 605 606
Air Carrier Safety Programs Not Considered		212	307	406 419 420		
Cause/Factors Not Aligned	84*G (Foreign Matter Damage) 84*I (Undetermined Cause) 84*J (Written Cause)					

The principal means of portraying the results of these evaluations are the accident cause fault trees described in the methodology section of Chapter 2 (Figures 2-6, 2-7 and 2-8). These fault trees are used in displaying the hierarchical levels at which the modified cause/factors used in this study are defined, and in determining the levels of aggregation of accident causes at which safety programs are directed. These determinations further serve to portray the connectivity among safety programs with common or overlapping objectives.

Further, to provide a broader perspective in interpreting the safety program evaluations, selected supplemental data are presented that are indicative of the extent to which the general aviation population responds to safety programs. Unlike the air carrier industry which is uniform in its essential attributes (regulation, use of facilities and equipment, operating procedures, etc.), the separate general aviation subpopulations vary significantly. These varying attributes influence the extent to which general aviation participates in various safety programs or is able to use facilities and services provided by the FAA in the interest of safety in the national aviation system. These supplemental data and their safety implications are described in the following paragraphs prior to discussing the individual subpopulation evaluations.

SUPPLEMENTAL DATA USED IN SAFETY PROGRAM EVALUATION

Several supplemental sources of operational data were drawn upon in interpreting the results of the safety program evaluations. These data consist of:

a. Avionics equipment installed in general aviation aircraft
b. Instrument ratings held by pilots involved in accidents
c. Types of flight plans filed for flights resulting in accidents
d. General aviation insurance requirements and costs of coverage.

Avionics Equipment

The Transportation Systems Center (TSC) conducted a survey for the FAA that provided estimates of the type of equipment and percentage of aircraft equipment in 1978.[18] These data were tabulated by the primary use and aircraft type categories making up the general aviation population. These data were used in the subject evaluation as one indication of the individual general aviation subpopulations' abilities to participate in the National Aviation System (NAS). Specifically addressing this point, the TSC report states:

> "Avionics capability groups (CGS) are the means through which significant groups of avionics equipment are associated with aircraft capability to perform in the NAS. The word 'capability' takes on a number of meanings in conjunction with the NAS. It can refer to where an aircraft can fly, at what airports it can land, under what flying conditions it can fly or to what extent it can participate in the air route, landing and communications systems."

Two categories of equipage data were taken from this study. The first was the percentage of aircraft equipped with at least a two-way VHF radio, a VOR/ADF or a transponder and possibly all three. This capability group was labeled "basic". The second capability grouping was the percentage of aircraft equipped with the "basic" avionics and having the required additional avionics equipment to operate under instrument flight rules (IFR) if the aircraft was certified for that purpose. This second capabilities group was labeled "basic+".

The second set of equipage data extracted from the TSC report was the percentage of the general aviation fleet equipped with a complete instrument landing system (ILS). These data were used to determine the fraction of aircraft within each subpopulation that could utilize the more advanced and possibly safer landing systems. A summary of these data equipment surveys, by general aviation subpopulation, is given in Table 3-29.

Instrument Ratings and Flight Plans

The number of instrument ratings held by the pilots-in-command of the flights that were involved in accidents were taken from the NTSB accident records and tabulated in Table 3-30 by general aviation subpopulation. Also, the number and types of flight plans (also from NTSB records) that were filed (or not filed) were similarly tabulated by subpopulation. These data are given in terms of their percentage representation in the corresponding

TABLE 3-29. AVERAGE ACTIVE AIRCRAFT AND AVIONICS

GA Segment	Average Active[1] Aircraft	Aircraft Avionics[2]			Instrument Landing System (ILS)	
		None	Basic (percent)	Basic Plus	None	ILS (percent)
BUS	33,227	3	68	29	23	52
CORP	5,368	1	6	92	6	87
PER	77,328	13	49	38	49	19
AA	6,077	76	19	5	93	3
INST	12,295	5	55	40	41	24
AT	5,038	1	25	74	19	67
CORP-T	2,923	1	6	92	6	87
ROTOR	2,502	32	64	3	87	2

(1) Source, Battelle GAD Model, Reference 1
(2) Source, Avionics Survey, Reference 17

TABLE 3-30. PILOT INSTRUMENT RATINGS AND TYPE OF FLIGHT PLAN FILED FOR PILOTS INVOLVED IN ACCIDENTS (percent)*

Subpopulation	Pilot-in-Command Instrument Rated	Flight Plans		
		None	VFR	IFR
BUS	39	77	12	9
CORP	80	64	7	27
PER	22	83	12	04
AA	34	99	1	0
INST	29	86	12	01
AT	85	39	32	25
CORP-T	98	29	5	65
ROTOR	21	93	4	0.1

* Flight plans will not total 100% because of missing data in some accidents

accidents subpopulation. As for avionics equipage, these data were used as an indication of the capabilities and experience of general aviation pilots that are involved in the accidents and their likelihood of utilizing the facilities and services provided in the NAS.

General Aviation Insurance Requirements and Rates

Several of the largest general aviation insurance companies in the United States were contacted to determine their requirements and rates for aviation insurance. They were requested to quote the rates as a percentage of hull value insured (the standard method of pricing) and to give the general requirements a owner or operator would have to meet to qualify for the quoted rate. These rates are summarized in Table 3-31 by general aviation subpopulation.

Table 3-31. TYPICAL INSURANCE RATES FOR GENERAL AVIATION AIRCRAFT

Subpopulation	Rate as a Percent of Hull Value Insurance	Annual Average Liability Costs
Personal/Business	2.5 to 12	$500.00
Corporate	.6	400.00
Aerial Application	8 to 9	1200.00*
Instructional	5	400.00
Air Taxi	5 to 6	750.00
Rotorcraft	6 to 12	500.00

* Plus additional "Draft" or "Chemical" insurance in many states.

Actual insurance rates, of course, vary significantly with each individual operator, his business, the pilots that fly the aircraft, etc... The purpose of these data was to provide an examination of the impacts of nonregulatory factors on general aviation safety.

The restrictions placed on the issuance of insurance influence safety in the aviation industry in a manner similar to that associated with Federal regulation. For example, the requirements for insuring an aircraft in the personal use category only require that the pilot operating the aircraft have a private pilot certificate and 100 accident-free flight hours. The average rate for insurance in this category would be at least 12 percent. Moreover, several companies state that they would probably not assume the risk, even with the high rate. These requirements contrast sharply with corporate users who pay the lowest rate in the general aviation industry and had the highest minimum insurance requirements to qualify. Generally, corporate pilots must have a minimum of 1,000 accident free flight hours, hold a commercial certificate (with an instrument rating for a preferred rate) and be "type certified" in the aircraft being operated. Further, the insurance companies required an on-site inspection of the corporate operation to investigate the acceptability of maintenance and operational practices. These two examples (Corporate and Personal) illustrate the varying influence of "external regulation" in primary use categories that are only indirectly regulated by the FAA. Indirect regulations are those which effect the overall operation of the aviation system such as FAR Part 91 (General Operating and Flight Rules) or FAR Part 61 (Pilot Certification). At the opposite end of the spectrum, an example of direct regulation of a user category is FAR Part 135 (Air Taxi regulations) or FAR Part 121 (Air Carrier Regulations). These regulations establish the minimum standards by which an operation can be conducted.

The information derived from this review of insurance rates and requirements added an outside dimension to the evaluation of the safety programs. It provided an additional perspective in interpreting the evaluations of safety programs of a regulatory nature and served to explain why some highly regulated subpopulations (Air Taxi) and indirectly regulated subpopulations (Corporate) had similar low accident rates.

SUBPOPULATION SAFETY PROGRAM EVALUATIONS

As stated at the outset of this section, the effectiveness of FAA safety programs was examined with respect to each of the eight general aviation subpopulations. The primary use and aircraft type subsegments making up each subpopulation were previously judged to be similar (homogeneous) in their accident behavior and in selected operating attributes pertinent to safety. The evaluations are comprised of three parts:

a. A summary of accident statistics and safety related operating attributes

b. Delineation of leading cause/factors

c. Evaluation of safety programs with respect to the accident causes they were designed to mitigate.

The principal results of the evaluations are displayed in the context of accident cause fault trees for human, mechanical and environmental cause categories. Specifically, safety programs are shown in the fault-tree hierarchy at the highest level at which they align (directly or indirectly) with accident causes. In accord witn fault tree logic, a safety program aligned at a given accident-cause level also subsumes all lower level accident causes or connected branches of the fault tree. For example, in Figure 3-4, Safety Program 415 (FAR Part 67, Medical Standards and Certification) is aligned at the physiological cause level and, consequently, subsumes Externally Generated Trauma, Pathological and Psychological Dysfunction accident causes. Collectively, the distribution of safety programs throughout the fault trees indicate the breadth of safety program coverage (and hence, indicate apparent gaps or voids in program coverage), combinations of programs addressing a common set of accident causes, and the scope of accident causes addressed by single programs.

Also, the most frequently cited cause/factors are displayed in the respective fault trees at the level of accident cause aggregation they represent. In conjunction with these alignments, the percentage of accidents reported in a given general subpopulation in which the cause/factor was cited is given. For example, in Figure 3-4, cause/factor 64*2Z (Operational Decision Error) is displayed in the third tier of the fault tree and was cited in 14 percent of the accidents reported in the Business, Single- and Multi-engine Piston subpopulation.

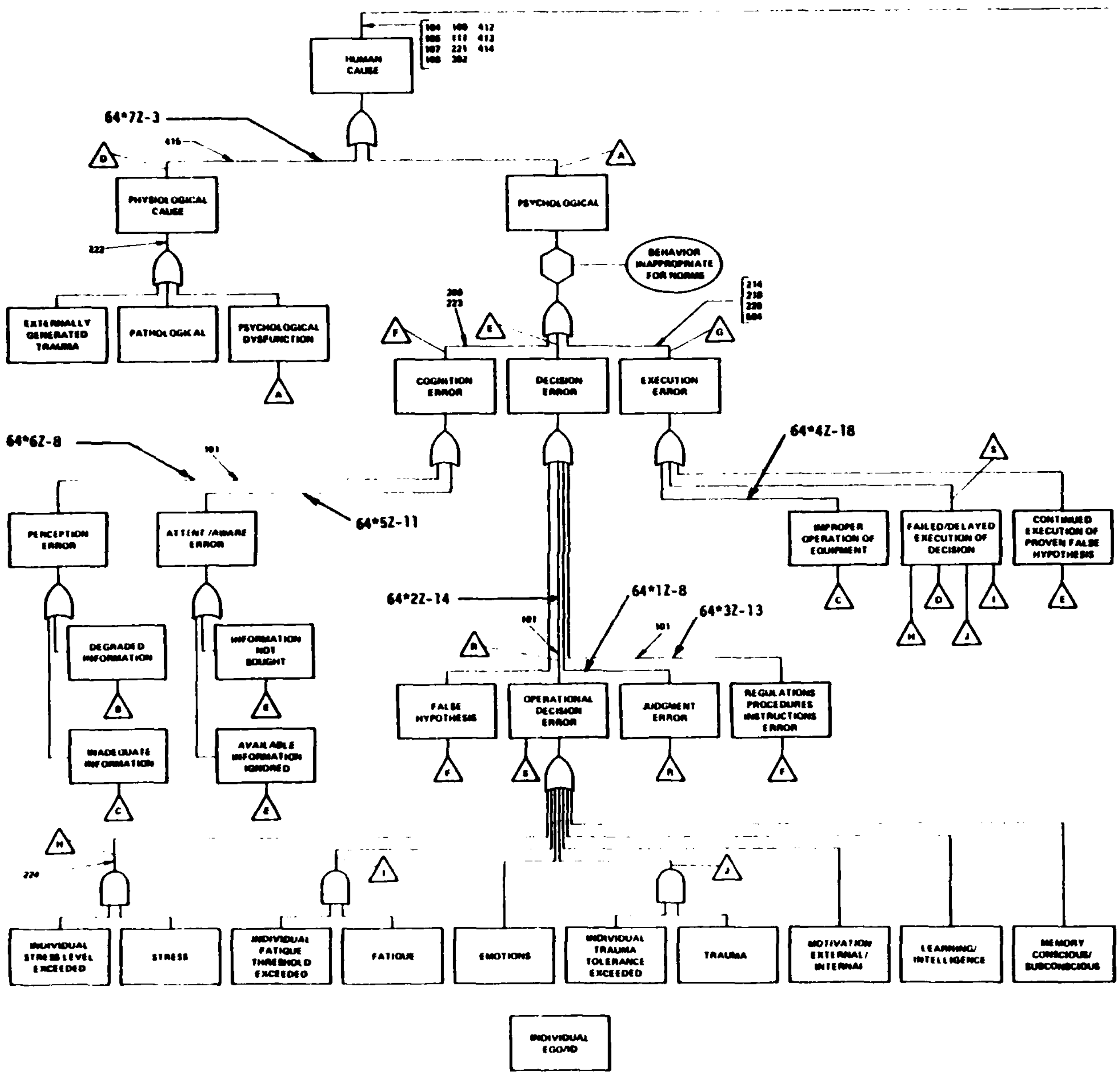

FIGURE 3-4. HUMAN ERROR FAULT TREE DIAGRAM: BUSINESS, SINGLE- AND MULTI-ENGINE PISTON

Business, Single- and Multi-Engine Piston

The Business, Single- and Multi-Engine Piston subpopulation is comprised of the following general accident and operating characteristics:

a. The accident rate was 0.08 accidents per 1,000 flight hours. This rate is approximately one-half that for the entire general aviation population.

b. The impact of FAA regulation is marginal and indirect mainly entailing FAR's for general operation procedures, pilot and equipment certification.

c. 68 percent of the aircraft in this subpopulation are equipped with "basic" avionics. Twenty-nine percent are "basic+" equipped and three percent have no avionics equipment.

d. The average annual insurance rate for aircraft in this group is 2.5 to 12 percent per 1,000 dollars of the aircraft's hull value.

e. 52 percent of the aircraft are equipped with a complete ILS system and 23 percent have none of the ILS components.

f. Pilot qualifications and ratings run the entire gamut of the general aviation industry. Thirty-nine percent of the pilots involved in accidents had instrument ratings.

g. The most prominent accident type is engine failure or malfunction (23 percent).

The cause/factor characteristics are characterized in Table 3-24 and, more specifically, in Figures B-1 through B-10 in Appendix B. In summary, the characteristics are as follows:

a. All human error cause/factors are either increasing or maintaining a constant rate of occurrence.

b. The human error causes 64*4Z, 64*2Z, 64*3Z and 64*5Z represent over 56 percent of the accident cause citations.

c. Mechanical causes account for only five percent of the total cause/factor citations.

d. The top ten cause citations represent over 84 percent of the total cited in the segment.

The safety programs and related cause/factors for which evaluation findings are given below are displayed in the fault tree diagrams in Figures 3-4 through 3-6. The safety programs and the top ten cause/factors cited as causes of accidents in this subpopulation are located at the highest levels on the error paths of the fault tree (human, mechanical, or environmental) with which they are associated. As noted earlier, the respective safety programs and cause/factors subsume all lower level accident causes on connected branches of the fault tree. Based on these fault tree alignments, the findings given below pertain to the linkage between safety programs and leading accident cause, breadth of safety program coverage, and adequacy of the treatment of identified safety hazards by associated safety programs.

The findings concerning safety program effectiveness for this subpopulation are:

a. Safety programs directed at preventing human error appear to have little effect in reducing the citation rates of these errors in business flying. This finding stems from the continuing high frequency of all types of human error in this subpopulation.

b. Safety programs aligned against mechanical cause/factors appear to be effective. Only two of the 28 total mechanical causes cited in the accident records have any significant impact on business flying.

c. The only cause citation for the entire range of environmental error possibilities is 68*3Z (Human Error-Procedures Failure etc...for Personnel Other Than Pilots) and this error accounts for only four percent of the total cause/factor citations. However, this apparently low frequency of overall error citation may not be entirely attributable to the safety programs in this area. Rather, it may reflect a combination of limited data (because of the low level of investigative effort generally associated with general aviation accidents) and a general lack of understanding of the operating system's role in an accident. This understanding, described in detail in the earlier air carrier study, concerns the limits of effectiveness of using mechanical aids or substitutions to mitigate human error problems.

d. One problem that appears unique to this subpopulation and the subpopulation Personal, Single- and Multi-Engine Piston is human failure due to physiological causes. Although the problem is not great in comparison to other human errors, the cause/factors appears adequately dealt with by the Safety Program 415 (Medical Standards and Certification) in all subpopulations

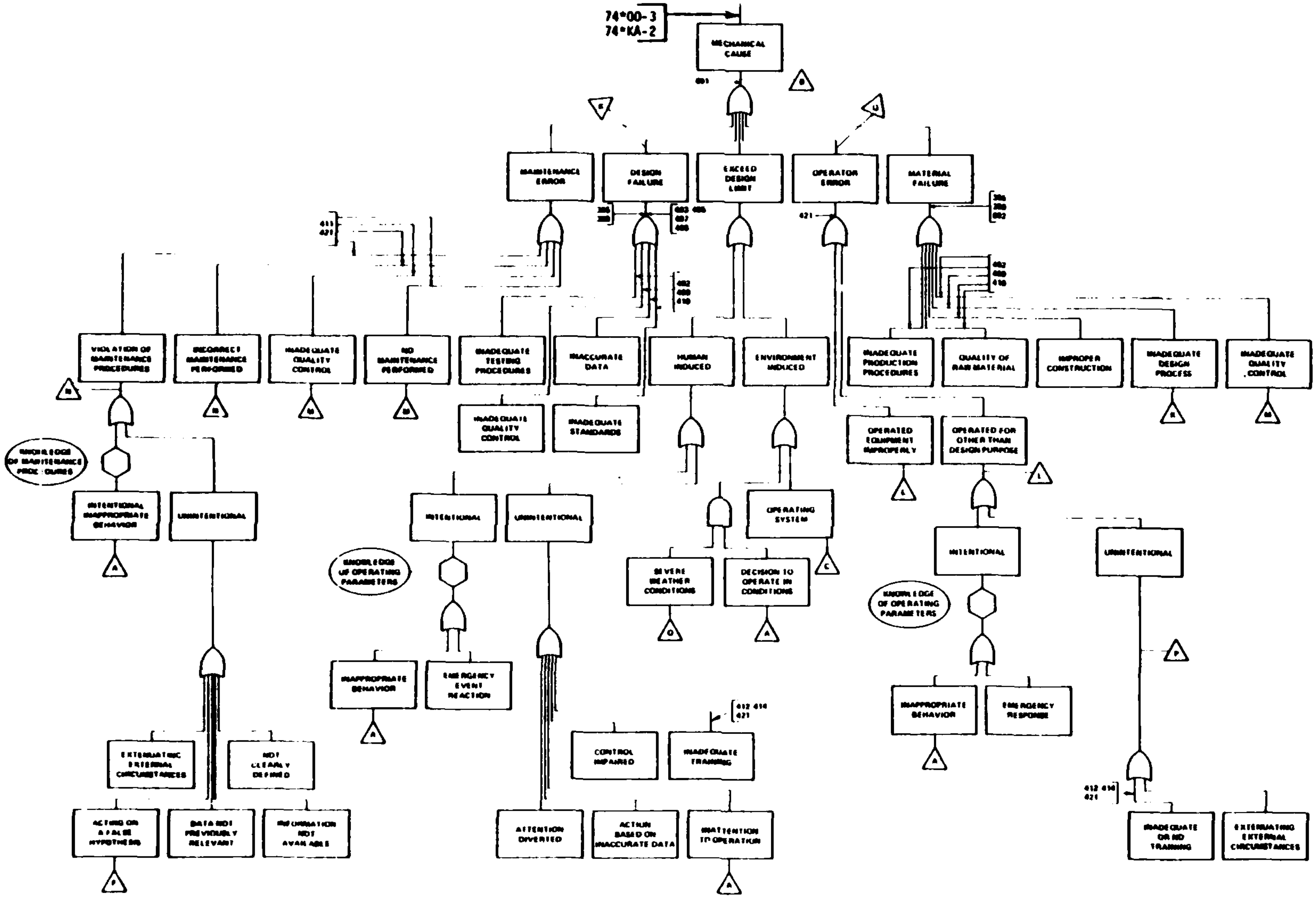

FIGURE 3-5. MECHANICAL ERROR FAULT TREE DIAGRAM: BUSINESS, SINGLE- AND MULTI-ENGINE PISTON

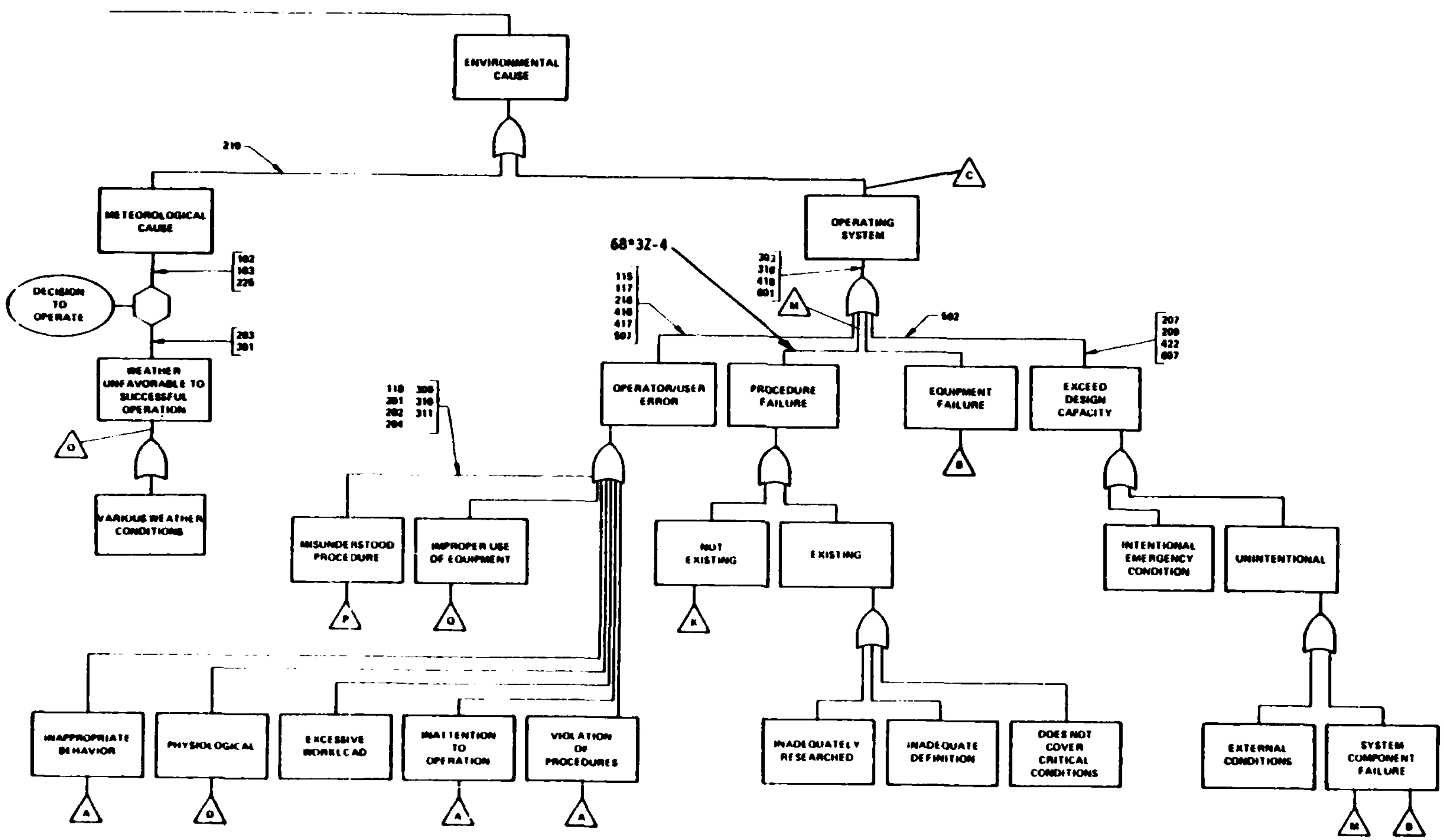

FIGURE 3-6. ENVIRONMENTAL ERROR FAULT TREE DIAGRAM: BUSINESS, SINGLE- AND MULTI-ENGINE PISTON

except these two. This may be attributable to the magnitude and diversity of the pilot population in terms of license qualifications and the medical requirements to meet those qualifications.

Corporate, Single- and Multi-Engine Piston

This subpopulation is comprised of the following general accident and operating characteristics:

a. The accident rate was 0.05 accidents per 1,000 flight hours. This rate is one-third of that for the entire general aviation population.

b. The impact of FAA regulation is marginal and indirect mainly entailing FAR'S for general operating procedures, pilot and equipment certification.

c. 92 percent of the aircraft in this subpopulation are "basic+" only and one percent have no avionics equipment.

d. The average annual insurance rate is 0.6 percent per 1,000 dollars of hull value; the lowest rate in the general aviation industry by approximately an order of magnitude.

e. 87 percent of the aircraft are equipped with an ILS system and six percent of the aircraft have no ILS components.

f. 80 percent of the pilots involved in accidents were instrumented rated. The pilots in this segment are required to have a commercial license and have at least 1,000 accident-free flying hours to qualify for insurance coverage.

g. The most prominent accident cause is engine failure or malfunction (19 percent).

The cause/factor characteristics are characterized in Table 3-24 and, more specifically, in Figures C-1 through C-10 in Appendix C. In summary, the characteristics for this subpopulation are:

a. Human error cause citations dominate this segment representing 70 percent of the total cause/factors cited.

b. Although these cause/factor citations fluxuate over the 1971-1977 time period, no significant trends are apparent, but this is due mainly to the low number of accidents for this subpopulation (only two percent of the total general aviation accident population).

c. The mechanical causes 74*00 and 74*KA (Engine Failures or Malfunctions) account for only six percent of the total cause/factor citations. One other mechanical cause which appears to be unique to this subpopulation and in the Air Taxi subpopulation is 70*CB. This cause/factor accounts for three percent of the citations in this subpopulation and two percent of Air Taxi cause/factor citations.

d. The top ten cause/factor citations represent over 80 percent of the total accident citations in this subpopulation.

The safety programs and related cause/factors for which evaluation findings are given below are displayed in the fault tree diagrams in Figures 3-7 through 3-9. The safety programs and the top ten cause/factors cited as causes of accidents in this subpopulation are located at the highest levels on the error paths of the fault tree (human, mechanical, or environmental) with which they are associated. As noted earlier, the respective safety programs and cause/factors subsume all lower level accident causes on connected branches of the fault tree. Based on these fault tree alignments, the findings given below pertain to the linkage between safety programs and leading accident cause, breadth of safety program coverage, and adequacy of the treatment of identified safety hazards by associated safety programs.

The findings concerning safety program effectiveness for this subpopulation are:

a. The safety programs related to all three categories of error (human, mechanical and environmental) appear to be generally effective in preventing accidents.

b. The only cause/factor area that suggests a need for safety program improvement is human error.

Personal, Single- and Multi-Engine Piston

This subpopulation is comprised of the following general accident and operating characteristics:

a. The accident rate is 0.28 accidents per 1,000 flight hours. This rate is the highest among all subpopulations and is almost twice that of the entire general aviation population.

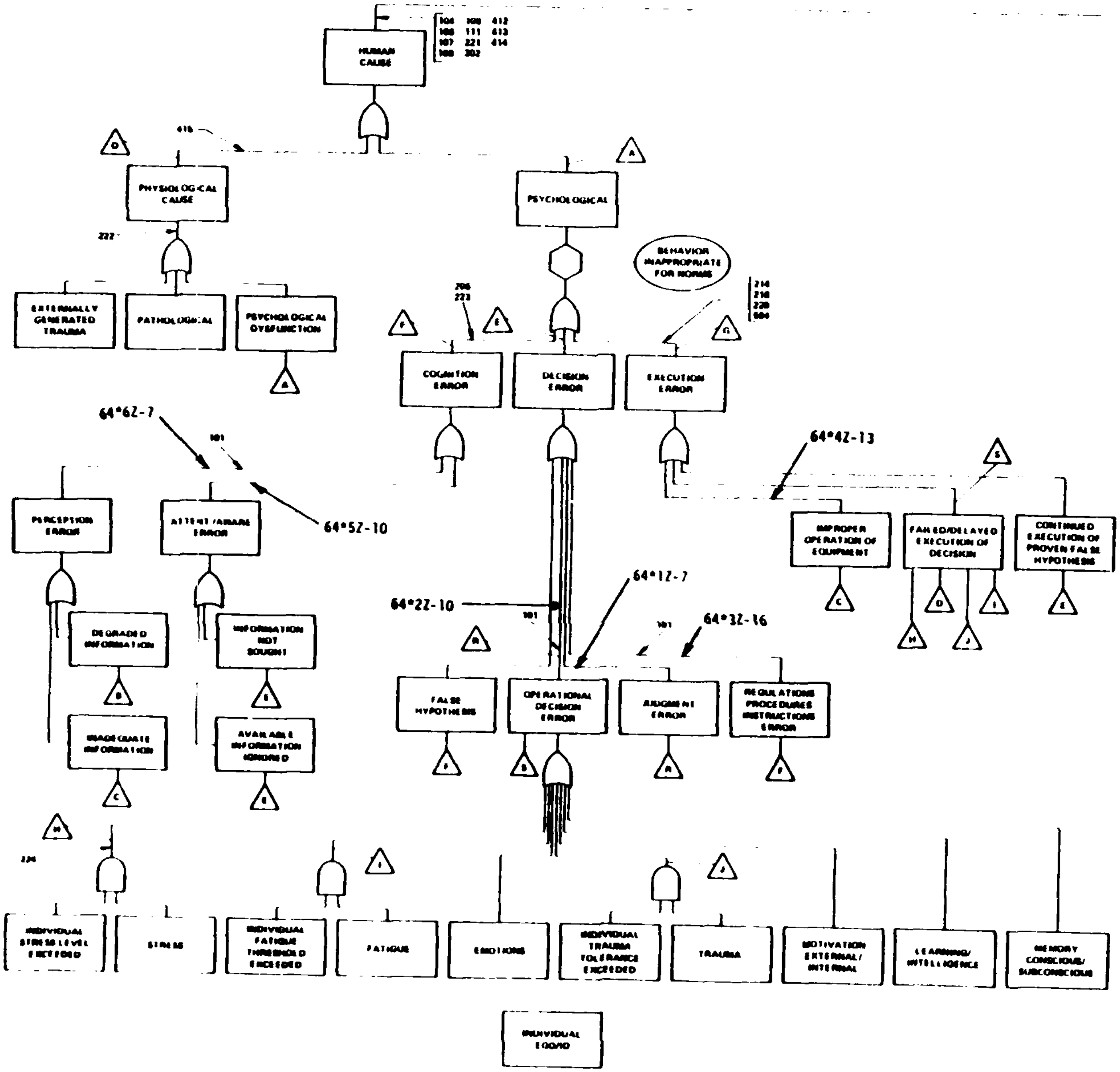

FIGURE 3-7. HUMAN ERROR FAULT TREE DIAGRAM: CORPORATE, SINGLE- AND MULTI-ENGINE PISTON

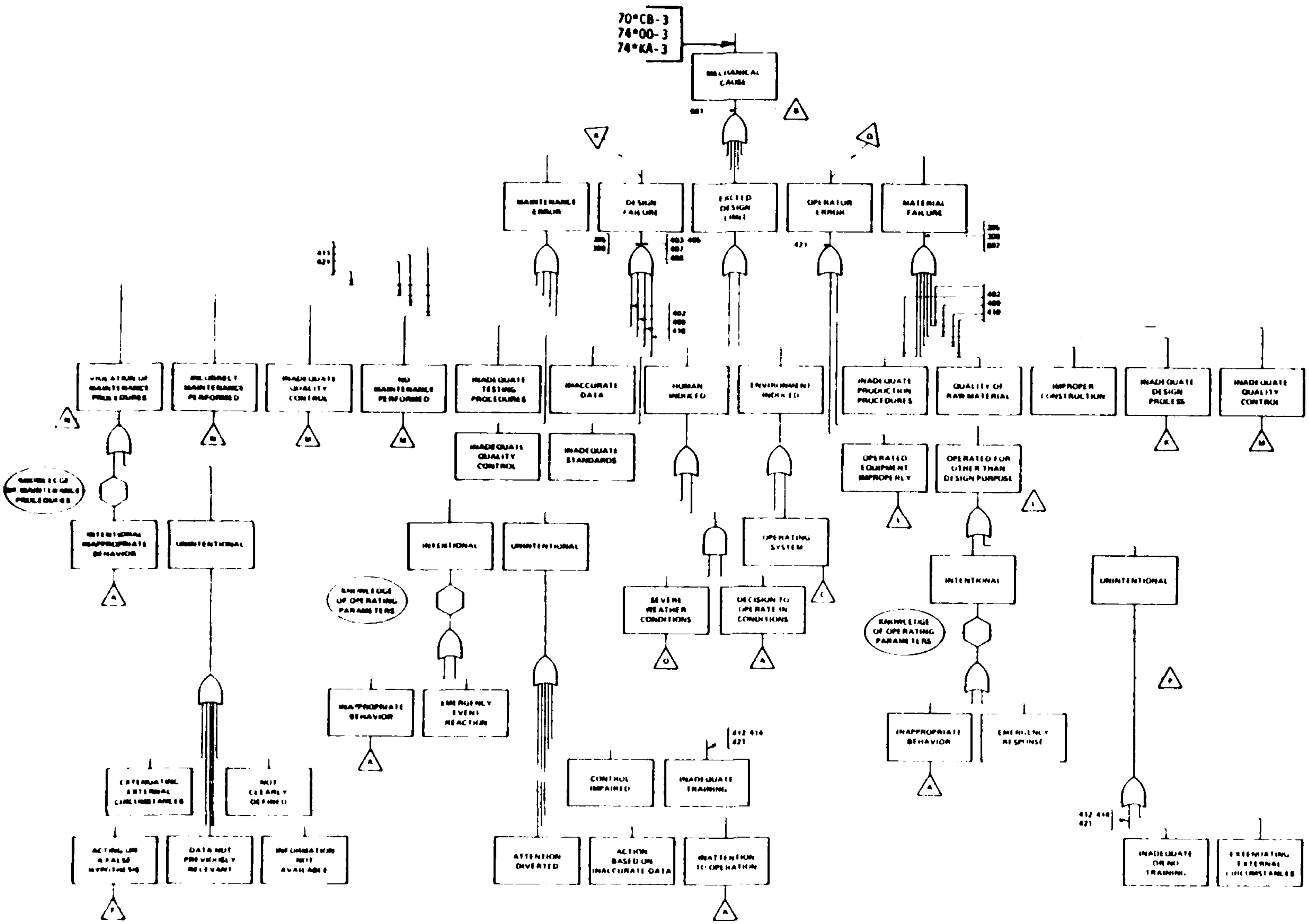

FIGURE 3-8. MECHANICAL ERROR FAULT TREE DIAGRAM: CORPORATE,SINGLE- AND MULTI-ENGINE PISTON

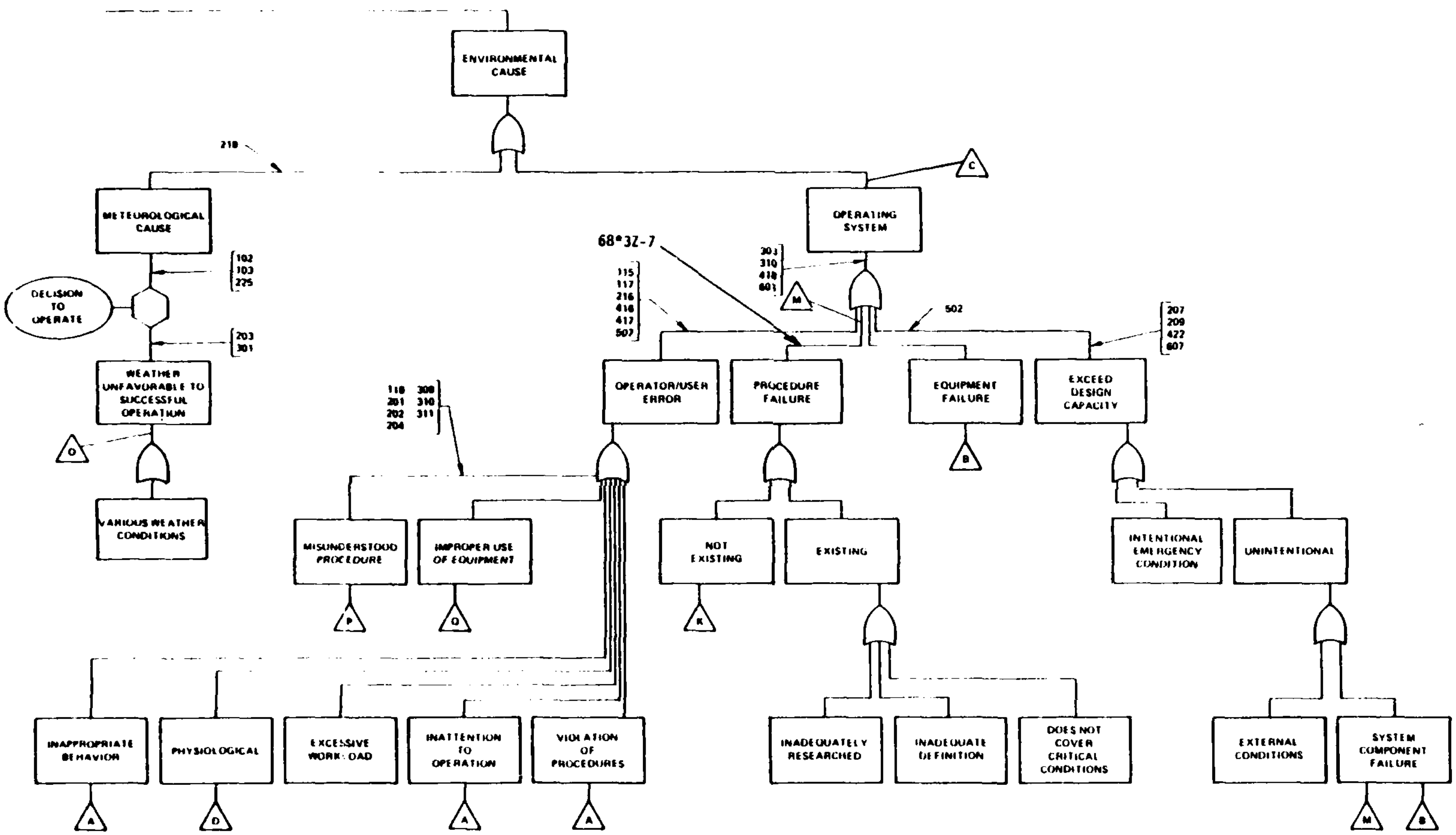

FIGURE 3-9. ENVIRONMENTAL ERROR FAULT TREE DIAGRAM: CORPORATE, SINGLE- AND MULTI-ENGINE PISTON

b. The impact of FAA regulation is marginal and indirect, mainly entailing FAR's for general aviation operation procedures, pilot and equipment certification.

c. 49 percent of the aircraft in this subpopulation are equipped with "basic" avionics. Only 38 percent have "basic+" equipment and 13 percent have no avionics.

d. The average annual insurance rates are 2.5 to 12 percent per 1,000 dollars of hull value.

e. 49 percent of the aircraft in this subpopulation have no ILS components on board. Only 19 percent have a complete ILS system.

f. The pilot certificates and ratings reflect a general cross section of the aviation population. Only 22 percent of the pilots involved in accidents had an instrument license; this was the lowest of the fixed wing user groups.

g. The leading accident type is engine failure or malfunction (23 percent).

The cause/factor characteristics are characterized in Table 3-24 and, more specifically, in Figures D-1 through D-10 in Appendix D. In summary, the characteristics for this subpopulation are:

a. All human error cause/factor citations are either increasing or maintaining a constant rate of occurrence.

b. Cause/factors 64*4Z, 64*2Z, 64*3Z and 64*1Z represent over 56 percent of all the cause citations in this subpopulation.

c. Mechanical causes represent only four percent of the cause citations. The entire four percent relate to engine failure or malfunction.

d. The top ten cause/factors comprise 86 percent of the total subpopulation accident citations.

The safety programs and related cause/factors for which evaluation findings are given below are displayed in the fault tree diagrams in Figures 3-10 through 3-12. The safety programs and the top ten cause/factors cited as causes of accidents in this subpopulation are located at the highest levels on the error paths of the fault tree (human, mechanical, or environmental) with which they are associated. As noted earlier, the respective safety programs

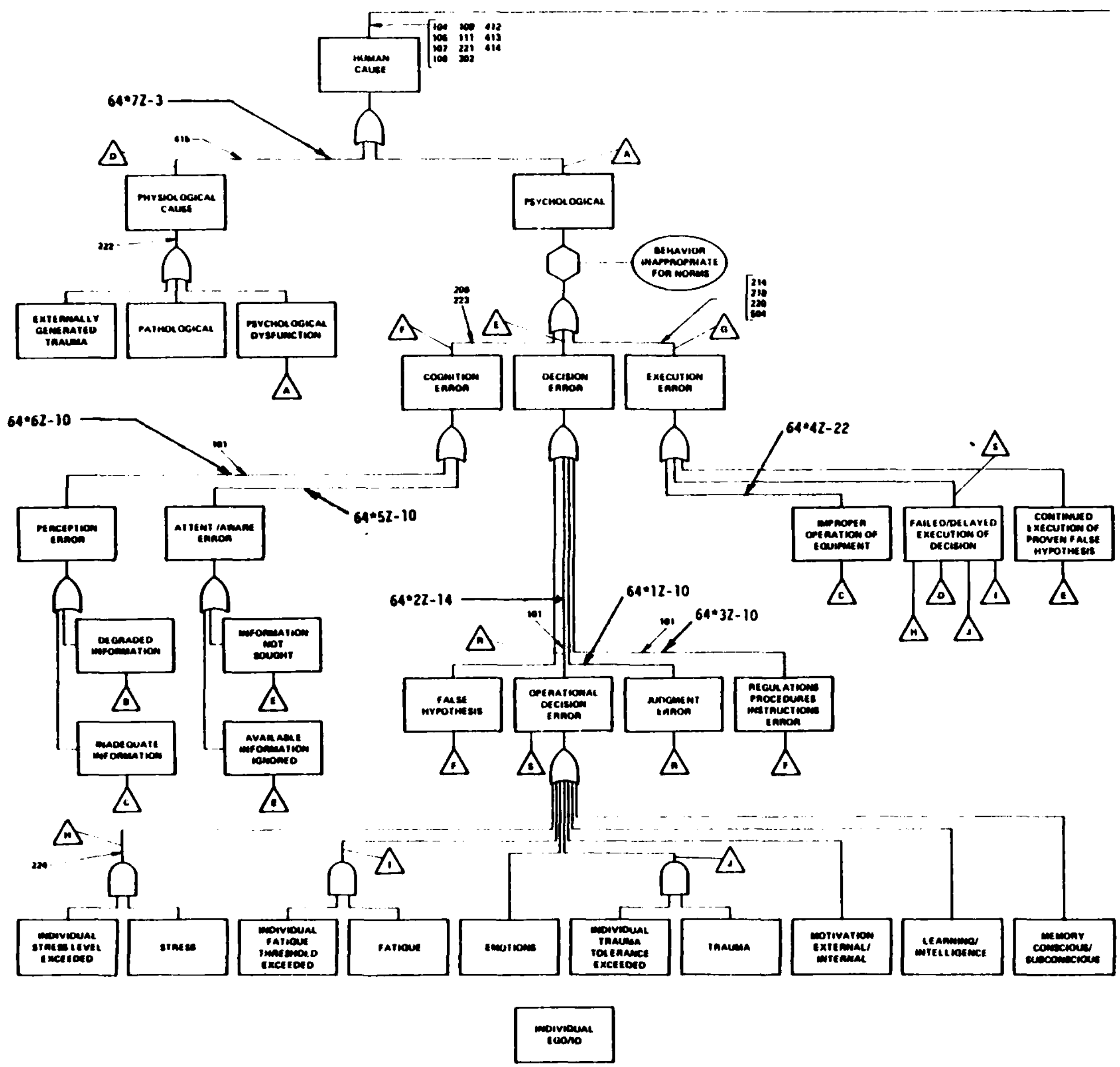

FIGURE 3-10. HUMAN ERROR FAULT TREE DIAGRAM: PERSONAL, SINGLE- AND MULTI-ENGINE PISTON

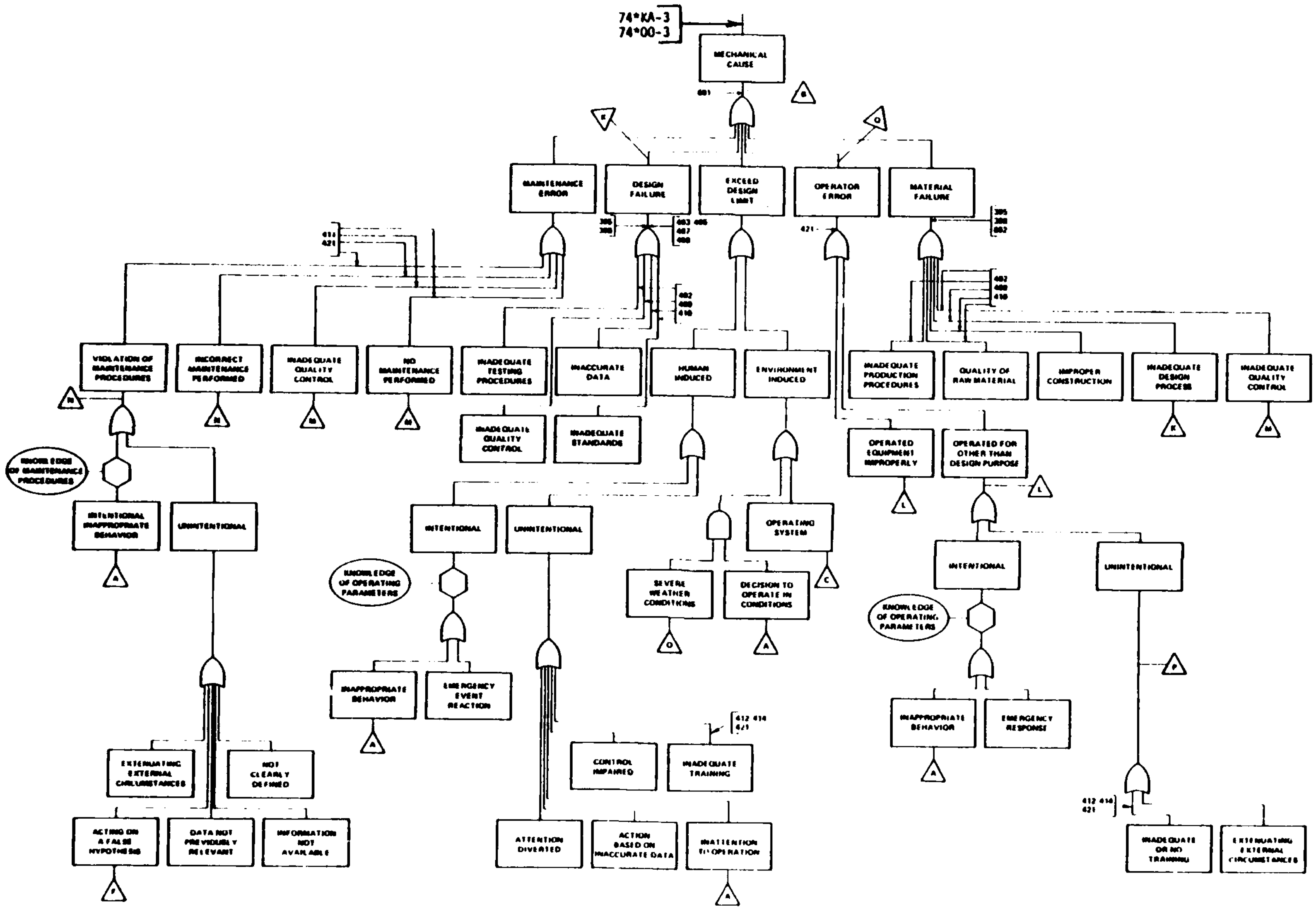

FIGURE 3-11. MECHANICAL ERROR FAULT TREE DIAGRAM: PERSONAL, SINGLE- AND MULTI-ENGINE PISTON

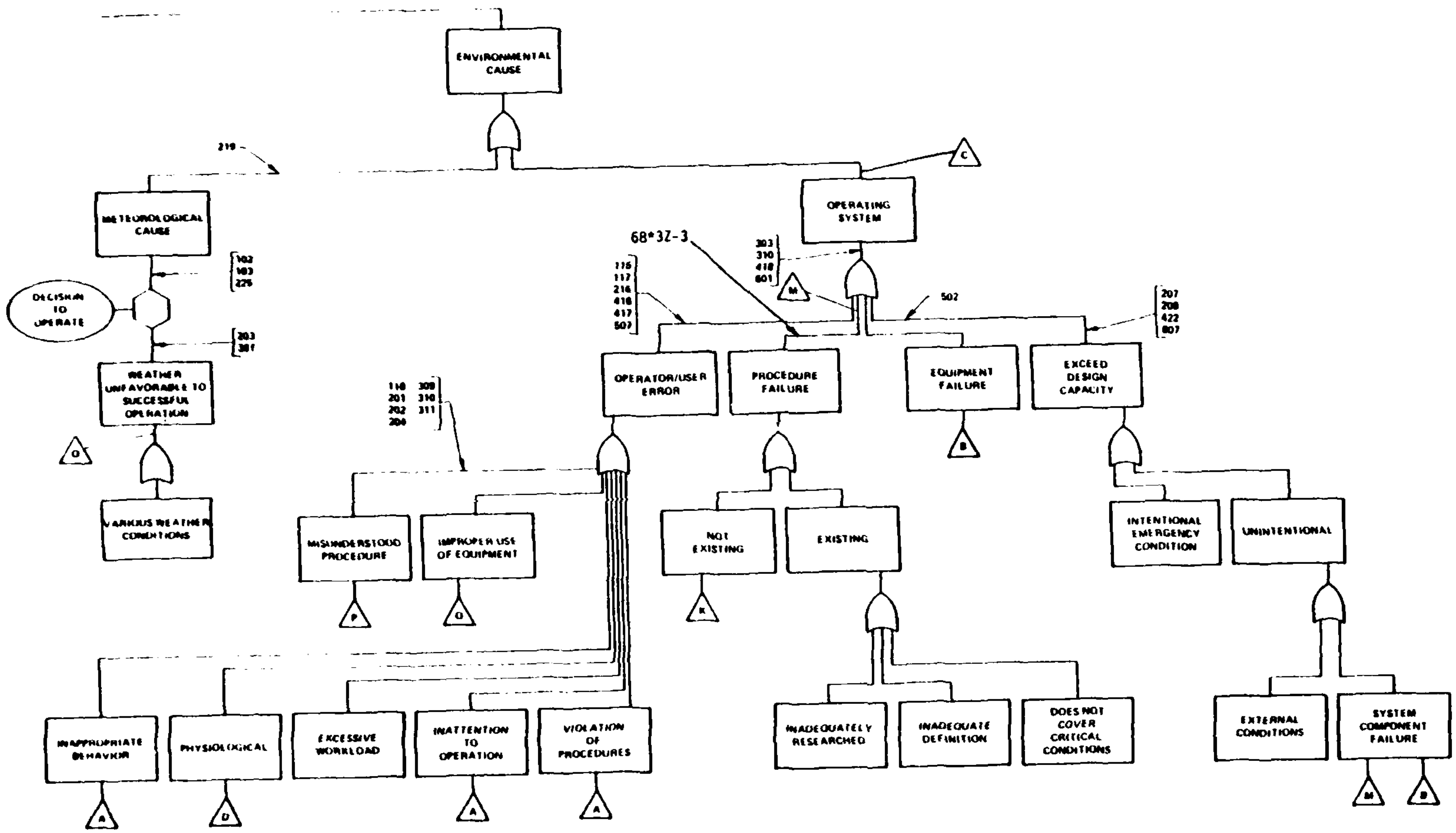

FIGURE 3-12. ENVIRONMENTAL ERROR FAULT TREE DIAGRAM: PERSONAL, SINGLE- AND MULTI-ENGINE PISTON

and cause/factors subsume all lower level accident causes on connected branches of the fault tree. Based on these fault tree alignments, the findings given below pertain to the linkage between safety programs and leading accident cause, breadth of safety program coverage, and adequacy of the treatment of identified safety hazards by associated safety programs.

The findings concerning safety program effectiveness for this subpopulation are as follows:

a. The few safety programs directed at preventing human error appear to be having very little impact in reducing the accident rate in this subpopulation. This is especially noticeable with respect to human error associated with cause/factor 64*4Z (Improper Operation of Equipment).

b. Mechanically oriented safety programs appear to be dealing with the accident causes adequately, with only engine failures or malfunctions eluding prevention. It should be recognized that mechanical failure rates are even lower than those for the Corporate subpopulation described earlier. The reason for this apparent low rate is believed to be the result of lack of determination of accident cause because of incomplete accident investigations. The lack of accident investigation detail was more prominent in this subpopulation than any other in the population.

c. Environmental programs in this subpopulation reflect the same findings as those for the Business, Single- and Multi-Engine Piston subpopulation. The cause/factor citation 68*3Z is cited in only three percent of the total accidents. This apparently low frequency of overall error citation may not be entirely attributable to the safety programs in this area. Rather, it may reflect a combination of the low level of investigative effort generally associated with personal accidents and possibly the general lack of understanding by safety experts of the operating systems role in an accident.

Aerial Application, Single- and Multi-Engine Piston

This subpopulation is comprised of the following general accident and operating characteristics:

a. The accident rate is .22 accidents per 1,000 flight hours. This rate is second only to that for the Personal use subpopulation and is approximately 50 percent greater than the overall population rate.

b. There is a high level of direct regulation by the FAA.

c. The aircraft in this subpopulation are 19 percent "basic" and five percent "basic+" avionics equipped. Only three percent of the aircraft have a complete ILS. 76 percent have no avionics and 93 percent have no ILS components.

d. The average annual insurance rates are 8 to 9 percent of the hull value. The liability rates, especially for special insurance protection required by some states for spraying chemicals, are three times that of the next closest user category.

e. 34 percent of the pilots are instrument rated even through an accident has never occurred while on an IFR flight plan.

f. Pilot qualifications include a type certificate rating and demonstration of competency in aerial application.

g. The leading accident type is engine failure or malfunction (30 percent). A close second accident type is collisions of all types except accidents between aircraft. Collisions account for 26 percent of all accidents in this subpopulation.

The cause/factor characteristics for this subpopulation are characterized in Table 3-24 and, more specifically, in Figures E-1 through E-10 in Appendix E. In summary the characteristics are:

a. Human error cause/factors citation rates in this subpopulation have been cited at a constant rate over the 1971-77 period.

b. Mechanical Errors (74*KA and 74*00) were cited more frequently as causes of accidents in this subpopulation (10 percent of the total) than in any other general aviation subpopulation.

c. Cause/factor 84*7 (Evasive Maneuver to Avoid Collision) is cited in two percent of the accidents. This citation reflects the general mode of flying in this subpopulation (slow and close to the ground) and the hazards associated with it.

d. The human error cause/factors 64*5Z, 64*6Z, 64*4Z and 64*3Z represent over 53 percent of the total citations in this subpopulation.

e. The top ten cause/factors comprise over 82 percent of the total cause/factors cited in accidents in this subpopulation.

The safety programs and related cause/factors for which evaluation findings are given below are displayed in the fault tree diagrams in Figures 3-13 through 3-15. The safety programs and the top ten cause/factors cited as causes of accidents in this subpopulation are located at the highest levels on the error paths of the fault tree (human, mechanical, or environmental) with which they are associated. As noted earlier, the respective safety programs and cause/factors subsume all lower level accident causes on connected branches of the fault tree. Based on these fault tree alignments, the findings given below pertain to the linkage between safety programs and leading accident cause, breadth of safety program coverage, and adequacy of the treatment of identified safety hazards by associated safety programs.

The findings concerning safety program effectiveness for this subpopulation are:

a. The indirectly aligned safety programs dealing with human error in this subpopulation appear to have little effect in preventing accidents. This lack of effectiveness is most evident in the areas of Perception (64*6Z) and Awareness (64*5Z); the two leading accident causes for Aerial Application. The second highest cited accident type in this segment is Code N (Collision with Object). These two causes are cited more than 61 percent of the time for Code N accidents. There are no safety programs even indirectly identified with this problem.

b. Generally, the mechanical safety programs appear to be effective in preventing most mechanical errors. However, this subpopulation is plagued with the same engine problem citations as are found in the other subpopulations (74*00 and 74*KA account for 10 percent of the citations). It is believed that these are not purely mechanical filures. The basis for this finding is discussed in the summary findings in Chapter 4.

c. Environmental causes do not appear to be a major factor in this subpopulation. Cause/factor 68*3Z is cited at a slightly higher rate (six percent) in this segment than the average (four percent) but its trend is steady over the study period. Cause/factor 84*7 (Evasive Manuever) is used in the accident records as a qualifier of the pilot's action and is cited 80 percent of the time with accident type N (Collisions) and U (Engine Failure of Malfunction).

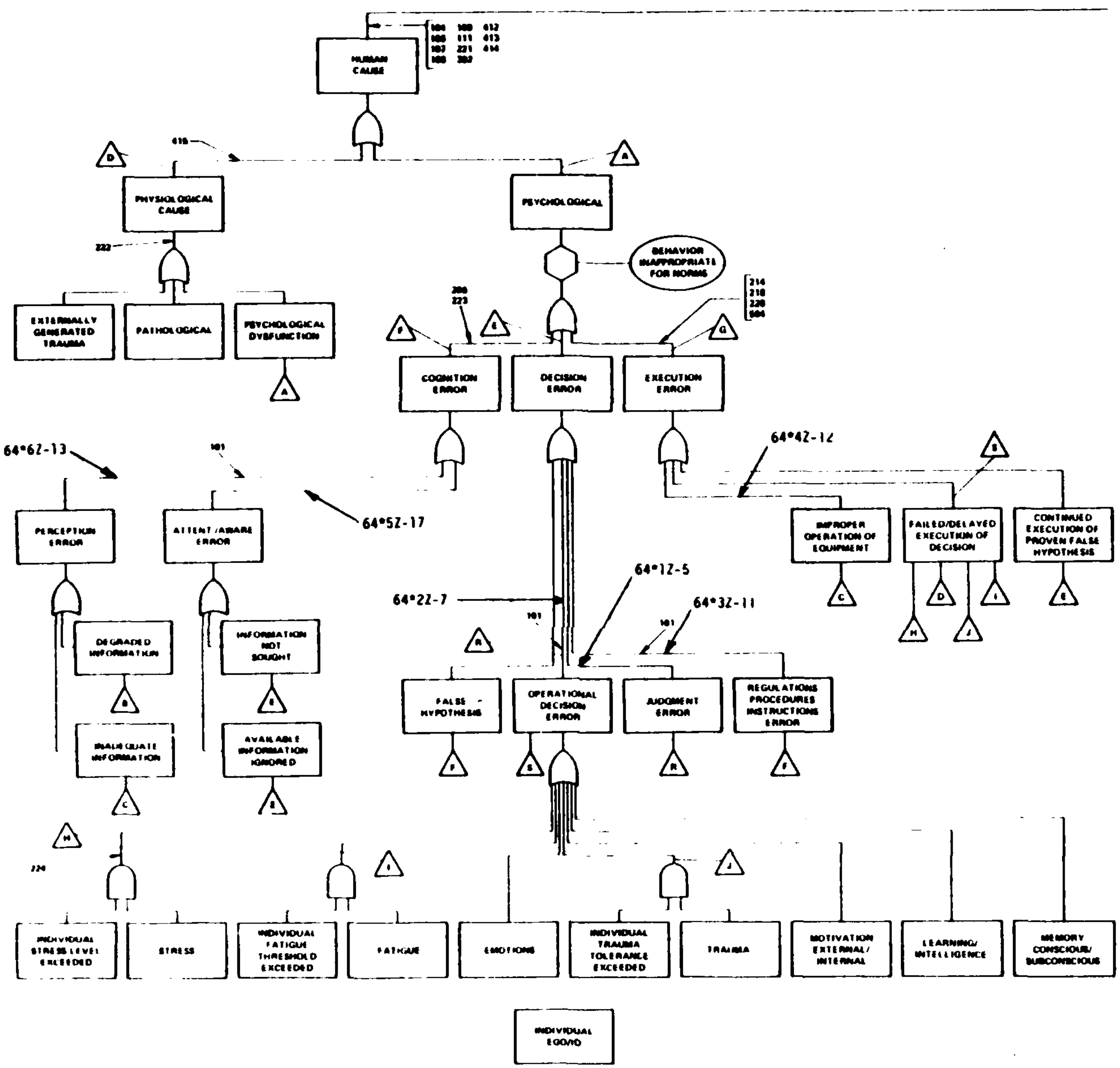

FIGURE 3-13. HUMAN ERROR FAULT TREE DIAGRAM:
AERIAL APPLICATION, SINGLE- AND MULTI-ENGINE PISTON

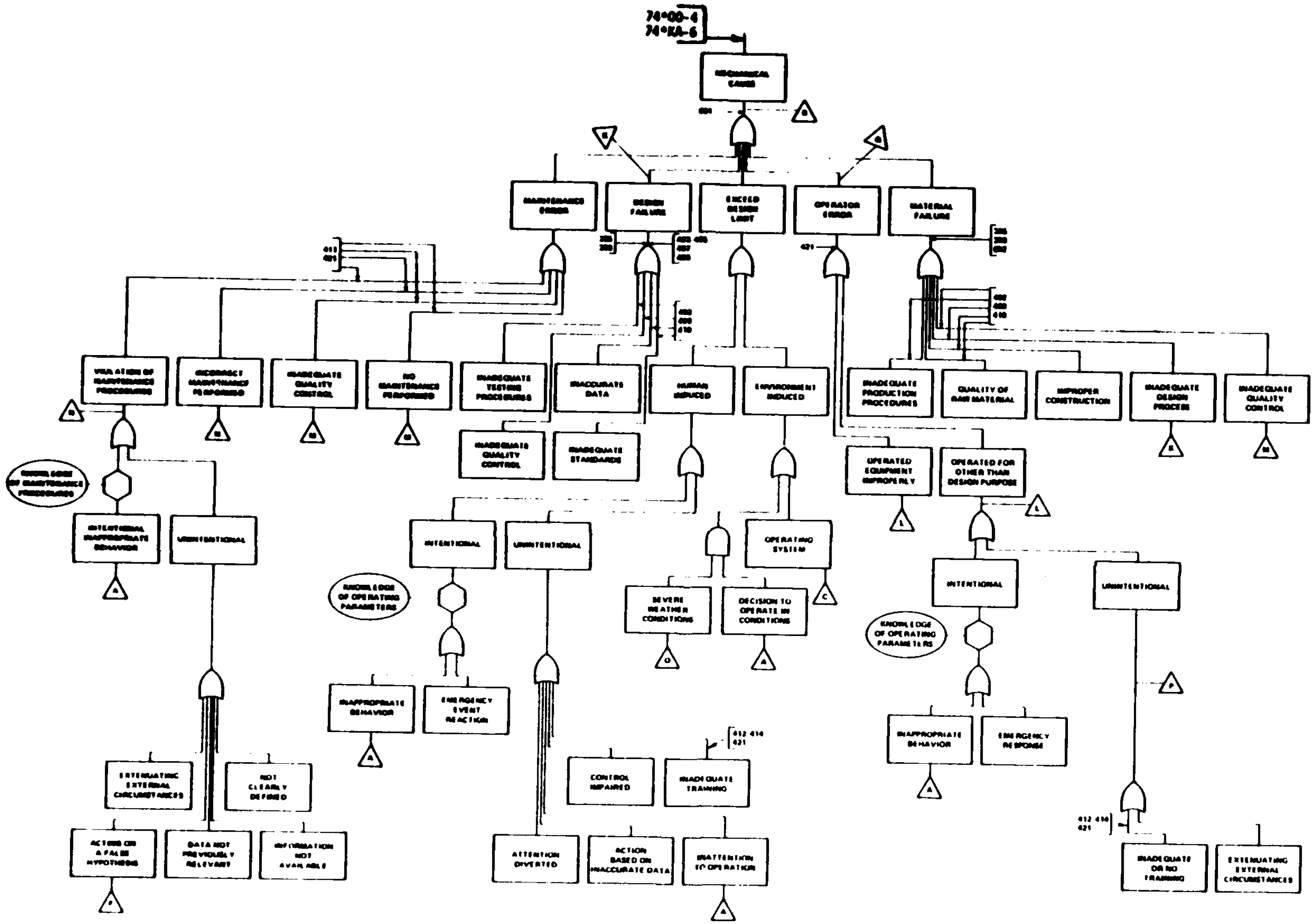

FIGURE 3-14. MECHANICAL ERROR FAULT TREE DIAGRAM:
AERIAL APPLICATION, SINGLE- AND MULTI-ENGINE PISTON

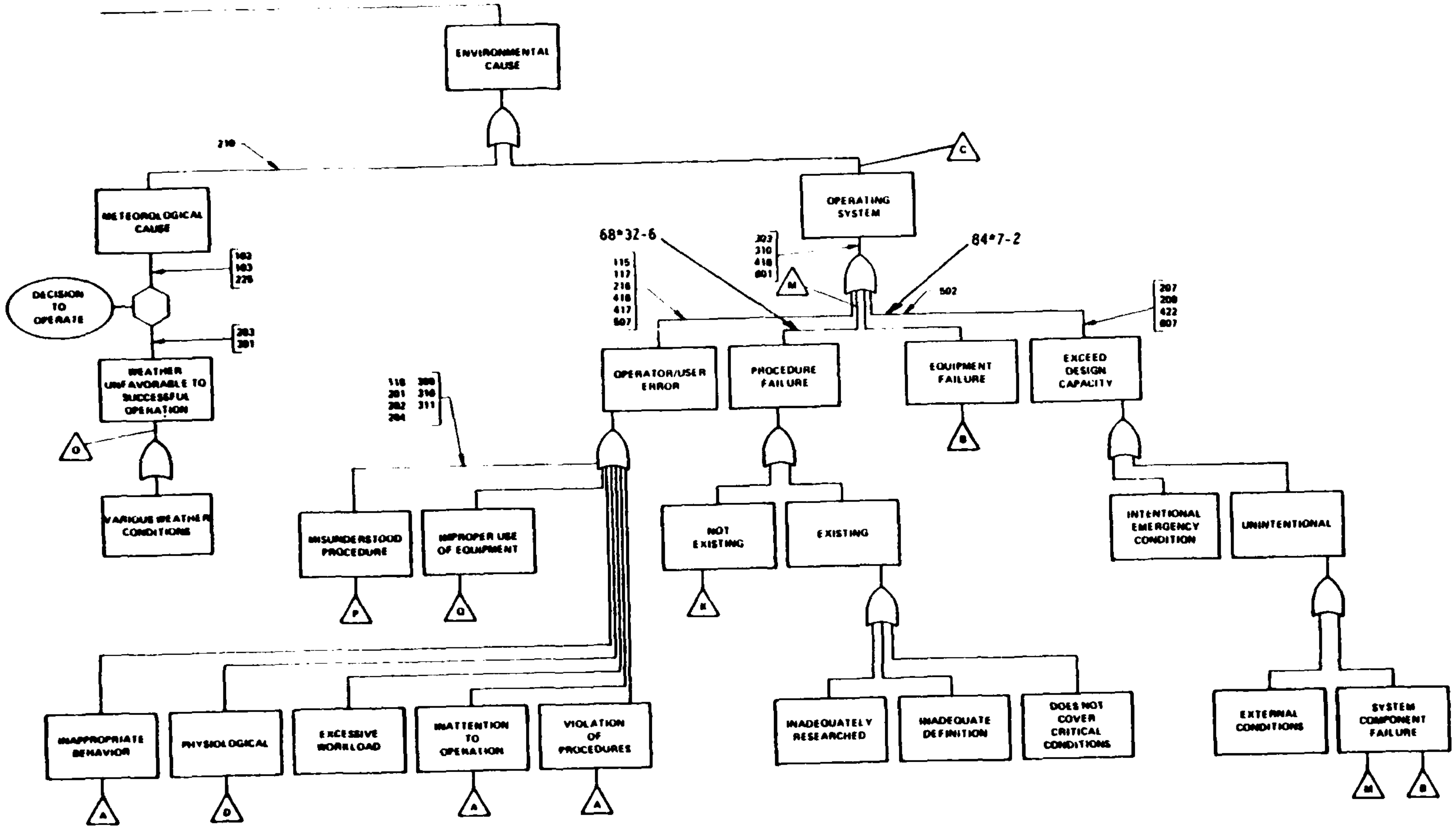

FIGURE 3-15. ENVIRONMENTAL ERROR FAULT TREE DIAGRAM: AERIAL APPLICATION, SINGLE- AND MULTI-ENGINE PISTON

Instructional, Single- and Multi-Engine Piston

This subpopulation is comprised of the following accident and operating characteristics:

a. The accident rate is 0.11 accidents per 1,000 flight hours. This rate is greater than that for the general aviation population by approximately 40 percent.

b. There is a moderate level of direct regulation by the FAA.

c. 55 percent of the aircraft are "basic" avionics equipped while 40 percent are "basic+" equipped. Twenty-four percent of the aircraft have ILS systems and 41 percent have no ILS components at all.

d. The annual insurance rates are five percent of the hull value, assuming the aircraft are part of an approved flying school or fixed base operation that has not had a major accident in the last three years. Aircraft not falling into this group are insured at rates similar to those rates of personal flying.

e. Pilot qualifications generally require that an instructor be a certified flight instructor (CFI) with a minimum of 500 accident-free flight hours.

f. Only 29 percent of the pilots in this subpopulation had instrument ratings.

g. The most prominent accident type is Ground/Water Swerve (22 percent). Engine failure is approximately the same in magnitude (21 percent).

The cause/factor characteristics are characterized in Table 3-24 and, more specifically, in Figures F-1 through F-10 in Appendix F. In summary, the characteristics for this subpopulation are:

a. Five of the human error citations (64*4Z, 64*3Z, 64*5Z, 64*2Z and 64*6Z) are increasing in frequency, while the remaining two (64*1Z and 68*3Z) are maintaining a constant, but moderate rate of occurrence.

b. Mechanical errors have their lowest citation rate in this subpopulation. Cause/factors 74*00 and 74*KA (the only two mechanical errors cited) are cited in less than three percent of the accident citations in this subpopulation.

c. Cause/factor 82*H (Unfavorable Winds) is cited in about one percent of the accidents. This cause/factor falls into the same category as 84*7, in that it is used to state a condition, rather than a cause of an accident. Cause/factor 68*3Z is cited in three percent of the accidents, which is slightly below average (four percent) for all subpopulations.

d. The top ten cause/factors represent 91 percent of the total subpopulation citations, of which 84 percent are human error.

The safety programs and related cause/factors for which evaluation findings are given below are displayed in the fault tree diagrams in Figures 3-16 through 3-18. The safety programs and the top ten cause/factors cited as causes of accidents in this subpopulation are located at the highest levels on the error paths of the fault tree (human, mechanical, or environmental) with which they are associated. As noted earlier, the respective safety programs and cause/factors subsume all lower level accident causes on connected branches of the fault tree. Based on these fault tree alignments, the findings given below pertain to the linkage between safety programs and leading accident cause, breadth of safety program coverage, and adequacy of the treatment of identified safety hazards by associated safety programs.

The findings concerning the safety program effectiveness for this subpopulation are:

a. The safety programs dealing with human error appear to have little effect in preventing accidents. This subpopulation has the highest rate of human error (84 percent) involvement of the eight subpopulations investigated. The cause/factor 64*4Z represents the highest, single rate of involvement of human error cause/factors and also has the highest number of safety programs indirectly aligned with it.

b. Mechanical safety programs appear to be effective in preventing accidents. Only two mechanical cause/factors (of 28 possible) are cited in the segment, and at at a combined rate of less than three percent.

c. Environmental programs appear to be adequate in their effectiveness with only a low percentage of citations (four percent total) occurring in the segment.

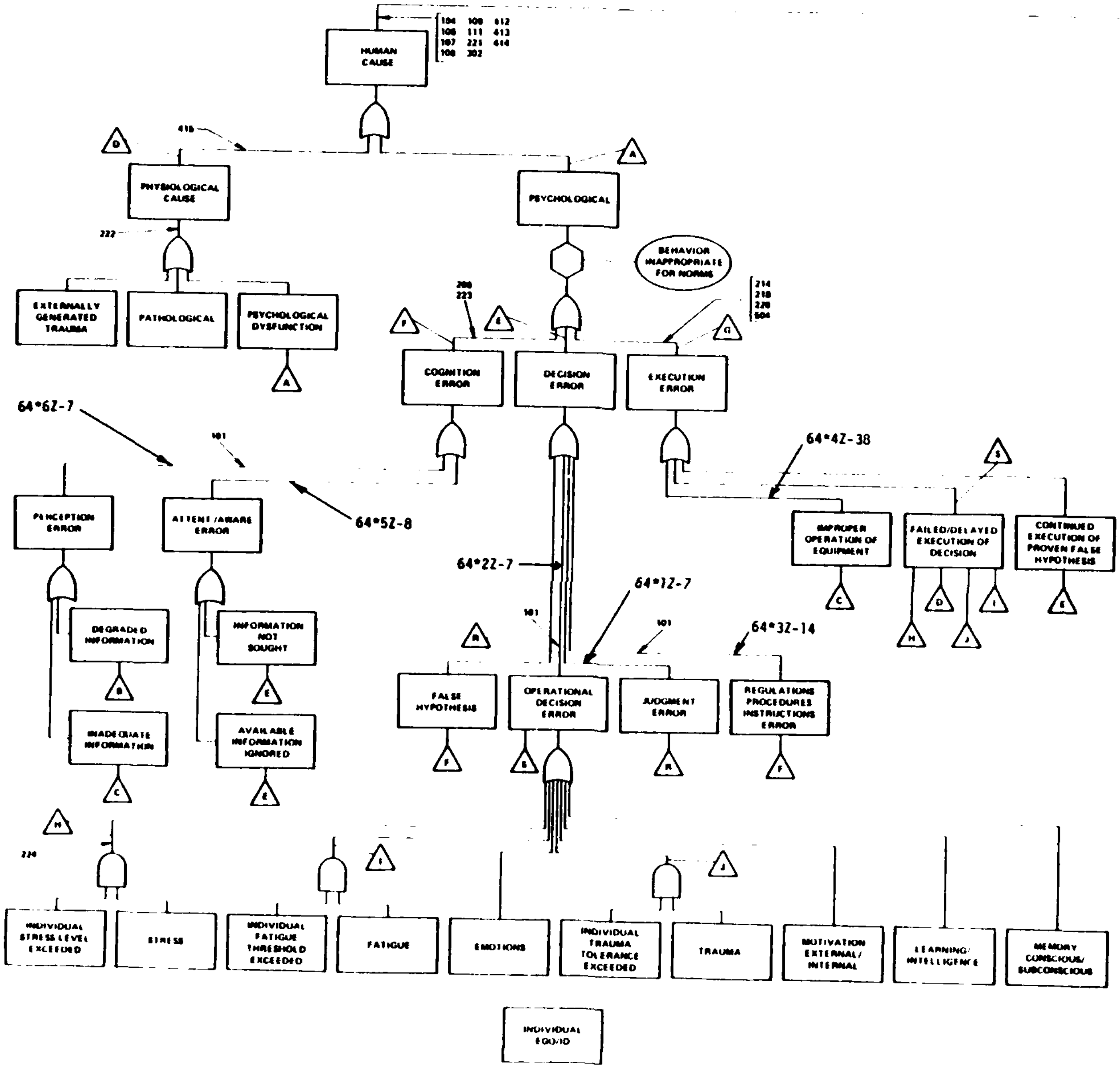

FIGURE 3-16. HUMAN ERROR FAULT TREE DIAGRAM:
INSTRUCTIONAL, SINGLE- AND MULTI-ENGINE PISTON

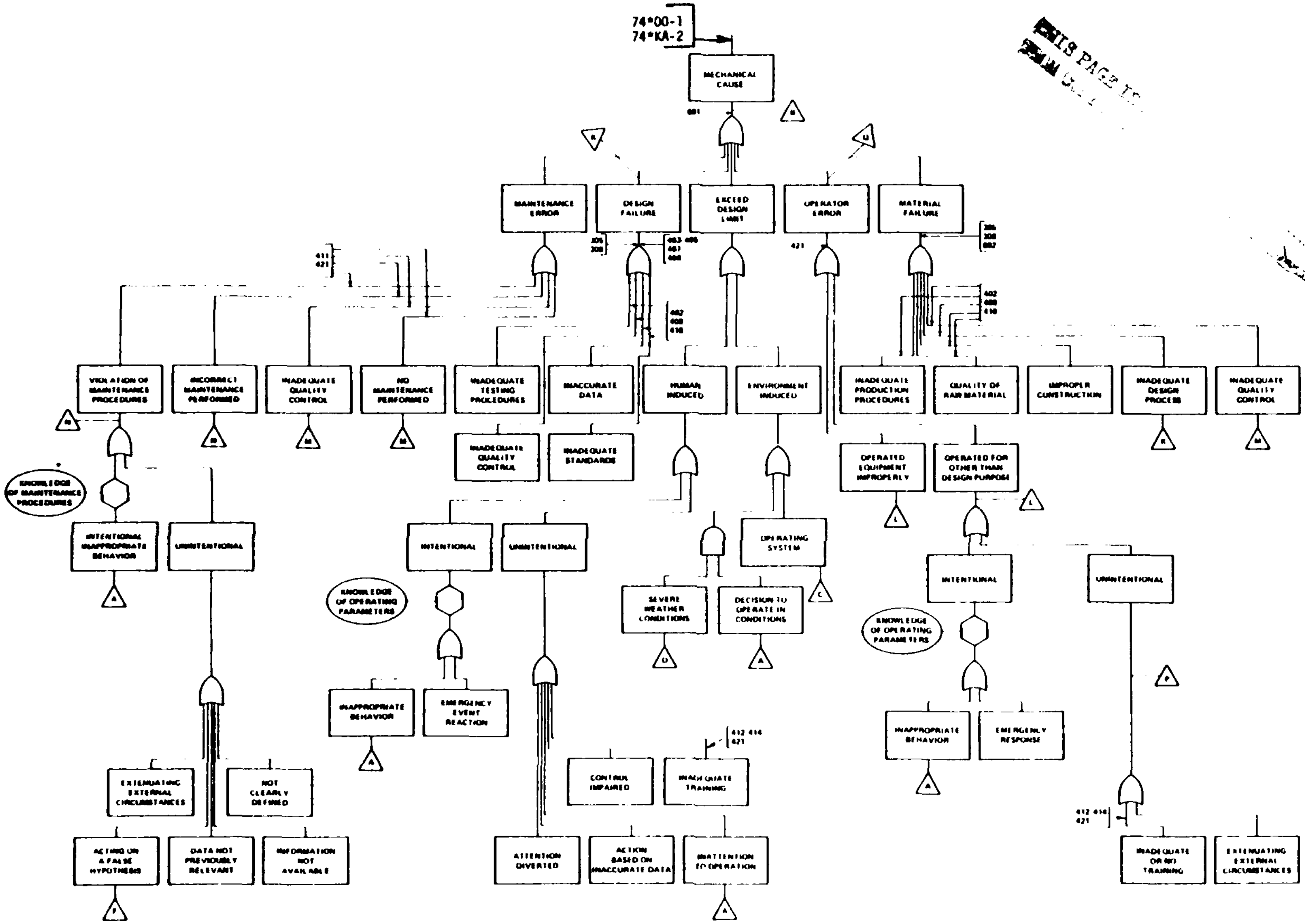

FIGURE 3-17. MECHANICAL ERROR FAULT TREE DIAGRAM: INSTRUCTIONAL, SINGLE- AND MULTI-ENGINE PISTON

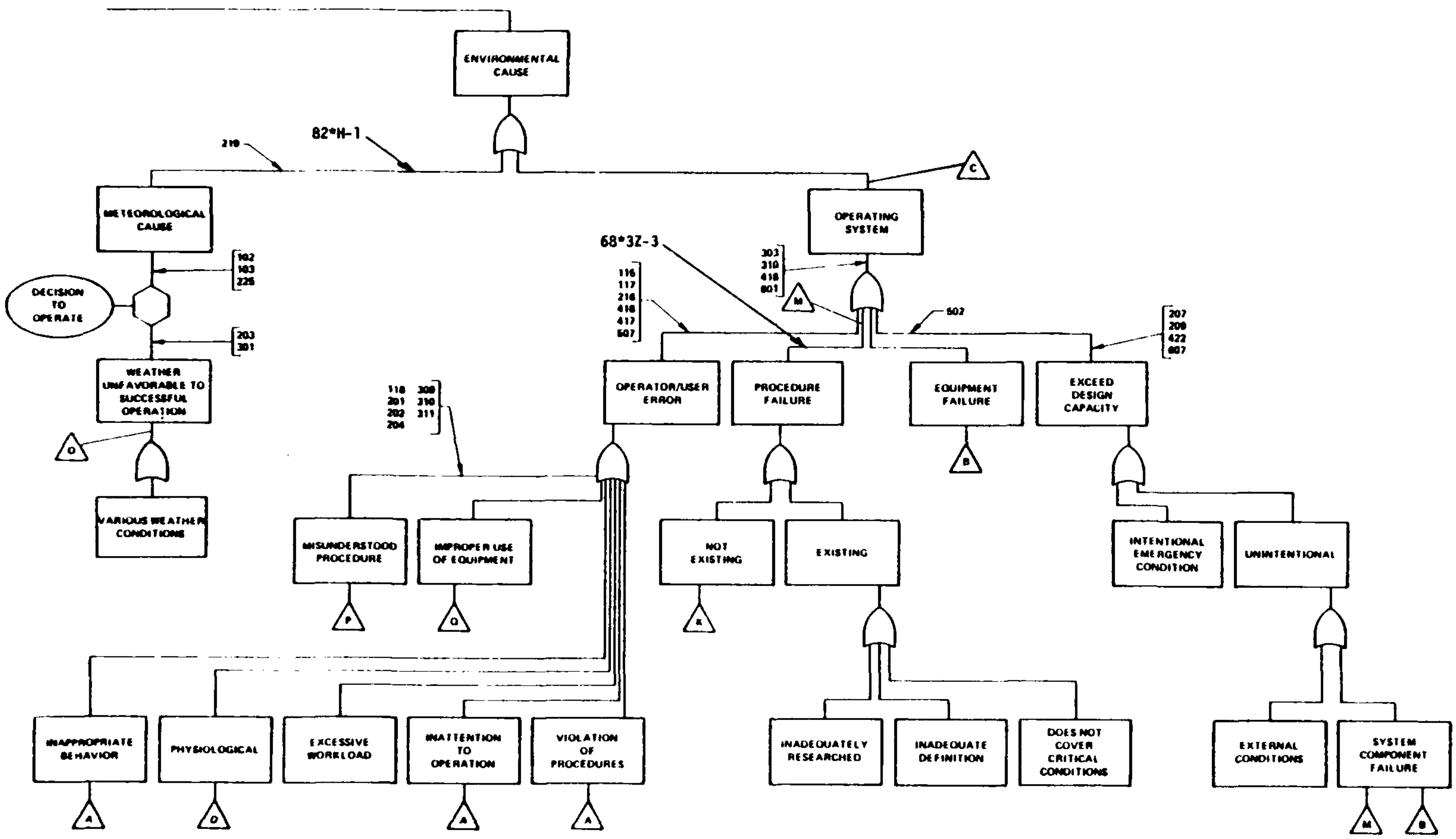

FIGURE 3-18. ENVIRONMENTAL ERROR FAULT TREE DIAGRAM: INSTRUCTIONAL, SINGLE- AND MULTI-ENGINE PISTON

Air Taxi, Single- and Multi-Engine Piston, and Turboprop and Turbojet

This subpopulation is comprised of the following accident and operating characteristics:

a. The accident rate is 0.06 accidents per 1,000 flight hours. This rate is less than the population accident rate by 25 percent.

b. There is a high level of direct regulation by the FAA.

c. 74 percent of the aircraft are equipped with "basic+" avionics while 25 percent have "basic" equipment. Sixty-seven percent of the fleet is equipped with an ILS system and 19 percent have no ILS components.

d. The annual hull insurance rates are five to six percent of the aircraft's value.

e. 85 percent of the pilots are instrument rated and the FAA requires that a pilot have a commercial license to operate an air taxi aircraft. In addition, type certificates, proficiency checks and special ratings may be required depending on the operation.

f. The two most prominent accident types are Engine Failure or Malfunction (18 percent) and Collisions (18 percent)--all types except between aircraft.

The cause/factor characteristics are characterized in Table 3-24 and, more specifically, in Figures G-1 through G-10 in Appendix G. In summary, the characteristics for this subpopulation are:

a. Human error cause/factors are either increasing or maintaining moderate to high rates of occurrence. Human error represents 74 percent of the total accident citations.

b. All mechanical errors (74*00, 74*KA and 70*CB) comprise seven percent of the total subpopulation citations.

c. The cause/factor 68*3Z is cited in over seven percent of the accidents. This rate represents the highest rate for any subpopulation, with 68*3Z in the segment Corporate, Single- and Multi-Engine Piston, a close second at less than seven percent.

d. The top ten cause/factors represent 80 percent of the total citations in this subpopulation.

The safety programs and related cause/factors for which evaluation findings are given below are displayed in the fault tree diagrams in Figures 3-19

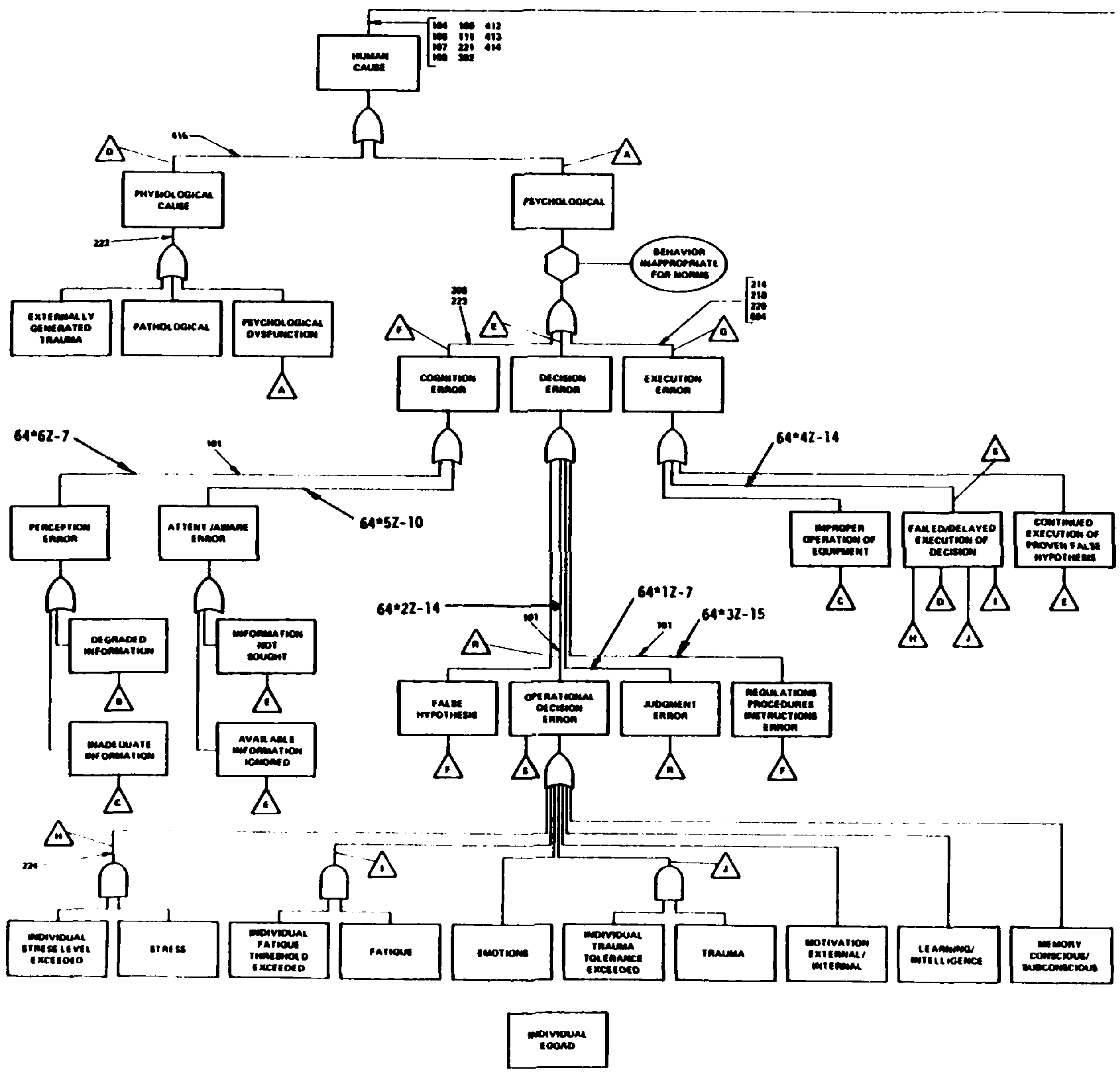

FIGURE 3-19. HUMAN ERROR FAULT TREE DIAGRAM: AIR TAXI, SINGLE- AND MULTI-ENGINE PISTON, TURBOPROP AND TURBOJET

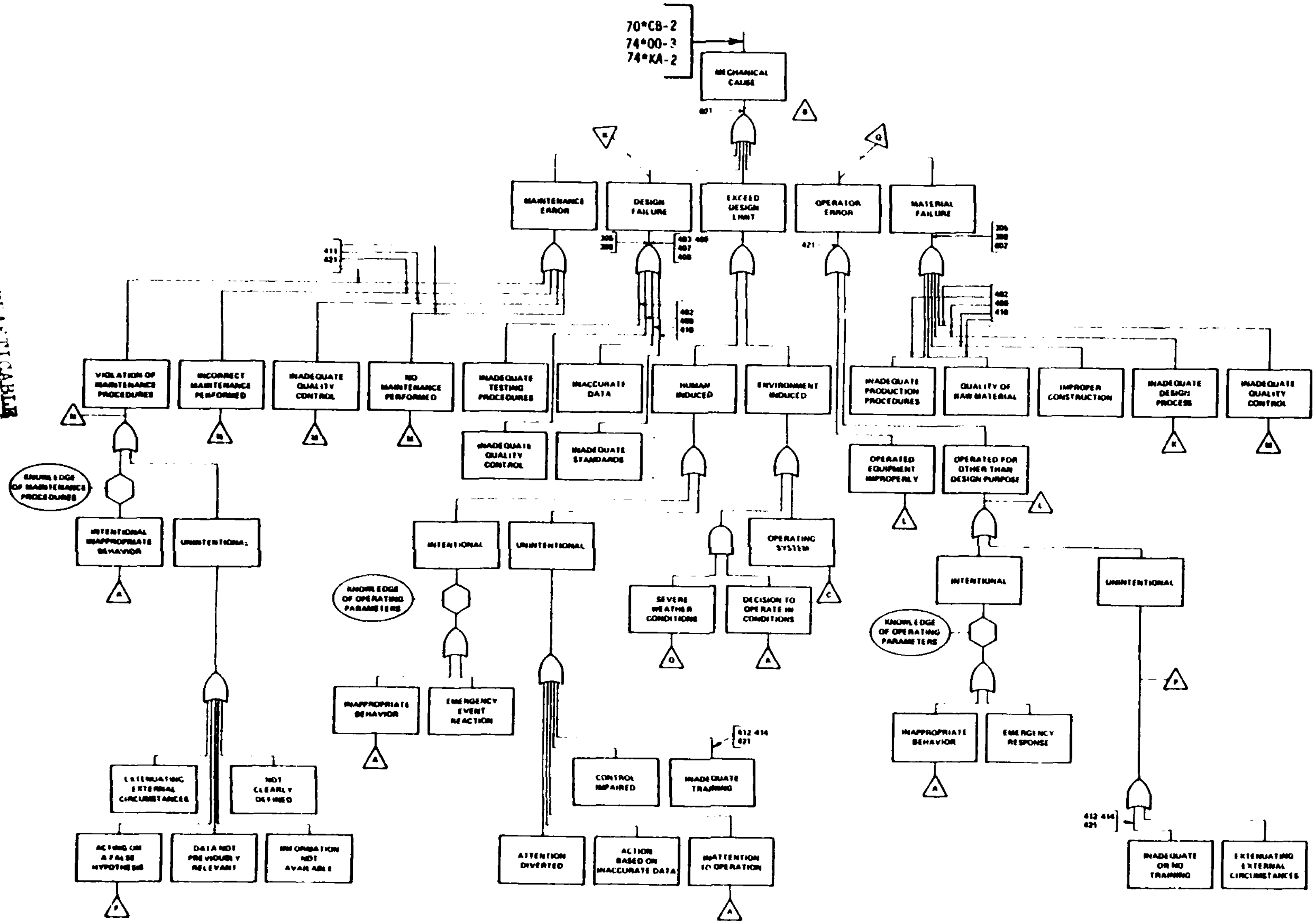

FIGURE 3-20. MECHANICAL ERROR FAULT TREE DIAGRAM: AIR TAXI, SINGLE- AND MULTI-ENGINE PISTON, TURBOPROP AND TURBOJET

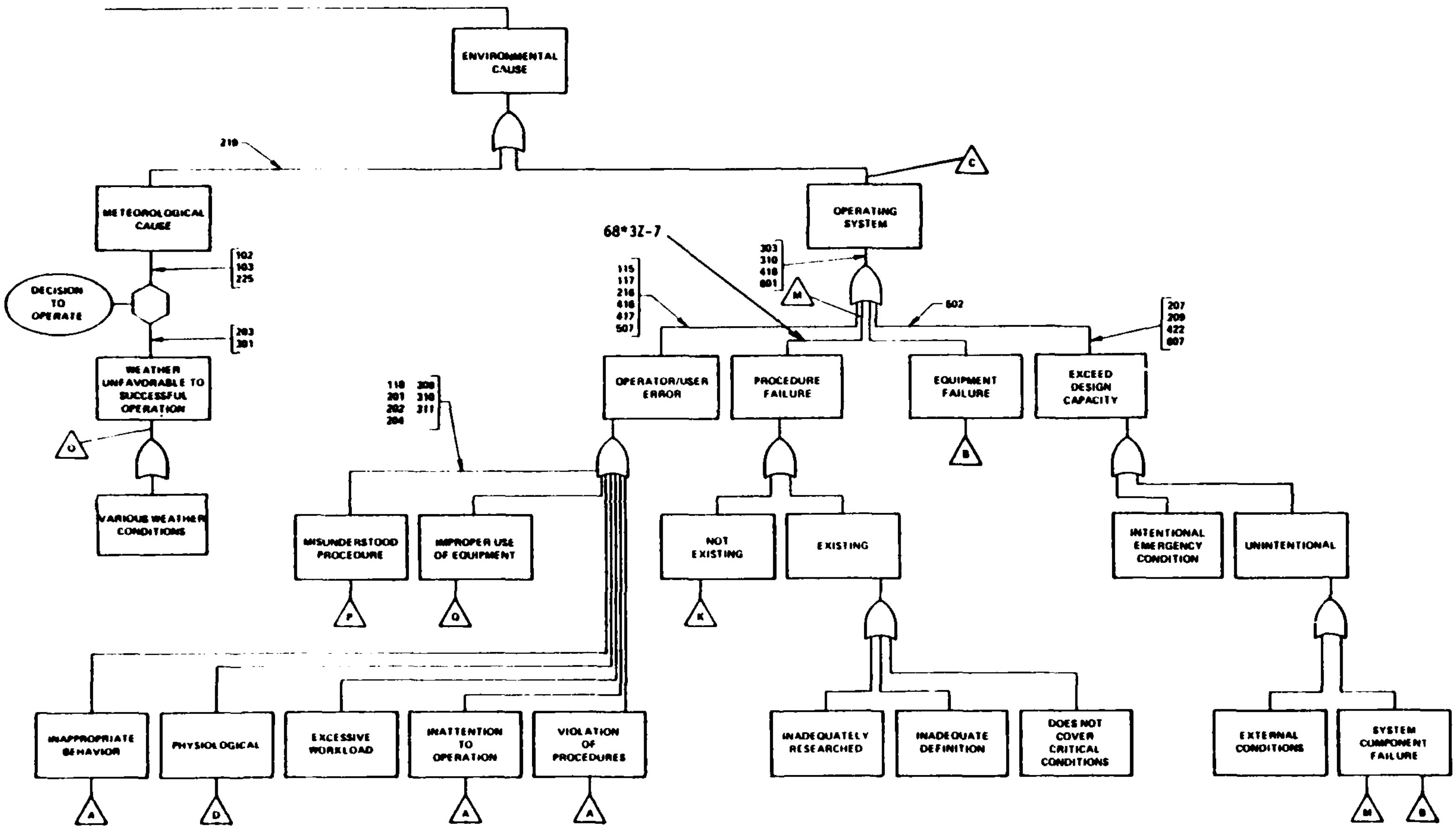

FIGURE 3-21. ENVIRONMENTAL ERROR FAULT TREE DIAGRAM: AIR TAXI, SINGLE- AND MULTI-ENGINE PISTON, TURBOPROP AND TURBOJET

through 3-21. The safety programs and the top ten cause/factors cited as causes of accidents in this subpopulation are located at the highest levels on the error paths of the fault tree (human, mechanical, or environmental) with which they are associated. As noted earlier, the respective safety programs and cause/factors subsume all lower level accident causes on connected branches of the fault tree. Based on these fault tree alignments, the findings given below pertain to the linkage between safety programs and leading accident cause, breadth of safety program coverage, and adequacy of the treatment of identified safety hazards by associated safety programs.

The findings concerning safety program effectiveness for this subpopulation are:

a. Safety programs directed at preventing human error do not appear to be effective in preventing accidents related to those errors.

b. In general, mechanical programs appear to be mitigating most mechanical errors in accidents. This subpopulation shares a landing gear problem with the segment Corporate, Single- and Multi-Engine Piston. It is believed that this problem is not mechanical, but a human error problem. Over 76 percent of the 70*CB citations in both subpopulations are cited in accidents where the pilot did not ensure the gear was down, inadvertently retracted it, or retracted it too soon. Fifty-one percent of the remaining accidents had citations of 70*CB combined with 64*3Z (Human Error, Procedures, etc...). These facts all strongly indicate that these problems are not mechanical in nature.

c. Environmental safety programs in this subpopulation appear to be preventing the accidents associated with it. However, as for the Multi-Engine Piston subpopulation, this finding may reflect inadequate investigative detail or lack of understanding of the operating systems role in accidents.

Corporate, Turboprop and Turbojet

This subpopulation is comprised of the following general accident and operating characteristics:

a. The accident rate is 0.01 accidents per 1,000 flight hours. This rate is the lowest of all subpopulations representing approximately 10 percent of the population rate.

b. The impact of FAA regulation is marginal and indirect, mainly entailing FAR's for general operation procedures, pilot and equipment certification.

c. 92 percent of the aircraft are equipped with "basic" avionics equipment, 87 percent of the aircraft have a complete ILS system, six percent have no ILS components and only one percent have no avionics.

d. 98 percent of the pilots involved in the accidents had instrument licenses. In general, insurance companies require a corporate pilot to have a commercial license (preferably an instrument ticket), 1,000 accident-free flying hours as pilot-in-command, type certification, and recurrent training. They also perform inspections of the maintenance and operational facilities used by the operator.

e. The annual insurance rate is the lowest in the industry--0.6 percent per 1,000 dollars of hull value.

f. The leading accident type is Collisions (all types, except between aircraft) accounting for 16 percent of total accidents, followed closely by Engine Failures which account for 13 percent of total accidents.

The cause/factor characteristics are characterized in Table 3-24 and, more specifically, in Figures H-1 through H-10 in Appendix H. In summary, the characteristics for this subpopulation are:

a. Human error comprises 65 percent of the total cause citations in this subpopulation. The most prominent cause/factor is 64*3Z (Human Error-Procedures, etc...) which represents 25 percent of the total error citations in this subpopulation. This rate is more than one-and-one-half times the next highest citation rate (16 percent in Corporate, Single- and Multi-Engine Piston) and generally more than twice the average rate of 64*3Z citations.

b. The mechanical errors in this subpopulation reflect the higher degree of aircraft sophistication, in that the cause/factor 75*00 (Aircraft System Errors) appears only in this segment and at a rate of three percent. Cause/factor 74*00 is cited in three percent of the accidents.

c. This subpopulation also has the only citations of 80*00 (Airport/Airways-random) and 80*BY (Airport Conditions-Other) as respective rates of three percent each. Because these cause categories are only generally defined, no detailed explanation can be given for their occurrence.

d. The top ten cause/factors represent over 84 percent of the errors cited in this subpopulation.

The safety programs and related cause/factors for which evaluation findings are given below are displayed in the fault tree diagrams in Figures 3-22 through 3-24. The safety programs and the top ten cause/factors cited as causes of accidents in this subpopulation are located at the highest levels on the error paths of the fault tree (human, mechanical, or environmental) with which they are associated. As noted earlier, the respective safety programs and cause/factors subsume all lower level accident causes on connected branches of the fault tree. Based on these fault tree alignments, the findings given below pertain to the linkage between safety programs and leading accident cause, breadth of safety program coverage, and adequacy of the treatment of identified safety hazards by associated safety programs.

The findings concerning safety program effectiveness for this subpopulation are:

a. Safety programs directed at preventing human error do not appear to be effective. This lack of effectiveness is most evident in the area of errors associated with procedures, regulations, instructions and responsibilities (64*3Z). The exceptionally high rate of 64*3Z would suggest a major problem in that this subpopulation is comprised of pilots with the highest average flight hours, certifications and operational qualifications. This subpopulation also represents one of the highest levels of interface with the National Aviation System (NAS). An explanation suggested by this situation is that the NAS is somehow involved in these accidents, or the quality and detail of accident investigation in this subpopulation exposes a clearer picture of the real human errors occurring in the system.

b. Mechanical safety programs appear to be operating with essentially the same effectiveness as in the other subpopulations. The errors (74*00 and 75*00, both cited in three percent of the accidents) are occurring at an almost constant rate.

c. Environmental safety programs again appear to be preventing accidents, but the same caution should be indicated with this finding as was stated earlier in segment Business, Single- and Multi-Engine Piston. The cause/factor 68*3Z (Other Personnel-Procedures, etc.) is cited at a higher

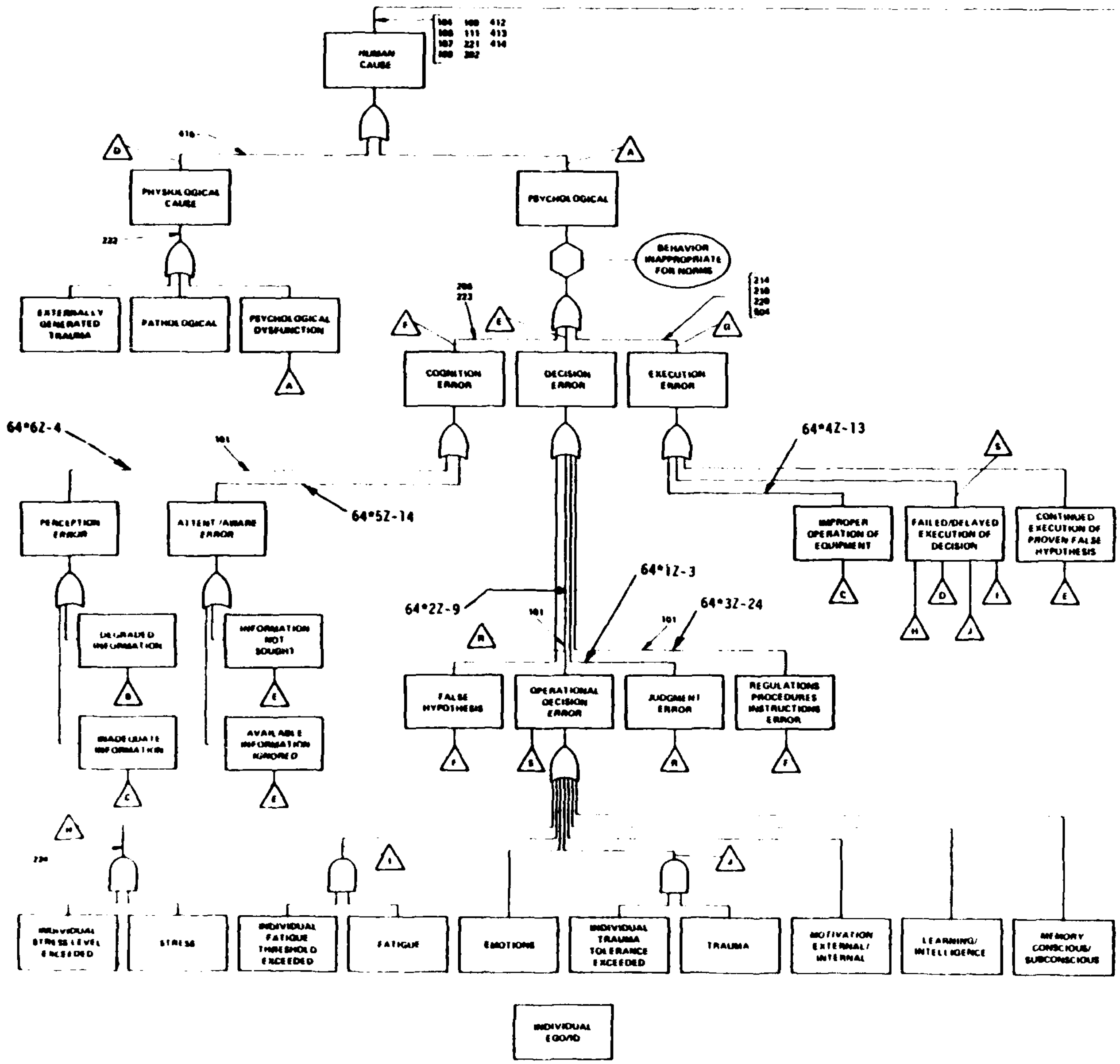

FIGURE 3-22. HUMAN ERROR FAULT TREE DIAGRAM. CORPORATE, TURBOPROP, AND TURBOJET

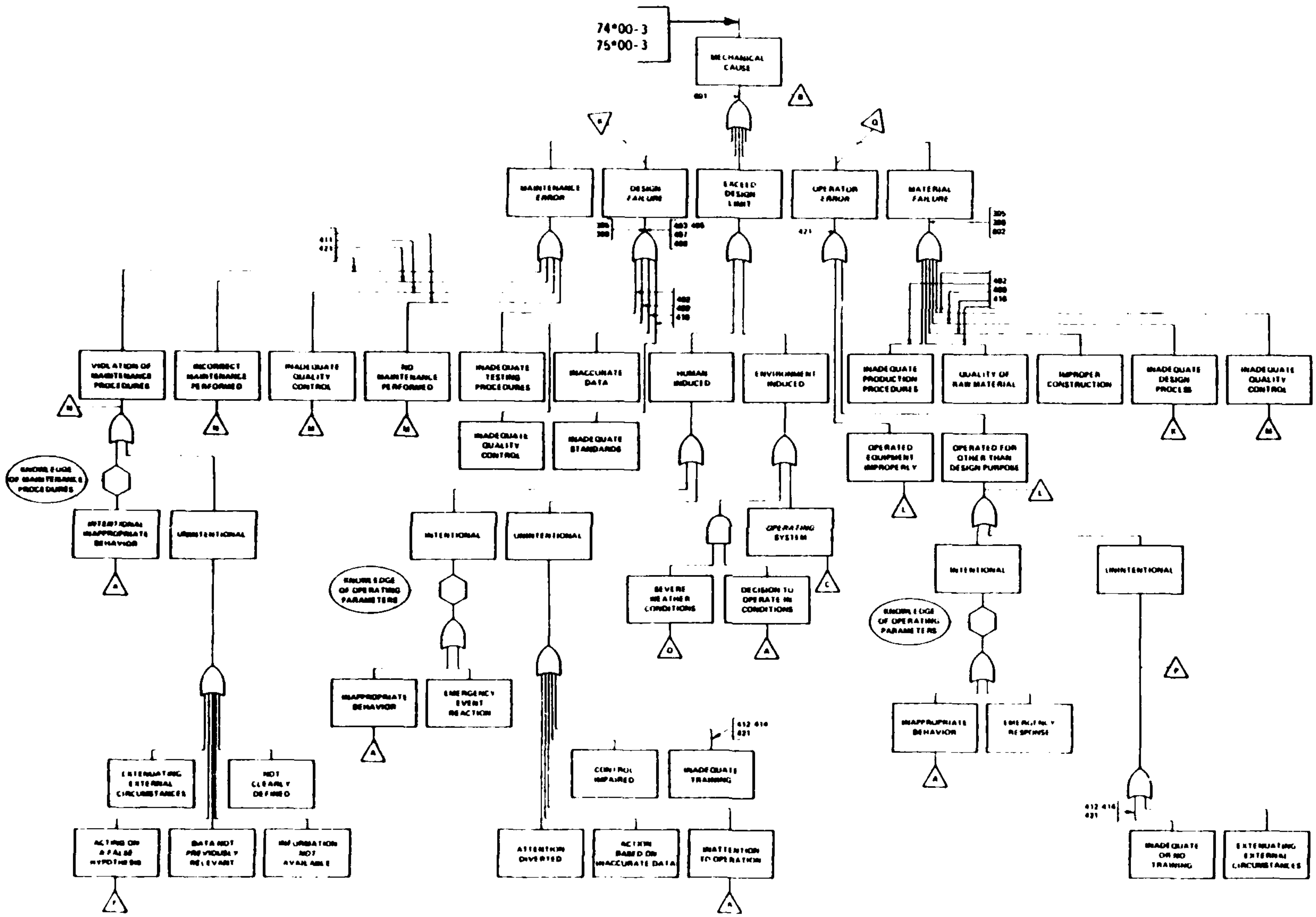

FIGURE 3-23. MECHANICAL ERROR FAULT TREE DIAGRAM: CORPORATE, TURBOPROP AND TURBOJET

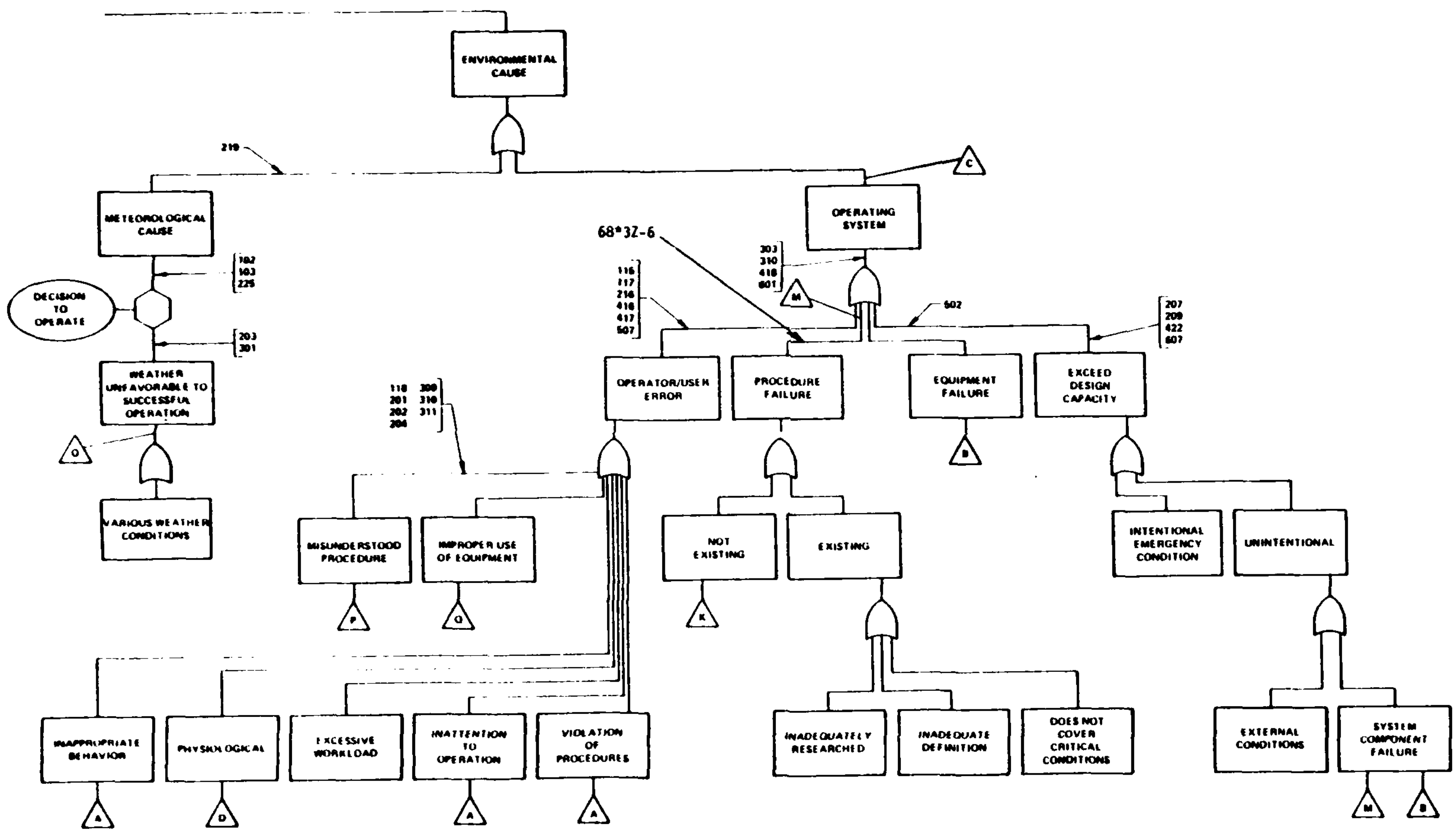

FIGURE 3-24. ENVIRONMENTAL ERROR FAULT TREE DIAGRAM: CORPORATE, TURBOPROP AND TURBOJET

than average rate indicating again a problem with human error in the system, possibly even caused by the system itself.

Rotor (All Categories)

This subpopulation is comprised of the following general accident and operating characteristics:

a. The accident rate is 0.21 accidents per 1,000 flight hours. This rate is the third highest of the eight subpopulations and is more than twice the average accident rate for the general aviation population.

b. This category is effected by some direct regulation (FAA Part 135 or Part 141, etc...) when operating in user categories like Air Taxi or Instructional, but often receives exemptions from other general operating rules. These exemptions reflect the unique operating characteristics of the aircraft.

c. 32 percent of the aircraft in this subpopulation have no avionics equipment and 87 percent have no ILS system. 64 percent have "basic" avionics equipment, three percent have "basic+", while two percent have a complete ILS system.

d. The insurance rates for this group vary from six to 12 percent of hull value. The rate is dependent on the type of operation, the aircraft and pilot's qualifications.

e. The leading accident type is engine failure or malfunction accounting for 31 percent of the total accidents.

The cause/factor characteristics are characterized in Table 3-24 and, more specifically, in Figures I-1 through I-10 in Appendix I. In summary, the characteristics for this subpopulation are:

a. The human error cause/factor 64*4Z (Operation of Equipment represents 25 percent of the total cause citations in this subpopulation). Combined with all other human error causes the rate of citation increases to 73 percent.

b. The rate of mechanical error is the highest among the eight subpopulations. Over 15 percent of the accidents involve mechanical failures. This high rate is due primarily to the citation of helicopter-specific mechanical failures, 78*00 (Helicopter Components-Random) which is cited in eight percent of the accidents.

c. The cause/factor 68*3Z is occurring at a steady rate (five percent), which is slightly above the population average.

d. The top ten cause/factors in this segment represent 88 percent of the total cited in these accidents.

The safety programs and related cause/factors for which evaluation findings are given below are displayed in the fault tree diagrams in Figures 3-25 through 3-27. The safety programs and the top ten cause/factors cited as causes of accidents in this subpopulation are located at the highest levels on the error paths of the fault tree (human, mechanical, or environmental) with which they are associated. As noted earlier, the respective safety programs and cause/factors subsume all lower level accident causes on connected branches of the fault tree. Based on these fault tree alignments, the findings given below pertain to the linkage betwen safety programs and leading accident cause, breadth of safety program coverage, and adequacy of the treatment of identified safety hazards by associated safety programs.

The findings concerning safety program effectiveness for this subpopulation are:

a. Human-error occurrences in helicopter accidents are increasing and appear to be unaffected by the safety programs directed at this area.

b. Mechanical safety programs appear to be less than effective in preventing errors in this segment. This is believed to be due in part to the technologically complicated nature of the helicopter and the various hazardous operations in which they are used. The rates of engine failures or malfunctions are slightly higher than the larger general aviation population average.

c. The environmental safety programs appear to be preventing accidents. This segment, however, showed the lowest integration into the NAS (besides Aerial Application which has little contact with the NAS) and thus should not be considered as an accurate reflection of the environmental safety program's effectiveness.

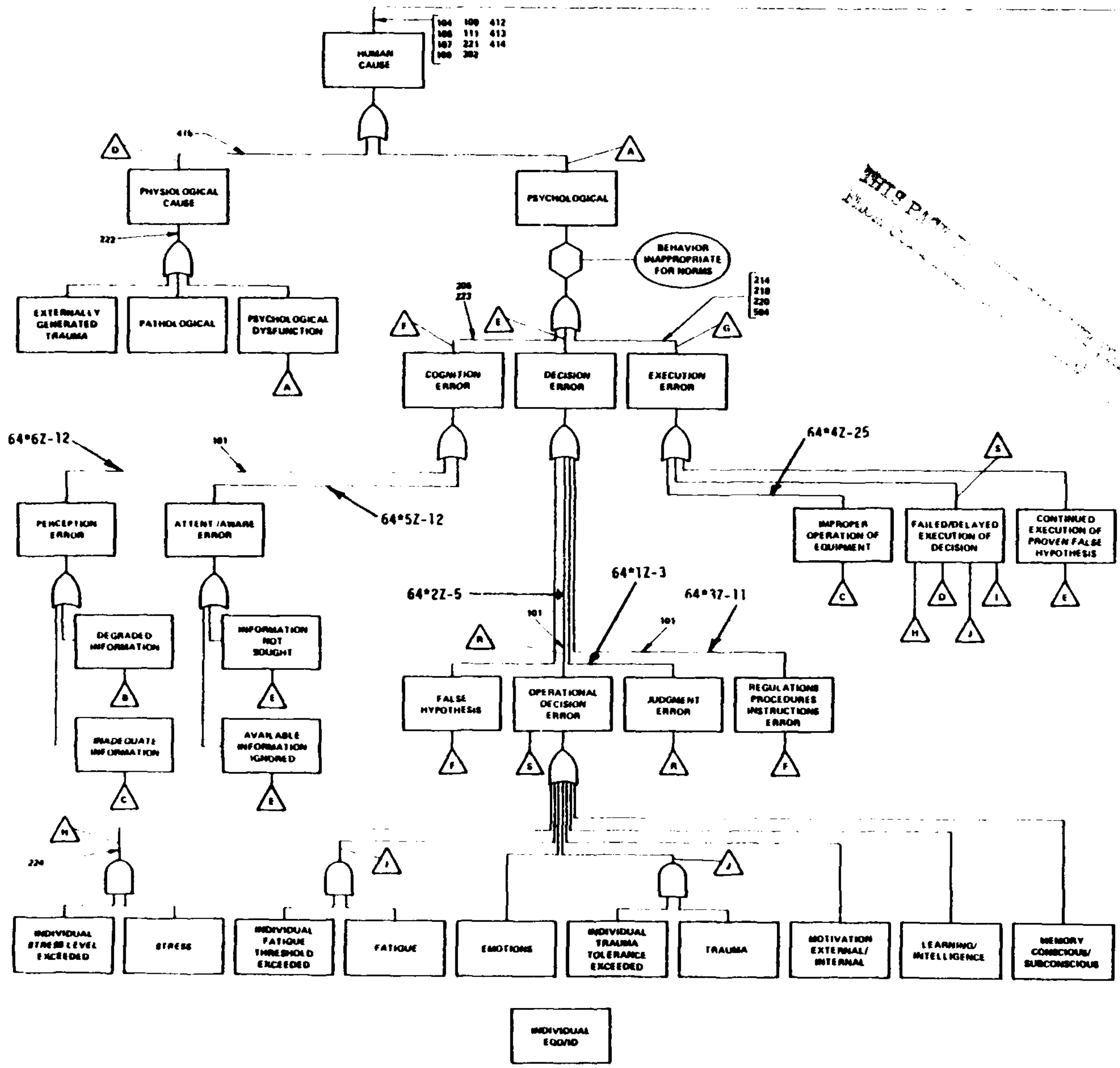

FIGURE 3-25. HUMAN ERROR FAULT TREE DIAGRAM: ROTOR (ALL CATEGORIES)

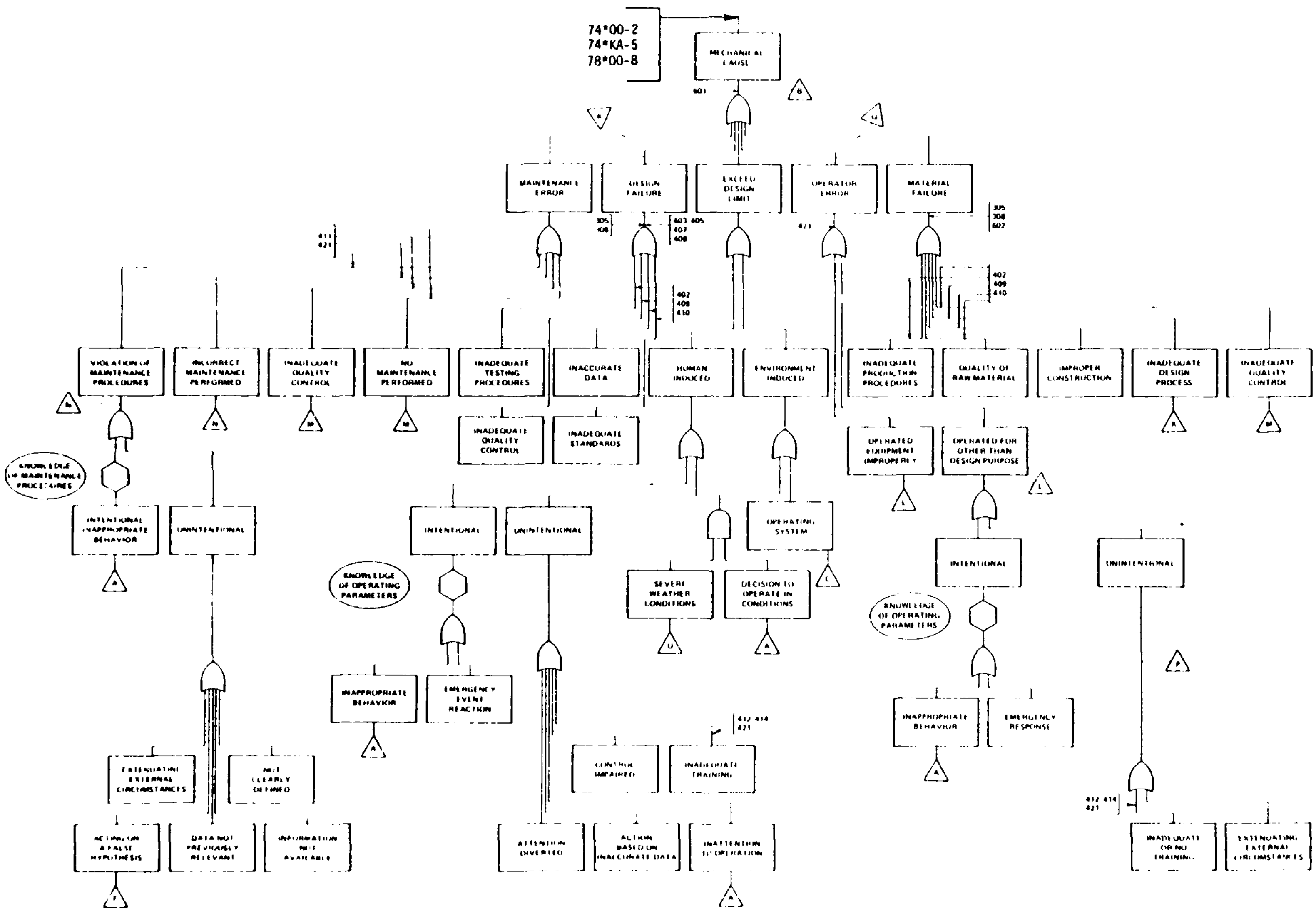

FIGURE 3-26. MECHANICAL ERROR FAULT TREE DIAGRAM: ROTOR (ALL CATEGORIES)

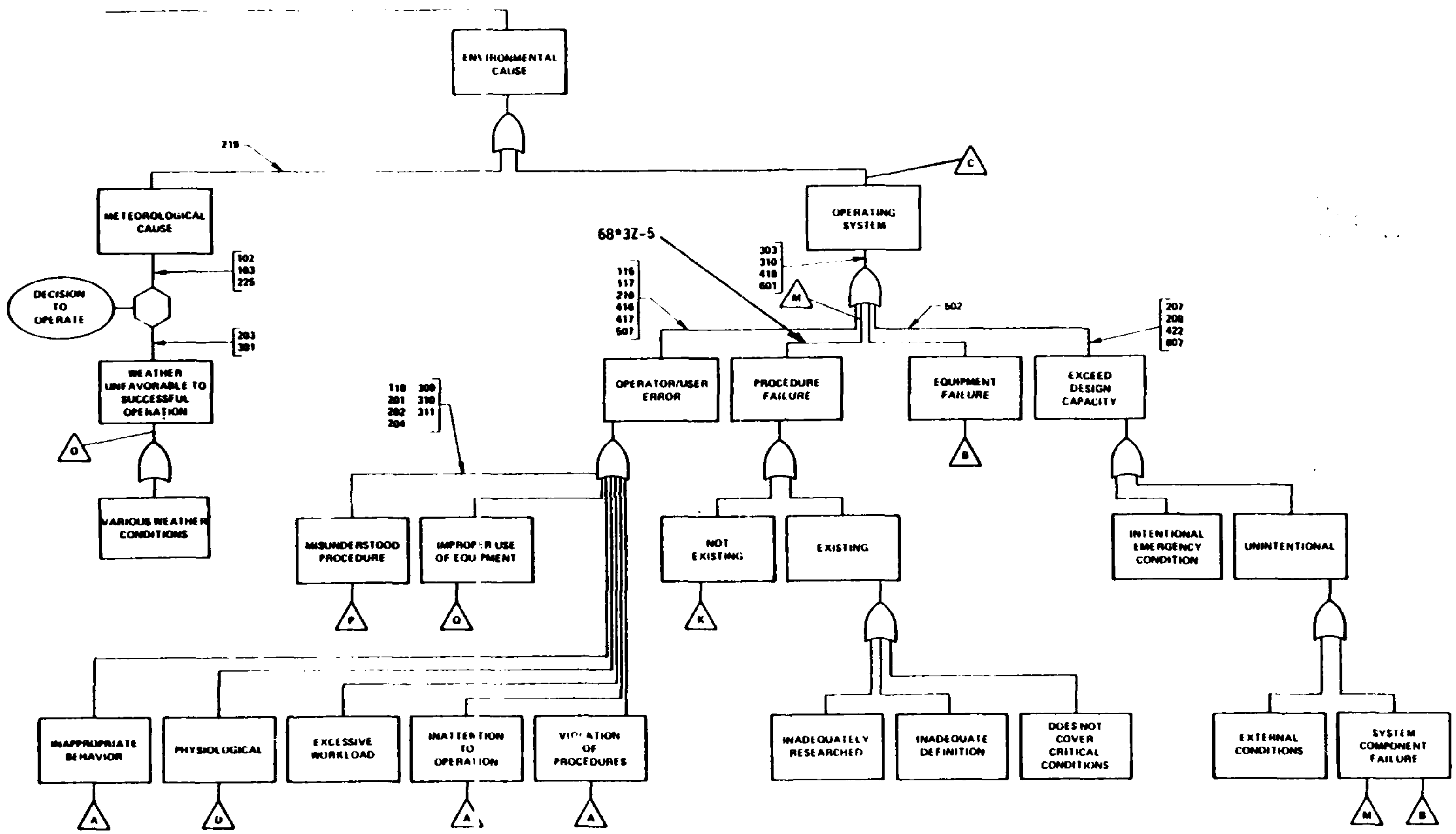

FIGURE 3-27. ENVIRONMENTAL ERROR FAULT TREE DIAGRAM: ROTOR (ALL CATEGORIES)

CHAPTER 4. CONCLUSIONS, AND RECOMMENDATIONS

This chapter presents the conclusions and recommendations arrived at in this study in two separate sections by the same titles.

CONCLUSIONS

The assessment of the FAA safety programs serves two purposes. The first is to measure the effectiveness with which the existing safety program system is operating. Stated more succinctly, to what measurable extent are these safety programs preventing accidents? The second purpose, which is essentially ancillary to the first, is to determine where new programs and initiatives are needed to improve the effectiveness of the safety program system. The measurement of effectiveness in this study is based mainly on empirical data; the NTSB's general aviation accident records. This data source can only provide a measure of where observable problems are occurring. It is not a comprehensive basis for identifying (though an indication) where safety problems may be occurring but are being dealt with effectively by the safety system. The conclusions of this study are presented in the following manner:

- Human Error Safety Programs
- Mechanical Safety Programs
- Environmental Safety Programs
- The NTSB Accident Records
- The FAA General Aviation Data
- The Profile of a Successful Safety Program
- General Conclusions.

Human Error Safety Programs

The human-error related safety programs are having little direct effect on preventing the accidents associated with this causal area. The overall trend of human error occurrence has remained steady or increased in every subpopulation of general aviation examined in the analysis. The involvement of human error ranges from a substantial 65 percent of the causes in Corporate, Turboprop and Turbojet flying to a high of 84 percent in Instructional, Single- and Multi-Engine Piston operations.

The apparent lack of safety program effectiveness in this causal area is attributed to three factors:

a. An inadequate understanding of the causes of human error accidents

b. An inadequate alignment of existing human error safety programs against the causes of the accidents. The safety programs currently directed at this area appear to treat the symptoms or effects of the cause and not the cause.

c. The absence of an integrated, logical structure of safety programs designed to deal with the entire range of human error problems.

The major human-error problem centers around four of the cause/factors identified in the accident records. They are:

a. Improper Operation of Equipment (64*4Z)

b. Procedures, Regulations, Etc. (64*3Z)

c. Other Personnel--Procedures, Regulations, Etc. (68*3Z)

d. Operational Decision Error (64*2Z).

These four cause/factors represent over 50 percent of the human errors in the seven-year accident history examined in this study. Although these cause/factors are often cited together in a great many cases in the various general-aviation segments, their precise relationships could not be determined using the current accident records. A note of caution is in order concerning possible misinterpretation of the high rate of cause 64*4Z (Improper Operation of Equipment). This high rate stems mainly from the fact that in accidents, the apparent lack of pilot technique is easily observed. Consequently, in many investigations where additional resources are not available to investigate the cause/factors further, the causal assignment stops with pilot technique. This fact should not diminish the importance of the role that operation of equipment plays in an accident. Rather, it emphasizes that the lack of data from both the accident investigations and the operating system prevents an accurate determination of the problem.

The safety programs associated with the prevention of human error reflect the absence of clear human error definitions and of an integrated, logical safety-program structure. These problems were identified by examining the relationships of the safety program objectives and approaches with the hazards found in the accident records. Essentially, the objectives of a safety program are defined as those statements which identify the hazards the program is designed to prevent. The hazards in this case are defined in terms of the cited cause/factors of accidents. The method for investigating these program objectives is to align them with their respective hazards, if possible, using the direct/indirect criteria discussed earlier in this report. For example, the safety program Detecting/Sensing/Tracking Hazardous Weather (301), deals directly with the cause/factor 84*X (Thunderstorms). This same program would have an indirect effect on 84*L (Turbulence in Flight Associated with Clouds or Thunderstorms) denoting that some secondary benefit is derived by the latter cause/factor. Not all alignments, especially those that are indirect, are as straightforward as the example stated above, but they do serve to identify voids in safety program coverage.

These voids are evident in the human error fault tree summary in Figure 4-1. The fault tree displays very localized clusters of safety programs (identified by three-digit codes: see definitions in Tables 2-17 through 2-22) at high levels in the tree. This clustering effect is typical of programs with a common objective (e.g., the prevention of human error) that attempt to deal with inadequately defined problems. Program clustering can also result from poorly defined safety program objectives or objectives that are only indirectly related to the problem. However, these latter two problems were rarely found to be the case in regard to these FAA safety programs. Generally, the problems in the human error category stem from the lack of information necessary to predict, describe and prevent a safety hazard.

The full impact of this clustering effect can not be determined with the current accident data. However, the disparity between the safety program locations and the concentration of accident causes can be demonstrated. Inserted into the human error fault tree (Figure 4-1) are the various rates (in ratio to the total study cause citations) of the major human error causes. These rates are located at a point above their currently identified labels. For example, 64*4Z-(23%) is located above the box labeled Improper Operation

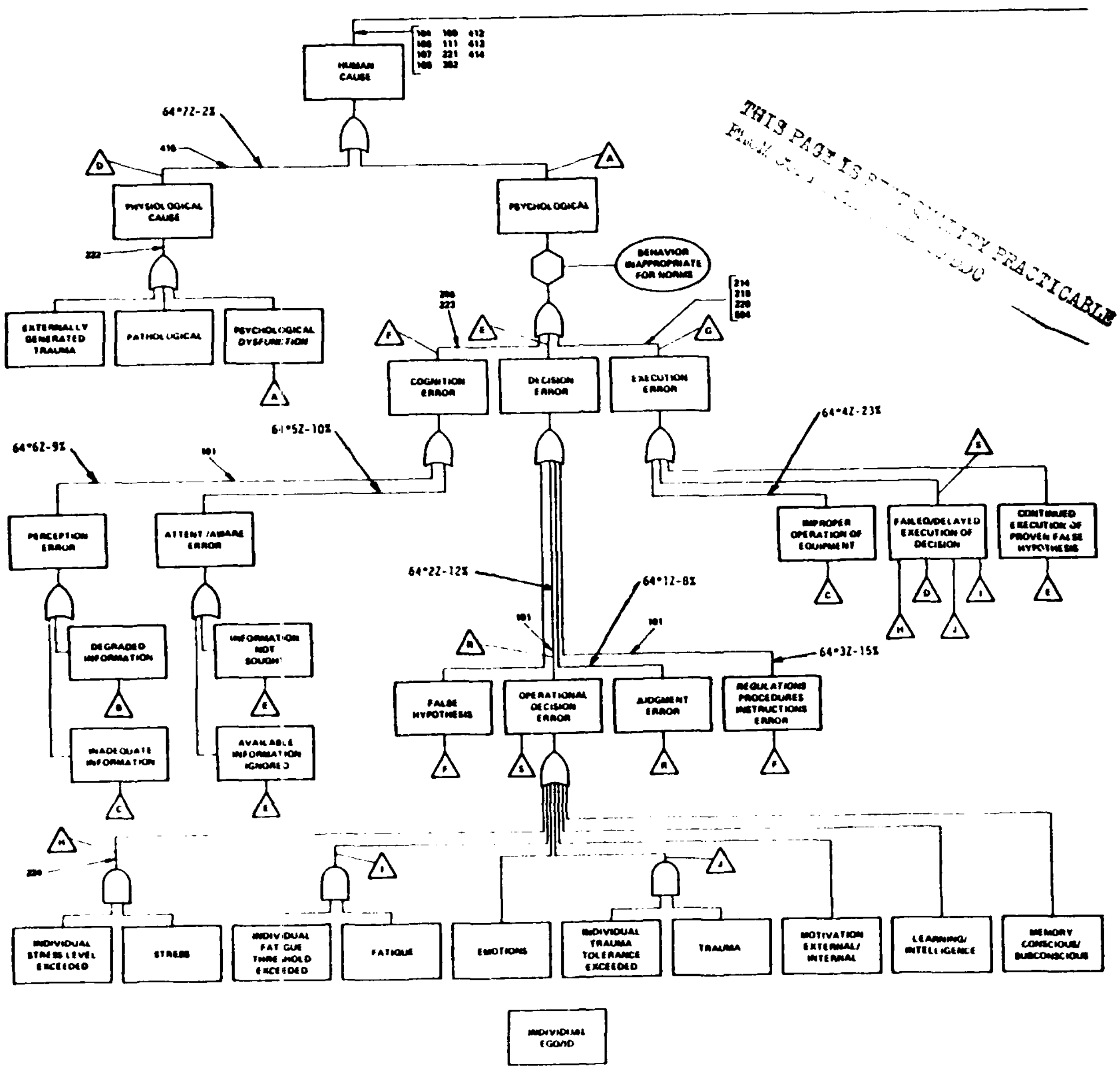

FIGURE 4-1. PLACEMENT OF SAFETY PROGRAMS IN HUMAN ERROR FAULT TREE AND PERCENTAGES OF MAJOR CAUSE/FACTOR OCCURRENCES

of Equipment. This indicates that 23 percent of the cause citations in the human error tree are coming from this causal area. Together, the seven major causes located in the tree represent 80 percent of the total citations of the seven-year general aviation history. It is important to note that these disparities do not establish that a given program (or cluster of programs) is ineffective in preventing accidents. This fact cannot be determined on a purely empirical basis. It does indicate from the analysis, however, that these programs do not appear properly aligned to prevent a sizeable number of errors from occurring in the system. Further, it also indicates a considerable gap in the understanding of what the real problems may be in aircraft accidents. One definite finding confirmed by this fault tree analysis technique is that the control of human error is the major problem facing the FAA safety system.

The complete evaluation of the FAA's safety programs with respect to the causes of aircraft accidents requires a second method of examining safety program effectiveness. Because a safety program is a conceptual response to an accident event, it was believed that the approach used in addressing causes was important. Thus, the safety programs evaluated in this study are examined not only with respect to their objectives (utilizing the fault tree), but also with respect to their approach to the safety problem. An easily identifiable link should exist if the program is well conceived and the accident cause equally well defined. These two methods of investigation provide a means for measuring the safety system's responsiveness to hazards and for evaluating whether the programs work in a coordinated, and comprehensive manner. There are basically four approaches identified in the list of FAA safety programs examined in this study. They are:

a. Programs that are directed at assisting the system operators (pilots, air controllers, etc.) in the performance of their work. These programs might have the dual purpose of increasing system capacity while enhancing safety (e.g., ILS, VASI, DME, ARTS III, etc.)

b. Programs which form an active monitoring system of the aviation industry's equipment, manufacturing, maintenance, and operational procedures (e.g., SWAP, MAC, QASAR, etc.). Placed within this group are other operational monitoring systems such as conflict prediction, MSAW, detection/tracking of hazardous weather and the tracking of non-beacon-equipped aircraft.

c. Programs which are remedial in nature and are designed to counter new or increasingly troublesome safety threats in the system (e.g., wind shear detection, crashworthiness, hazardous material handling, frangible approach light systems, etc.)

d. Regulations, procedures, education and enforcement programs directed at maintaining an overall minimum safety level in the aviation system (e.g., FAR's, safety seminars, spot checks cabin safety, etc.).

The purpose of examining safety program approaches is to be able to determine if any relationships exist between programs with either similar or different objectives. For example, do some programs appear to interact more effectively in preventing certain types of accidents? Does a program involving regulatory enforcement (approach number 4) have an equal effect in all areas of the general aviation population or is it dependent on other programs for support in accident prevention?

An example of the above stated relationship of safety program interaction is provided in a comparison of the general aviation segments Air Taxi and Corporate. In general, the pilot qualifications and experience levels are very similar in these two segments. The operational situations are essentially the same, providing passenger service (with Air Taxi also providing some cargo service). Both segments display a relatively high degree of participation in the National Aviation System. Two major differences are the direct regulation of the Air Taxi industry by FAA (FAR Part 135) and a much lower insurance rate for the Corporate operator. A comparison of the two segments accident rates is shown in Table 4-1. In the first grouping (all single-, multi-, turboprop- and turbojet-engine airplanes), it can be seen that the air taxi segment has twice the accident rate of the Corporate segment (1083 accidents versus 659 accidents over seven years). When these segments are separated into piston- and turbine-engine groupings it can be seen that the Air Taxi, Turboprop and Turbojet group still has twice the accident rate of the identifical corporate group. In the piston-engine groupings, corporate flying shows a one-and-one-half times better accident rate than the Air Taxi piston-engine aircraft. It is important to note that the dominant accident

TABLE 4-1. ACCIDENT RATE COMPARISON FOR THE CORPORATE AND AIR TAXI SEGMENTS

Segment (Aircraft Types)	Accident Rate (1000's Flight Hours)	Dominant Accident Type(s)	Dominant Cause/Factor(s)
Air Taxi (SEP + MEP + T/P + T/J)	.06	U, N	64*3Z, 64*2Z
Corporate (SEP + MEP + T/P + T/J)	.03	U	64*3Z
Air Taxi (T/P + T/J)	.02	MØ	64*3Z
Corporate (T/P + T/J)	.01	N	64*3Z
Air Taxi (SEP + MEP)	.07	U, N	64*3Z, 64*2Z
Corporate	.05	U	64*3Z

types are almost identical in all groupings (U = engine failure, N = collision with object, MØ= collision with ground-controlled). Further, the dominant cause/factor in all groupings is 64*3Z (Failure to Perform According to Procedures, Regulations, etc.). Thus, these accident-rate differences are not the direct product of different types of accident causes, but appear to be related to some other factors within the specific segments. There are many possibilities as to the nature of these variables, such as safety attitudes of the operators, more strict insurance coverage requirements, etc. Unfortunately, the current data do not permit a more refined definition of them. This exercise does, however, portray the possibility that safety program reactions vary from segment-to-segment and within a segment. Further, that safety program effectiveness may be dependent on an effective interaction with other safety approaches.

Table 4-2 summarizes those safety program approaches relating to the human error cause/factors found in the accident records. Table 4-2 also contains a summary of the direct and indirect alignments that these safety programs formed with the same cause factors. The general accident cause descriptions (left hand column of the table) relate to that portion of the respective fault tree (human error in this case) with which these programs are associated. These latter data are included only for references purposes. The safety approach that dominates the human error safety programs is the "operator assistance" type. Operator-assistance type programs represent 50 percent of the programs in the human error cause category, with safety standards (approach number 4) providing 30 percent of the approaches. Generally, operator assistance type programs are predominant in the human error category for two reasons. First, the most readily observable problem in an accident is an apparent pilot skill or technique error (non-behavioral human failure). For example, many approach accidents involving undershoots and overshoots of an airport runway have been attributed to the pilot's inability to maintain a proper approach angle. So as a corrective safety reaction to the problem, several systems (e.g., VASI or ILS) have been devised to assist the pilot in the performance of the approach. The second reason for the high number of operator assistance programs has been the ability to predict and describe many of the safety problems without depending on the accident data. For example,

TABLE 4-2. SAFETY PROGRAM EVALUATION SUMMARY: HUMAN FACTOR ACCIDENT CAUSES

Accident Cause	Safety Programs		Cause/Factor Alignment	
Description	Code	Approach	Direct	Indirect
Human Cause	101	Operator Assistance	--	64*2Z, 64*3Z, 64*6Z
	104	"	--	64*4Z, 64*5Z
	106	"	--	64*4Z, 64*6Z
	107	"	--	64*4Z, 64*6Z
	108	"	--	64*4Z, 64*6Z
	109	"	--	64*4Z, 64*6Z
	111	"	--	64*4Z, 64*6Z
	218	Remedial	--	64*4Z, 64*6Z
	221	Safety Standards	--	64*2Z, 64*3Z, 64*4Z
	302	"	--	64*1Z, 64*2Z, 64*3Z
	412	"	--	64*1Z, 64*2Z, 64*3Z
	413	"	--	68*3Z, 68*00
	414	"	--	68*00, 68*3Z
Physical Incapacitation	415	Safety Standards	64*7Z	--
Cognition Error	206	Monitoring	--	64*5Z, 64*6Z, 84*7
	223	Remedial	--	64*6Z
Execution Error	214	Operator Assistance	--	64*4Z
	220	"	--	64*4Z
	504	"	--	64*4Z
Stress	224	Remedial	--	68*00, 68*3Z

* See Tables 2-16 to 2-21 for Code Identifications

there is the capability to clinically research an approach problem in a simulator, test the results in the real environment and then develop a mechanical system to perform the approach (e.g., ILS system). Such a system certainly has a beneficial safety effect overall. Rather than try to determine the human error problem involved, this approach simply removes the human element from the operation. The biggest problem associated with the second approach, however, is that the problem being dealt with may not be the real cause of the accident.

Overall, the alignments of the human error safety program objectives and approaches are directed at dealing with the readily observable factors (sometimes labeled as symptoms) of human error. The lack of accurate accident data concerning human error is causing a dependency on providing safety with hardware substitutions for human control. There is no question that these programs are making safety contributions. These contributions will continue to be limited, however, until more data are developed to understand the full extent of human error involvement in accidents.

Mechanical Safety Programs

The array of safety programs aligned against the mechanical causes of accidents is doing a more than adequate job of preventing solely mechanical accidents. The safety programs associated with this area are coordinated, interwoven and have an excellent data feedback loop which keeps the various programs atuned to the safety hazards. This determination of mechanical safety program effectiveness is amplified by the fact that the general aviation industry has the widest possible range of aircraft types, operational uses and maintenance practices. As a result of this effectiveness, the involvement of mechanical failures in aircraft accidents is limited to 12 percent of the total cause citations. Additionally, the 12 percent of mechanical citations are inflated by virtue of a significant involvement of human/ mechanical error relationships. The real nature of these relationships cannot be completely understood with current data, but some indication of their impacts are discussed in the following sections.

Figure 4-2 displays the placement of the safety programs related to the prevention of mechanically caused accidents in the fault tree. One characteristic which distinguishes these safety program placements from the other two fault trees (human and environmental) is the dispersion of programs throughout the upper level of the tree. This high level placement and dispersion reflect safety programs with broader safety objectives (usually covering multiple safety hazards) than those encountered in the other fault trees. This dispersion is believed to be characteristic of a safety program system in which a high degree of safety-objectives coordination has been achieved.

The mechanical error fault tree also contains the six major mechanical cause/factors that appeared in one of the top ten segment lists during the analysis. These six cause/factors combine to contribute over seven percent of the error citations to the study. The remaining five percent of the mechanical citations are distributed over 22 other cause/factors which were considered statistically random and not usable in the analysis. The top six are displayed at the highest level of the mechanical error fault tree because no direct link between the error labels and the lower levels of the tree could be identified. Thus, they are considered to be failures generally attributed to the system.

Table 4-3 is a summary of the safety program and cause/factor alignments found in the mechanical error analysis process. The Table also displays the summary of safety program approaches to the cause/factors found in the accident records. The alignment of mechanical programs with the cited cause/factors are entirely indirect except for the direct alignment of safety program 411 (FAR Part 43-Maintenance, Preventive Maintenance, Rebuilding and Alterations) with cause/factor 68*3Z (Other Personnel--Procedures, Regulations, etc...) which deals with several specifics in this safety area. The alignment results of the mechanical programs are similar to the human error summary (Table 4-2) in their indirectness, but for an entirely different reason. The human error programs are generally indirect in alignment because they only deal with part of the hazard identified in an error path. Mechanical programs are indirectly aligned because they deal not only with an entire safety hazard but usually two or more hazards under the same objectives. This alignment finding is reflected in the approach summary which is dominated almost completely by safety standards (32 percent of the programs) with only a

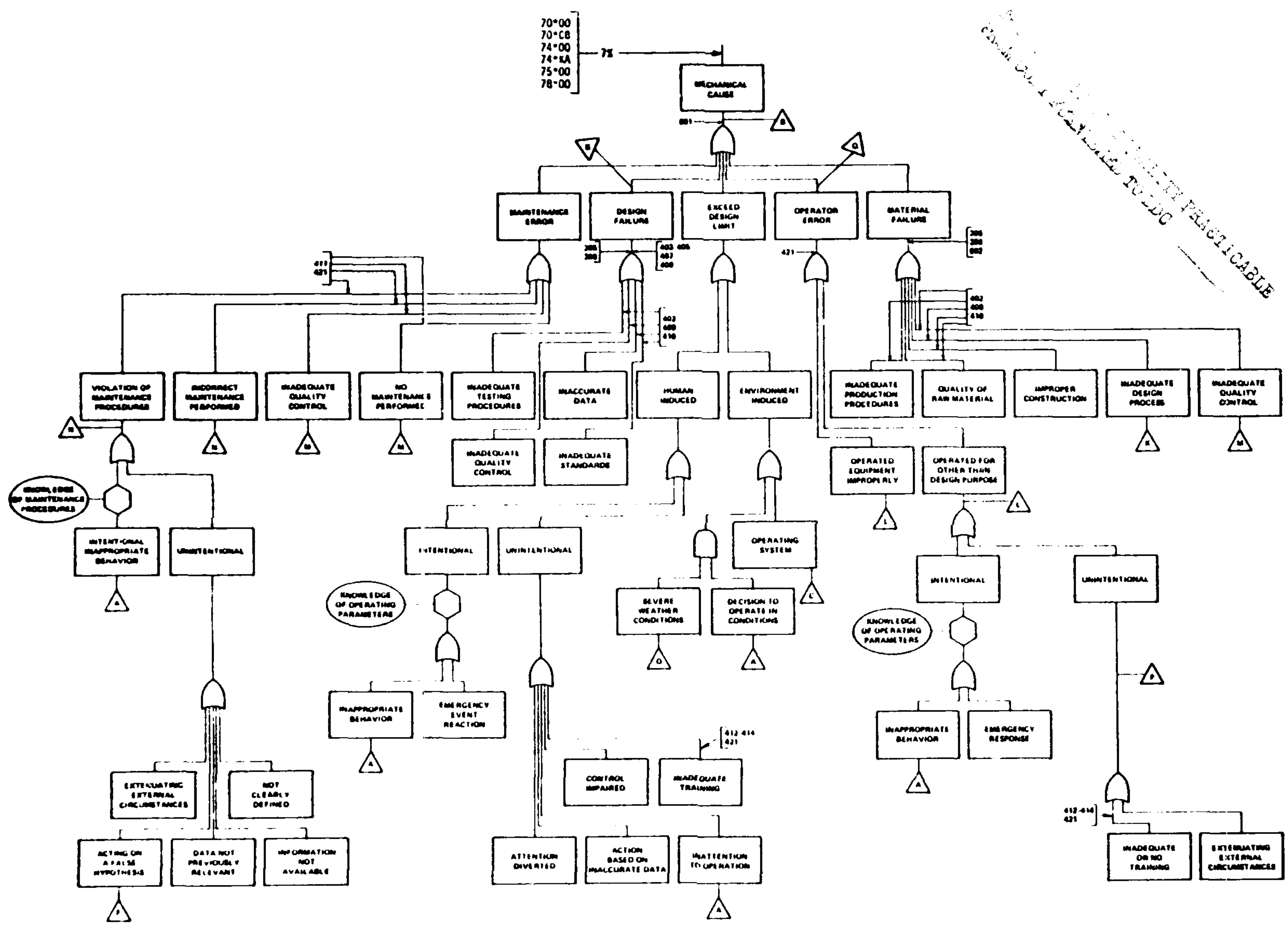

FIGURE 4-2. PLACEMENT OF SAFETY PROGRAMS IN MECHANICAL ERROR FAULT TREE AND PERCENTAGES OF MAJOR CAUSE/FACTOR OCCURRENCES

TABLE 4-3. SAFETY PROGRAM EVALUATION SUMMARY: MECHANICAL ACCIDENT CAUSES

Accident Cause Description	Safety Programs Code	Safety Programs Approach	Cause/Factor Alignment Direct	Cause/Factor Alignment Indirect
Mechanical Cause	601	Safety Standards	--	68*3Z
Maintenance Error	411	Safety Standards	68*3Z	70*00, 74*00, 75*00, 76*00, 78*00
	421	"	--	68*3Z
Design Failure	305	Monitoring	--	68*3Z, 70*00, 70*CA, CB, CC, CE, CF, CJ, CM
	308	"	--	68*3Z, 70*00, 74*00, 75*00, 76*00, 78*00
	402	Safety Standards	--	74*00, 75*00, 76*00, 78*00,
	403	"	--	70*00, 70*CA, CB, CC, CE, CF, CJ, CH
	405	"	--	78*00
	407	"	--	74*00, AB, AC, AD, AE, AF, AY, BA, BC, CB, CG, CH, CJ, DB, IO, KA
	408	"	--	74*00, 74*FA
	409	"	--	70*00, 74*00, 75*00, 76*00, 78*00
	410	"	--	70*00, 74*00, 75*00, 76*00, 78*00
Inadequate Training	412	Safety Standards	--	64*1Z, 64*2Z, 64*3Z
	413	"	--	68*00, 68*3Z
	421	"	--	68*3Z
Operator Error	421	Safety Standards	(See program code 421 above)	
Material Failure	305	Monitoring	(See program code 305 above)	
	308	"	(See program code 308 above)	
	402	Safety Standards	(See program code 402 above)	
	409	"	(See program code 409 above)	
	410	"	(See program code 410 above)	
	602	"	--	68*3Z

... 1/ through 2-22 for Identifications.

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EVALUATION OF SAFETY PROGRAMS WITH RESPECT TO THE CAUSES OF GEN--ETC(U)
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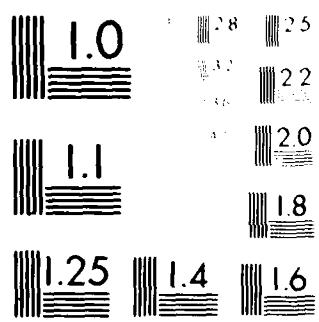
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2.0
1.8
1.25
1.4
1.6

few monitoring programs (18 percent of the total). The "standard" type safety programs tend to cover multiple safety hazards while utilizing the data feedback from the system to constantly re-evaluate their effect. Thus, their approach can be effective without being specifically aligned against a given hazard.

The overall success of the mechanical safety programs can be attributed to two major factors. The first is the nature of mechanical failures. A specific mechanical problem can be determined with or without the physical evidence of an accident. The mechanical limitations of a wing for example can be predicted, described and actions to prevent a failure taken. The second factor is the ability to confirm the safety approach taken for accident prevention. For example, if a wing of a given airplane is built to withstand a specific gravity force in turns, it can be tested in any number of ways prior to production to ensure its safety. Even after release for production, any problems with that wing are transmitted back through the system to be reevaluated as to their origin. If changes in the safety approach are warranted, they can be made, tested and retested as necessary. All of this close interaction makes for a safety system that is responsive and comprehensive in nature.

These findings of mechanical safety program adequacy, however, do not preclude room for improvement. There is a definite stagnation in the rate of decrease of mechanical cause occurrences in every segment of general aviation except corporate flying. As shown in Table 4-4 the trends of several sample mechanical causes have shown no real improvement over the seven-year period and in a number of cases they show increasing frequency. The cause of this apparent stagnation is difficult to identify. Essentially, although some mechanical areas show improvements, no overall trend can be linked with any changes in mechanically oriented safety programs.

A possible explanation for this absence of change in the overall mechanical cause area is the unresolved association of human error in mechanical accidents. The relationship of human and mechanical causes could not be fully explored with the current accident records because no hierarchical structure exists in the cause/factor framework. Such a hierarchy, which identified primary and secondary causes, might have provided data which distinguished

TABLE 4-4. TYPICAL TRENDS OF MECHANICAL CAUSES BY SAMPLE SUBPOPULATION
(cause occurrence rate per total segment accidents)

BUSINESS (SEP and MEP)

	1971	1972	1973	1974	1975	1976	1977
70*00	.018	.026	.003	.010	.018	.006	.003
70*CB	.016	.026	.023	.007	.013	.008	.013
74*00	.035	.031	.018	.036	.041	.030	.031
75*00	.014	.009	.023	.012	.015	.014	.005

PERSONAL (SEP and MEP)

	1971	1972	1973	1974	1975	1976	1977
70*00	.014	.012	.014	.013	.016	.016	.009
70*CB	.008	.008	.008	.009	.005	.008	.005
74*00	.015	.015	.018	.028	.024	.026	.025
75*00	.007	.006	.007	.011	.007	.010	.013

CORPORATE (T/P and T/J)

	1971	1972	1973	1974	1975	1976	1977
70*00	.053	--	.040	--	--	.125	--
70*CB	.105	.083	.040	--	--	.125	--
74*00	--	.083	.120	.048	.048	--	.050
75*00	.105	.013	.040	.048	--	--	.050

AIR TAXI (SEP, MEP, T/P and T/J)

	1971	1972	1973	1974	1975	1976	1977
70*00	.030	.034	.020	.006	.025	.037	.027
70*CB	.037	.025	.027	.036	.037	.012	.032
74*00	.037	.034	.020	.030	.049	.049	.064
75*00	.015	.025	.034	.030	.019	.018	.016

between a solely mechanical failure and a mechanical failure induced by human error.

One such unresolved relationship that is encountered in the accident records is the citation of 74*KA (Powerplant Failure--Undetermined Reason). This is technically designated a mechanical problem associated with powerplant operation. This cause represents the highest rate of mechanical citation in six of the eight segments and has the eighth highest citation rate of any cause/factors in the accident record. A correlation of this cause with the other top ten cited causes was performed on a segment-by-segment basis. This correlation established that, depending on the general aviation segment, 74*KA is cited between 32 and 62 percent of the time with human error citations. The human error causes that are most prominently associated with 74*KA are 64*3Z (Procedures, Regulations, etc...) and 64*6Z (Perception Failure). The high rate of citation for this cause/factor was discussed with a number of NTSB and FAA accident investigators to determine the basis for assignment of this cause. Basically, there are two reasons for its use in the records:

a. The physical evidence to establish the cause of the failure was either not available or destroyed in the accident

b. Insufficient investigatory resources did not permit a detailed engine testing or rebuilding analysis after the crash.

Additional comments about these two factors that were made by the investigators are that:

a. In the majority of the cases, human error is the suspected cause of the failure but that lack of physical data prevents a proper assignment of cause

b. The above statement could be verified if more time and resources could be invested in an investigation

c. In a significant number of cases the physical evidence at the scene of a general aviation accident is contaminated (altered) either intentionally or unintentionally, which hampers or prevents further investigation.

An indirect substantiation of these statements is found in the segment Corporate, Turboprop and Turbojet. In this segment, 13 percent of the accidents were due to engine failures or malfunctions. Yet, 74*KA was never cited as a cause in this segment. This contrasts with the segment Personal, Single-and Multi-Engine Piston where 23 percent of the accidents were due to engine failures or malfunctions and 74*KA was cited as the cause 20 percent of the time. To account for this difference, it was found that accidents in the Corporate segment (especially ones involving fatalities) received an investigative effort comparable to the level-of-effort associated with air carrier accidents. The intensive investigation by government personnel is matched by an equally intensive investigatory effort by the aircraft and engine manufacturers. A motivating force behind this additional private investigatory effort is generally attributed by experts to the assignment of accident responsibility and liability.

The ramifications of these essentially unknown human and mechanical error relationships on the FAA safety program efforts are twofold. First, they tend to mislead safety planners into efforts directed at technically mechanical, but essentially human problems. This results in programs dealing with observable symptoms, not causes. Secondly, these citations make the mechanical safety problems appear to be worse than they are in relation to the rest of the accident records. This has a negative impact to the extent that it causes a disproportionate share of the safety effort to be spent in the wrong problem area. If the cause/factor 74*KA is removed from the mechanical-error category the total number of accident citations due to mechanical failures is reduced almost in half.

Environmental Safety Programs

The environmental related safety programs represent two separate areas. The first area is the subsystem of programs associated with strictly meteorological conditions. The second subsystem area consists of those programs relating to the operational system comprised of humans, machines and procedures. The division of the environmental related safety programs into these two areas is a direct response to the accident data available for the analysis. Under a stricter interpretation of the term "system", all errors could be classified as system errors in the sense that they are occurring within a defined, finite operating system. However, because the accident investigation data are not necessarily organized in this manner, some dividing line is necessary to examine safety program effectiveness. For example, the examination of human error takes place in two parts of the fault tree; first, in its own major category (Human Error), and then again in the operating system under operator/user error. The errors are the same, but the investigative detail does not permit an in-depth examination of either the category human error or the interactions of human error in the operating system. So, to the extent that the errors can be distinguished (as a system type error) the safety programs related to them have been divided accordingly. The findings regarding the safety programs associated with these two major areas of the environmental cause tree are presented next under their respective headings, Meteorological Programs, and Operating System Programs.

Meteorological Programs. Table 4-5 illustrates the extent to which weather-related cause/factors were cited in general aviation accidents. It is observed that all weather cause/factor citations combined only account for three percent of the total causes cited in the seven-year accident history. Furthermore, a review of Tables 3-13 through 3-20 shows that weather was

TABLE 4-5. THE CITATION FREQEUNCY FOR WEATHER-RELATED CAUSE/FACTORS

	Cause/Factor	Number of Times Cited	
		As a Cause	As a Factor
82*H	Unfavorable Winds	594	1,691
82*00	Weather-Random Occurrences	389	5,435
82*M	Downdrafts/Updrafts	138	396
82*G	Weather-Carburetor Icing	114	356
82*J	Sudden Windshift	78	112
	Subtotal - Weather C/F's	1,313 (2.7%)	7,990 (48.2%)
	Total - All C/F's	48,783 (100%)	6,583 (100%)

not viewed as a major cause of accidents in any single general aviation segment. Thus, weather does not appear to be a major cause of general aviation accidents. By contrast, weather-related cause/factors were cited with great regularity as a factor in general aviation accidents--they accounted for 48 percent of all such citations. This is especially true for cause/factor 82*00. One possible explanation for this higher rate is the inability to determine exactly what part weather plays in an accident. That is to say that investigators may, with great regularity, suspect weather to be a cause but are unable to support such suspicions. It can be conjectured that they then resort to citing it as a factor. While this thesis cannot be proved, this area of contrasts seems worthy of further examination.

There are indications in the records that the problems associated with weather are not really meteorological ones. In the cases where the weather cause/factors are cited in a segment, they show a high degree of common accident citation (some over 50 percent of the citations) with the cause/factors 64*1Z (Judgement Error) and 64*2Z (Operational Decision Error). There is not enough investigative evidence, however, to establish stronger links between these statistical associations. These tentative findings indicate that the possible problem in this area is the observed lack of effectiveness on the part of general aviation pilots to gather, interpret and make decisions about the weather conditions. These findings also indicate that a far more complex relationship exists between the pilot's decision to fly and the weather he encounters than is currently being investigated.

In general, the current weather related programs appear to be providing an adequate level of program effectiveness. As was stated earlier, only three percent of the total accident causes were weather related. Figure 4-3 shows the distribution of FAA weather-related programs. The few programs listed here are, of course, supported by a vast weather gathering system operated by the National Oceanographic and Atmospheric Administration (NOAA). Together, these systems provide excellent coverage of the weather in the national aviation system. One new way weather programs could benefit is for there to exist a clearer understanding of the type of weather data general aviation pilots need, how they utilize it, and why. This includes not only the regulatory uses (like planning for an alternate airport) but pilot's perceptions of the system and how it effects their flying. As is noted in the fault tree (the circular symbol in the meteorological cause path), it is the decision to operate that ultimately brings the pilot in contact with weather. The more information that can be gathered regarding that decision, the more responsive the system can be to the needs.

Operating System Programs. The "operational system" as it is referred to in this study is comprised of the operator/user, the machines used, the physical plant, and the regulations and procedures that govern and influence the interactions of the first three elements. Figure 4-3 displays the distribution of safety programs associated with the operating system. The safety programs are clustered at relatively high levels in the tree and, at the same time, appear to cover most of the possible errors. These combined cause/factors represent only three percent of the total study citations. The cause/factor 68*3Z (Other Personnel--Performance, Regulations, etc.) is shown separately in the tree for reference only. Its effects are discussed earlier in the report under human error findings.

There are two factors believed responsible for the clustering effect and low citation rate found in the operating system. These are:

a. Accident causes are not clearly defined. They consist of action descriptors and the identification of conditions (present or absent) at the time of the accident. Also, these causes represent errors that relate to the other two branches of the fault tree (Human and Mechanical errors).

b. The interrelationships of the four elements of the operating system (operator/user, machine, physical plant and regulations/procedures) are unknown. In addition, the current accident investigations are not directed at discovering if such a relationship exists in an accident.

As a result of these two deficiencies in the accident information gathering process, no positive evaluations of operational safety program effectiveness can be made. This means that while the programs found in the operating system are probably contributing to system safety, no empirical data exist to determine if they are effective. Further, this lack of information appears to have

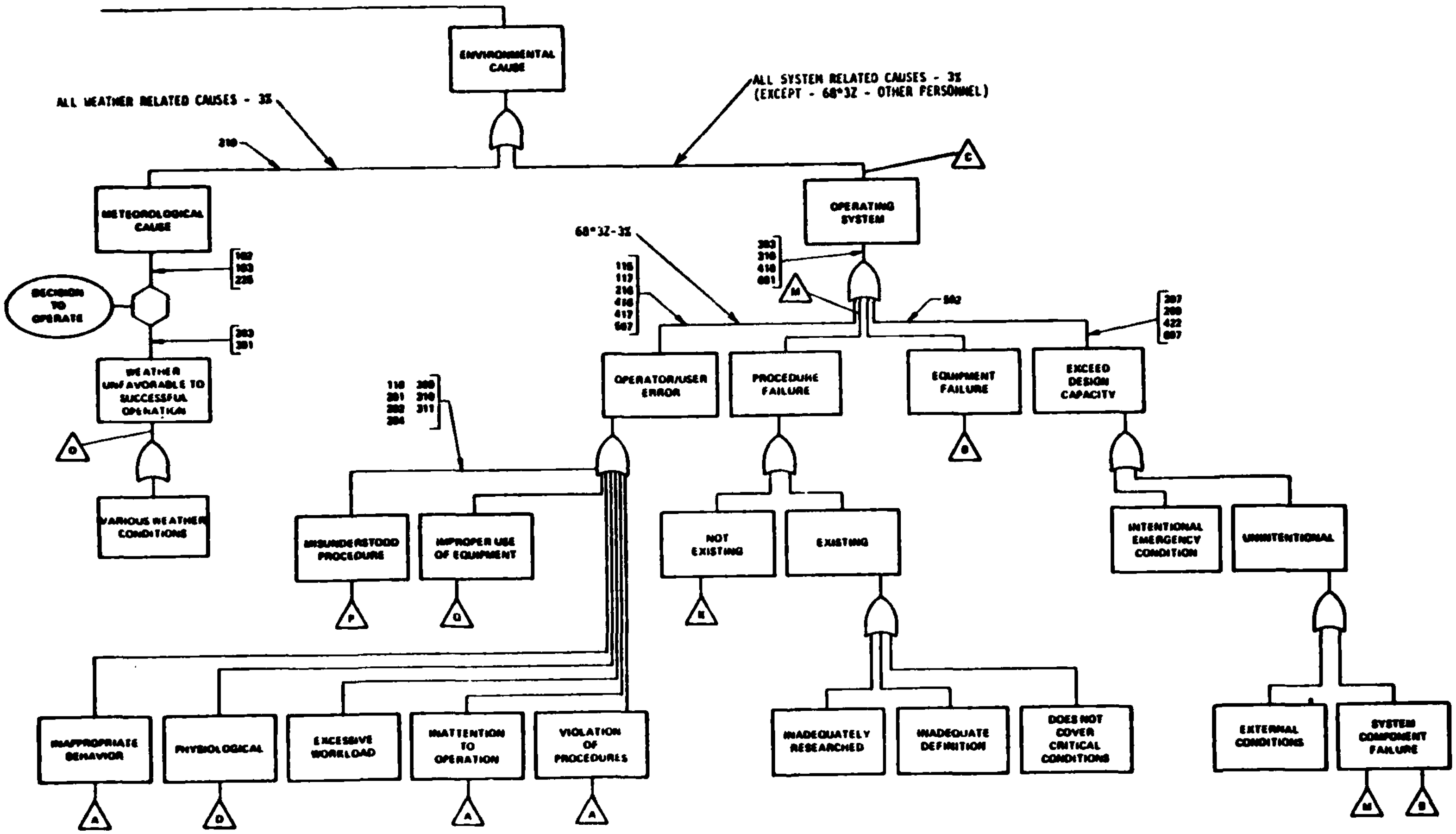

FIGURE 4-3. PLACEMENT OF SAFETY PROGRAMS IN ENVIRONMENTAL ERROR FAULT TREE

resulted in safety program concentrations in those safety hazard areas most easily detected without accident data. An example of this concentration is the cluster located on the error path, Operator/User Error, Misunderstood Procedure. The programs dealing with this problem area resemble the clusters in the human error tree in that the programs attempt to provide a substitute for human control when a human error problem is encountered. This dependency on substitution causes the cluster effect because the objectives become very similar in nature. Information for examining and predicting the long term effect of these substitutions on the system is needed to ensure that system safety problems are not being confused as human error problems.

The safety program approaches shown in Table 4-6 generally reflect the fault tree patterns of safety-program, cause/factor interactions. The predominant approaches are "system monitoring" and "safety standards". Together they represent over 80 percent of the environmental safety program approaches (23 out of 28). Programs with a system monitoring approach provide the checks in a sophisticated operating system against inadvertent human error. These monitoring programs are similar in nature to the operator assistance programs in that they sometimes provide for a substitute for the operator of the system. These programs are also (as are operational assistance types) not dependent on accident data for their development. Many times a monitoring system is the result of a prudent preventive measure necessary to compensate for a known human inability to keep pace with the workload. So, although the accident data do not necessarily support the use of such programs in all cases, that does not mean they are not necessary. Perhaps the problem of real concern is the automatic substitution or introduction of hardware without a full understanding of the problem. As stated earlier in the human error findings, care must be taken not to compound the problem while attempting to deal with the safety hazard.

The NTSB Accident Records

A significant portion of the analysis effort in this study utilizes the accident investigations and accident records maintained by the National Transportation Safety Board (NTSB). The usage of this information in this

TABLE 4-6. SAFETY PROGRAM EVALUATION SUMMARY: ENVIRONMENTAL ACCIDENT CAUSES

Accident Cause	Safety Programs		Cause/Factor Alignment	
Description	Code	Approach	Direct	Indirect
Meteorological Cause	102	Operator Assistance	--	68*00, 68*3Z, 82*00, 82*H, 82*J, 82*M, 82*G
	103	"	--	68*3Z, 82*00, 82*H, 82*J, 82*M, 82*G
	203	Monitoring	--	82*00, 82*H, 82*J, 82*M, 82*G
	219	"	--	82*00, 82*H, 82*J, 82*M, 82*G
	225	"	--	82*00, 82*H, 82*J, 82*M, 82*G
	301	"	--	82*00, 82*H, 82*J, 82*M, 82*G
Operating Systems	115	Safety Standards	--	80*00
	117	Remedial	--	80*00
	303	Safety Standards	--	84*3
	310	Monitoring	--	68*3Z, 80*00, 80*BY
	502	"	--	80*00
	601	Safety Standards	--	68*3Z
Operator/User Error	216	"	84*1	--
	416	"	--	84*8
	417	"	--	68*3Z, 68*00
	418	"	--	84*3
	507	"	--	68*00, 68*3Z
Misunderstood Procedure	118	Monitoring	--	68*3Z, 68*00
	201	"	--	84*7
	202	"	--	64*5Z, 64*6Z, 84*7
	204	"	--	68*3Z, 68*00
	309	"	--	68*3Z, 68*00
	311	"	--	68*3Z, 68*00
Exceed Design Capacity	207	Remedial	--	82*00
	209	"	--	80*00, 80*BC, 80*BD, 80*BY
	422	Safety Standards	--	68*3Z, 80*00, 80*BJ, 80*BY, 84*00
	607	"	--	68*3Z

*See Tables 2-17 through 2-22 for Identifications.

study required several modifications to be made to some data fields. In addition, during the investigation of these records, several additional analysis problems were discovered with the data. These problems limit the strength of the findings presented in this report. Thus, a summary of these problems is presented in this section to provide a proper perspective for the statements of findings.

The first important note is in regard to the NTSB'S computer file of accident records. The computer file was not designed as an analysis program per se, but as an information storage system. Although this system serves a function not entirely incompatible with an analysis effort, it is nevertheless incomplete for a study of this nature. Thus, several modifications were made to the data to make them more compatible with the analysis methodology (as described earlier in Chapter 2). The assumptions behind these alterations should be considered when reviewing these safety program evaluations.

The second important note associated with these safety program evaluations was the discovery of significant variations in the quantity and quality of the accident data from record to record. Specifically, the review of the original accident records reveals three problems associated with the accident investigations and records. These problems are:

a. That the resources directed at investigating the accidents of the various segments of the general aviation population vary significantly from group to group

b. That the quantity and quality of information about an accident event coincides with the above cited level of resource expenditures

c. That many pro forma citations of accident cause present a distorted view of the overall general aviation accident record.

Generally, the first two problems are understandable given the sheer magnitude of resources which would be required to provide a complete investigation for all 30,592 accidents in the study period. Indeed, not every accident requires the same level of investigation. The problems of the investigation themselves, however, are actually only the symptoms of a far larger question which must be addressed. This question concerns the serious lack of useful information relating to aviation accidents. Much of the accident information that is gathered today is collected for regulatory reasons.

Although this is of some value for safety analysis purposes, it falls short of providing a comprehensive view of specific safety hazards. Probably the best example of this problem is the investigation of a general aviation accident by the FAA. Under an interagency agreement between the NTSB and the FAA, the authority to investigate certain accidents is delegated to the FAA. Generally, these accidents are divided between the two agencies under the following categories:

FAA	NTSB
Aerial Application - Fatal	All Air Carrier
Home Built - Fatal	Air Commuter/Air Taxi
Restricted - Fatal	All Large Aircraft (over 12,500 lb)
Rotorcraft - Non-Fatal	Rotorcraft - Fatal
Airplane - Non-Fatal	Airplane - Fatal

This delegation of authority shifts the burden of investigation, but not the final assignment of cause, to the FAA. Assignment of cause is still decided by the NTSB based on the reported data. Thus, the accident data is sometimes filtered or handled by three parties (an FAA investigator, an NTSB investigator, and the NTSB personnel responsible for selecting the final statement of cause) before the assignment of cause is made in an accident. In addition to the investigation that is performed, the FAA is required by law to further identify if any of the following four items were involved in any accident.

a. Did the accident involve the aircraft's airworthiness certificate?

b. Did the accident involve the airman's certification?

c. Was an air-navigation aid involved?

d. Was there a violation of Federal Air Regulations?

What appears to be occurring in many of the investigations, due to the significant constraints on investigative resources, is that the discovery of accident cause is subordinate to answering these four questions. This leaves little, if any, of the resources for a more thorough investigation and often results in a superficial finding of accident cause. This problem is not necessarily related to the "fender bender" types of minor accidents where in-depth investigation might not be necessary. This investigative-resource problem ranges over the entire accident record including the investigation of fatal crashes.

The final problem associated with these accident records is the pro forma citation of an accident cause with respect to specific technical events in an accident. During the analysis of the original accident records, it was discovered that certain accident causes were always cited with specific accident types. Some, as in the case of "bird strike" discussed earlier in this Chapter, were obvious. Others were based on information requirements such as coding a mechanical cause whenever citing a mechanical accident type. One, however, that caused particular concern was the use of the "pilot error" code in accidents where the airplane was thought to have stalled or crashed in a spin. In strict technical terms, an airplane that is not "flying" at the time of crash simply means that it stalled sometime prior to the crash. While acknowledging that this statement is factual, it offers no grounds whatsoever to unilaterally assign the cause for the stall/spin to the pilot. Indeed, due to the lack of investigative detail in many of the accidents, it would be more appropriate to cite "stall/spin-unknown reason". There are also possible safety hazard distortions associated with these citations. Code 64*16 had the highest number of citations of the original individual 797 causes in the NTSB listing. This could lead to the false impression that stalls and spins due to the pilot's lack of control over the airplane is the number one safety problem in general aviation. The real problems, as indicated by this type of accident, are essentially unknown because no data exist to determine what additional conditions, if any, are involved with the occurrences.

Together, the two major points discussed in this section require that caution be exercised in the use of the accident records to support generalized statements about safety-program effectiveness. As stated previously, even with the numerous analytical changes made to minimize the impact of these problems, the accident data must be used carefully.

FAA General Aviation Data

There are four general sources of data available for use in system safety analysis. They are:

a. The data generated by clinical and theoretical research

b. The information derived from regulatory reporting requirements (sometimes safety specific)

c. The data feedback from the system (incident reports, etc...)

d. The accident investigations and reports.

A well-planned system safety program needs and utilizes all such sources to support the analysis of safety problems and the allocation of safety resources. A major problem which appears to be affecting the progress of the FAA system safety program is the lack of an adequate program to collect and retain the safety-related data generated by these four sources. This problem has been encountered and discussed throughout the term of this study. Most of the shortcomings are a result of three factors. They are:

a. The cost of collecting and maintaining the data is expensive, while the tangible benefits are difficult to portray

b. The data that are currently being collected have not been necessarily viewed or organized from a safety standpoint and thus not always usable for analysis purposes

c. The question of which data are necessary for safety analysis has never been completely answered.

These problems are not new to the FAA system safety program. This study has outlined several areas where the data deficiencies have contributed to misaligned safety programs (human error). In another area, it is the difficulties safety analysts have in determining the true dimension of a safety problem (as in the operating system error).

An example of one of these problems is best illustrated in the accident investigation and data collection system. The accident data system that has developed over the years has evolved mainly for the purpose of determining fault (which implies human fault) rather than of an accident cause. This investigatory direction has been largely influenced by the exogenous pressures of the legal system to assign either responsibility, negligence or culpability for an accident. Unquestionably, the intent of the investigation is to determine cause, but because the resources are not always provided to do so, the results are usually a finding of fault. There are two areas discussed in this study which underline this point. The first area is the pilot cause/factor listing; the second is the FAA accident investigation requirements. The "pilot error" cause/factors reflect a rather superficial understanding of human error. The labels used to describe pilot "cause" are directed at observed human failures with which blame or fault can be associated. These acknowledged limitations coupled with economic constraints on the FAA investigations have resulted in a paucity of valid general aviation accident data. In general, the determination of fault is not always compatible with an objective investigation which endeavors to answer why an accident occurred, not who is to blame.

Major improvements in the data gathering and analysis system (especially human factors) are necessary. The FAA needs to create more balance in and coordination among the four data sources (research regulatory, system feedback and accident investigations) to ensure new advancements in the safety system.

The Profile of a Successful Safety Program

The profile of a successful safety program was first developed in a companion to this report: "The Evaluation of Safety Programs with Respect to the Causes of Air Carrier Accidents". This profile included the following characteristics:

a. The program addresses a specific well-defined safety hazard.

b. The program explicitly treats all cause/factors (and their interrelationships) contained in the hazard definition.

c. Program interaction with complementary programs is explicitly coordinated in terms of approach prevention and alignment in its associated accident cause hierarchy.

d. The program receives timely data feedback from the incident/accident reporting system and uses these data to maximize its continuing effectiveness in terms of accident prevention.

These characteristics are present in varying combinations in virtually all successful safety programs. However, it has been established in this profile that it is the balance among the characteristics that makes the difference between successful and unsuccessful programs. An example of an ineffective program is Cockpit Human Factors Research (218). This program satisfies the first characteristic of a successful profile, but fails the remaining three. An example of a successful program is FAR Part 21, Certification Procedures--Products and Parts (402). This program has specific objectives, deals directly with an identifiable cause level, is in a complete and supportive safety group in terms of both objectives and approaches, and receives positive, direct data feedback on its effectiveness in mitigating accidents. The impact of this program (and its allied group) was found to be significant in preventing accidents (see Mechanical Safety Program Findings).

During the analysis of the general aviation data, additional examinations were made of this program profile. This was done to determine if other factors relating to program success could be discovered. Specifically, what has been found is that the successful programs rely heavily on being able to predict, describe and thus prevent the specific hazards with which they deal. The areas of greatest success appear to be concentrated where the most data (accident and non-accident related) are available. Mechanical safety programs provide an excellent example of the use of the prediction/description/prevention format. For instance, based on historical or theoretical data it can be predicted that a wing will separate from an airframe if its structural design limits are exceeded during operation. The structural strengths and limitations can be described in fairly precise engineering terms and, from these terms, numerous safety actions implemented to minimize the possibility of a failure. These safety actions could include higher structural design limits, standard maintenance practices, or any combination of the three. When these three factors (predictability, describability and preventability) are organized with a closed-loop data feedback system, an effective accident-prevention program can be established.

What is found in the accident records in terms of human error predictability is that only gross estimations can be made as to the types and possibilities of human error occurrence. This, in large part, is due to the lack of consistent, factual human error history from the aircraft accidents. This lack of historical data generally makes the task of describing human errors a speculative and theoretical exercise. This shortcoming in describing human error is most visible in the NTSB cause/factor listing for pilot error (see

Table 2-7) where descriptions of the pilot's actions or inactions are substitutes for the actual cause. Thus, given that the first two elements of a successful accident prevention system are weak, it can be expected that the human error program development, must be attacked largely through trial-and-error means.

General Conclusions

The Federal Aviation Administration has done a commendable job in organizing, coordinating and monitoring a vast array of safety programs. These programs have been successful in diminishing the accidents of a mechanical, weather and operating-system nature. The aviation industry (having solved most of the more straightforward problems) is now approaching a safety level where the control of human error is the major safety problem in the system.

All safety programs, under the broadest of interpretations, are related to the prevention of human error. This conclusion is a virtual truism; that is, the tracing of any accident through its various error paths to its root cause, ultimately encounters human error. Consequently, regardless of the level at which a safety program addresses a hazard, it is probably dealing with some partial effect of human error. The development and improvement of an effective safety program system, however, does not necessarily attempt to deal with human error at this basic level. In fact, knowledge that all system failures can be traced to human error in some form, is of no immediate value in preventing an error propagated at another level in the system. Further, the intricacies of human error relationships are such that the accurate description of these errors, given the current state of knowledge regarding human behavior, and thus their prevention, may never be completely successful. This does not mean that human error cannot be dealt with effectively. Rather, it is an acknowledgment that it may not be possible--non-practicable--to define these human errors in terms suitable for the formulation of safety programs to prevent them. Thus, safety is generally better enhanced by attempting to indirectly mitigate or create tolerances for human error than by trying to deal with them directly. While this safety approach for mitigating errors may have its success, it is limited. The current FAA safety system needs a better understanding of human error to ensure that such safety actions are not aggravating or complicating safety problems that are currently undiscovered in the system. This requires compilation of better human factors data.

The evolution of an effective safety program begins by dealing with the safety hazards that can be most readily predicted, described and prevented. As safety efforts expand, the accumulated data from the initial safety program successes (and failures) are used to refine and redirect its approaches and objectives. These improvements then provide a basis for dealing with problems not easily observed in the system, such as human error. Ultimately an effective safety program permits the truncation of a problem in the system at the lowest, most effective and efficient level possible.

The FAA mechanical safety program system, for the most part, embodies the characteristics outlined in the previous paragraph. The programs in effect today are the result of accumulated knowledge and its use to make improvements in the system. The evidence that mechanical programs have reached a high effectiveness is recorded in the low, total involvement of mechanical failures in accidents. It is also reflected in the relatively small number of mechanical safety programs that cover a vast range of problems in a very diverse aviation industry. Further, it is most important to recognize that these mechanical programs also deal effectively with human performance. This last conclusion supports the conclusion that human error can be mitigated and controlled by indirect safety measures.

In contrast to the success of mechanical programs, human error safety programs have failed to advance beyond solving readily observable problems. Generally, the failure to achieve further advances in this area is attributable to two problems. The first is the absence of data regarding the true proportions of human error in the system. This is the result of insufficient accident investigation. The second problem is an inability to predict under what circumstances a failure will occur. This second problem is partially a result of the first problem (lack of investigative detail), but is more directly related to the uncoordinated and inconsistent record keeping of even the most basic safety related general aviation details. As a result of these problems, the existing safety programs are not defined in terms of the human errors being encountered in the accidents. Thus, the majority of current human error safety programs appear to be having only scattered success at reducing the current accident rate.

There is an important question underlying the safety system's effectiveness which can only be obliquely addressed by the analysis of the safety programs themselves. This question is that of participation by the users of the system. Perhaps the most important characteristic distinguishing the general aviation subpopulations is the extent to which the individuals of the subpopulations participate in the safety system. This participation can take many forms in the system, from regulation of the subpopulations (e.g., FAR Part 135) to equipment requirements to utilize various parts of the national aviation system (e.g., ILS, Stage I radar service, etc.). The level of participation can be required or left to individual discretion. Sometimes the economics or technical sophistication of a system limits the various subpopulations' involvement. The level of a given subpopulation's participation is difficult to measure by any single factor or characteristic. The variables that govern system participation are numerous, they have complex relationships and their effect on the safety structure is relatively unknown. These variables, however, undoubtably have a direct impact on the level of safety afforded a subpopulation by the system.

The aircraft accident data, in conjunction with several other general aviation information sources, can provide an indication of system participation. Table 4-7 displays seven comparative characteristics which are used as subjective measures of system utilization. These characteristics and their sources are discussed earlier in this report. The first characteristic, FAA regulation, is cited as direct or indirect on the basis of the FAR'S controlling the individual subpopulations. For example, the subpopulation Air Taxi is controlled by FAR Part 135, while the subpopulation Personal is indirectly controlled by several FAR's. The next five characteristics (Insurance Coverage, ..., ..., ..., Number of Flight Plans Filed) are ranked by a simple high, medium and low scale. For example, a high rating in IFR Equipped Aircraft means that between 67 percent and 100 percent of the aircraft in this subpopulation are IFR equipped. A medium rating in insurance coverage requirements means that compared to the other seven subpopulations, the subject population

TABLE 4-7. COMPARATIVE CHARACTERISTICS OF SYSTEM PARTICIPATION OF THE GENERAL AVIATION SUBPOPULATIONS

Comparative Characteristics of System Participation	Subpopulations							
	BUS	CORP	PER	AA	INST	AT	CORPT	ROTOR
FAA Regulation	Indirect	Indirect	Indirect	Direct	Direct	Direct	Indirect	N/A*
Insurance Coverage Requirements	Low	High	Low	High	Low	High	High	High
Number of IFR Equipped Aircraft	Low	High	Medium	Low	Medium	High	High	Low
Number of ILS Equipped Aircraft	Medium	High	Low	Low	Low	High	High	Low
Number of Pilot IFR Rated	Medium	High	Low	Medium	Low	High	High	Low
Number of Flight Plans Filed	Low	Medium	Low	Low	Low	Medium	High	Low
Accident Rate (In 1,000 of Flight Hours)	.08	.05	.28	.22	.11	.06	.01	.21

* The category Rotor Includes Direct and Indirect Regulations because it covers all other user categories (Air Taxi, Corp, etc....)

has relatively stiffer requirements to meet for coverage than the low category. These requirements can be in the form of pilot hours, certificates of operation, maintenance practices or any of the other requirements sometimes imposed for insurance coverage. A low rating in a category like Flight Plans indicates that no greater than 33 percent of the aircraft were on flight plans (IFR or VFR) at the time of the accident. The last comparative characteristic, accident rate for the seven-year accident period, represents the "bottom line" for any safety system. This figure represents the systems effectiveness in preventing accidents.

These characteristics are qualitative, comparative measurements and are intended to provide only a general picture of subpopulation participation in the system. These characteristics, however, were selected not only for their commonality between subpopulations, but because they represent a level of participation based on the discretion of the individuals in each group. This means that the choice to participate (and to what degree) is made by the user of the system (the possible exception is the category FAA regulation where participation might be mandatory).

The results of this comparative examination indicate that the subpopulations that display low, overall association or participation in the system have correspondingly high accident rates. This is attributed to the fact that, even though the FAA promulgates many training and educational programs in addition to its regulatory safety programs, infrequent users of the NAS tend also to be infrequent participants in these programs. Thus, independent of improved safety performance directly attributable to pilot skills based on experience, greater attention is warranted in improving safety through incentives aimed at encouragement participation of infrequent users in the available training/educational programs. The relationship between low NAS participation and high accident rates is a especially prominent in the cases of the Personal, Aerial Application and Rotor Subpopulations. It is recognized that these subjective characteristics by no means explain either the extent of system participation by a subpopulation nor the differences in accident rates. They do, however, present a collective impression that system participation is a relevant issue in the determination of safety program effectiveness. Another important point to consider with these results is that these participation variables are conditions of human choice, so their outcome varies. In contrast, when safety programs requiring mandatory participation are examined (mainly mechanical programs) the safety effect is almost uniformly beneficial across subpopulations.

The determination of an individual's (or subpopulation's) participation with respect to evaluating safety program effectiveness is vital for two reasons. They are:

a. The safety programs may be well structured and address significant hazards, but the deciding factor in their safety effectiveness to the user is the desire, ability, constraints, or requirements of the individual to utilize the programs.

b. The above factor means that any improvements in the safety program that do not account for the exogenous variables affecting participation will not necessarily result in an increase in safety.

These two factors impose a significant burden on the safety system. In essence, this burden is deciding when the system needs to change to accommodate the user and when must the requirements for the user to participate in the system be increased. The elements that enter into those decisions are varied and complex and the data to explain their relationships, almost nonexistent. The discovery and development of these data, however, is a necessary component in understanding safety program effectiveness and the decision on how to transfer that effectiveness to the user.

RECOMMENDATIONS

The recommendations resulting from the analysis of the FAA safety programs involve three primary problem areas encountered in this study. The first problem area involves the quality and quantity of data being received from accident investigations. The second area concerns the absence of a coordinated program to collect and retain the necessary safety-related information regarding the general aviation population. The third area involves the extent to which the variables of system participation (economics, training, technology, and regulation) effect the safety benefits of a given general aviation subpopulation. There are four recommendations made to remedy these problems. They are:

a. The implementation of a new investigation strategy for aircraft accidents

b. The definition and development of the requirements for FAA safety related aviation data

c. The creation of a comprehensive, single-source data system to include;

- A standard lexicon
- Integration of all accident/incident data
- The multi-year retention of the data

d. The investigation of system participation.

New Investigation Strategies

There are two related changes recommended for the accident investigation strategies currently being employed by the FAA and NTSB for general aviation accidents. The first change is to expand the investigation emphasis from one which directs almost all investigatory resources at fatal accidents to one which considers selected fatal and non-fatal accidents with equal attention. This change would be directed at increasing the variety of safety data being gathered by the system, especially in the area of human error. In the field of human error analysis, a dead pilot or passenger contributes little information as to why an accident occurred. On the other hand, a pilot who has survived an accident may be able to supply the critical pieces of data concerning an accident cause. There are several problems associated with implementing this change, not the least of which is gaining the cooperation of the pilot(s) who is always under the threat of liability or disciplinary actions. The special importance of gaining this accident information, however, might include the waiving of such actions to ensure cooperation.

The second change recommended for the accident investigation strategies is to increase the quality and quantity of the data from the accident reports. This would result from increasing the number and the intensity of the accident investigations being conducted. There are essentially three approaches to gathering accident data. The first is a statistical approach in which information is collected about a large number of accidents. This approach provides perspective but sacrifices detail on any one accident. A second approach consists of the intensive study of a limited number of accidents. This yields less perspective and breadth than the statistical approach, but provides considerable depth (and information) about each individual accident. The third approach is the experimental in which extensive detail is obtained but the number of such tests and resulting perspective is necessarily limited.

The current FAA accident data system has essentially the first and third approaches in use. Aside from the quality problems, the greatest need seems to be to link the perspectives of the first approach with the details found in the third. This link can be found in the intensive investigation of a selected number of accidents. In other modes of transportation, these intensive accident investigations have been conducted by multidisciplinary teams consisting of engineers, physicians, forensic experts and safety analysts. The results have been to provide a theoretical and physical bridge between the sampled events and the population of accidents. This bridge appears to be the critical element in obtaining the data necessary to improve the current FAA system safety program.

FAA Safety Data Requirements

Several times in the conduct of the analysis of this study, the researchers encountered data deficiencies that prevented further investigation of safety program effectiveness. These problems were especially prominent in the human-error category and basically centered on the lack of information concerning the population. These deficiencies fall into three general categories:

a. General aviation data which are not gathered in any form
b. Information which is collected but not retained
c. Information brought into the system but not in a usable format.

The range of data items needed for the system is large. Further, the exact listing of data required by the safety system cannot be determined because the list is dependent on the causes of accidents. Since the accident causes are still being searched for, no real direction as to what data are needed can be expected from them. These two problems aggravate each other, with the results being only scattered, uncoordinated efforts to gather safety data.

The recommendation being made to break this cycle is to initiate a complete review of the data currently being collected by the FAA. This review should be directed at developing a comprehensive inventory of the data coming in, how it might be converted to safety use and what new information will be needed. This accounting is important because each year the various departments and field offices of the FAA produce information which could prove vital to safety program development. An example of such information is the voluntary flight proficiency checks given by FAA Accident Prevention Specialists (APS) at field offices around the country. These specialists offer free counseling and flight checks to pilots who are either observed having problems or who request assistance. A written report is filed by the APS detailing information about the individual, the problem he was having and how the check turned out. These reports are kept at the FAA regional level with a copy forwarded to the Washington headquarters of the APS office. The reports are destroyed annually with the only information retained being the fact that a check ride or counseling session was given. The loss of these data amounts to tens of thousands of records over the seven-year study period. Another example involves "flight assists". A "flight assist" results when a pilot calls on an FAA control facility (control tower, ATC, etc...) and requests help in conducting his flight. The problems can range from being low on fuel, lost and disoriented, having equipment problems, to simply not feeling well. For each assist, a log is recorded with data detailing the assist and its outcome. On those occasions when the flight assist is involved in an accident or regulatory violation it is followed up with additional investigation. The majority of assists, however, are not followed up and yet the safety related data which could be gathered from selective follow-ups is tremendous. For example, why was the aircraft low on fuel, how many hours did the pilot have in type, were there other circumstances to account for a higher fuel consumption and any other of a number of relevant pieces of data. The flight assist program logged over 25,000 assists during the accident study period. It can be recognized from just these two examples that the safety system does not suffer so much from a lack of data as it does from the misidentification of data already in the system. Restructuring, coordinating and following-up on the information entering the system would go a long way in narrowing the demand on data from the accident investigations. This in turn would permit accident investigators to concentrate their efforts on a narrower range of safety problems, especially human error. The overall results of these efforts would be enhanced safety program definition and accident prevention.

Comprehensive Single Source Data System

The final recommendation resulting from the findings of this study is the creation of a comprehensive, single-source safety data system. Such a data system would include at least the following:

a. The integration of all accident, incident and regulatory reported safety data

b. The development of a standard safety lexicon by which the diverse elements of the FAA, NTSB, NASA, United States Military and the aviation industry could communicate and utilize the safety data

c. The retention of the data over a long period of time (5 to 10 years) to improve the analytical quality of the safety system.

Perhaps the greatest loss of safety-related information results from not having such a data structure in place. A comprehensive structure is necessary to capture and retain the information being generated by the system. Certainly, the effectiveness of improvements made in the information gathering systems and the accident investigations are nullified if the data cannot be accurately related to the system. The standardization of the aviation safety lexicon would strenthen considerably the FAA's utilization of a significant amount of research work being conducted by the United States military forces. Introduction of such data, especially in the area of human error, could possibly reduce the need to duplicate similar research. More importantly, the use of a standard lexicon by all parties with a stake in aviation safety would vastly improve the total understanding of the problems.

Investigation of System Participation

The questions raised in the conclusions of this report regarding the participation levels of the individual subpopulations in the system safety programs address a matter of fundamental importance. Specifically, the best laid plans for achieving safe system operation are ineffective unless those who operate in the system "buy-in". In many respects, the FAA has walked the extra mile by not just regulating, but designing and implementing some innovative programs aimed at educating the less-active and/or non-professional pilots. While these efforts are commendable, further attention to this problem is warranted.

Implementation of the information-oriented recommendations, discussed above, represents an important start on this problem. Data on the separate subpopulations should be carefully studied to further delineate those areas in which the operator's diligence is less than desirable. Survey or other techniques should be used to identify the obstacles and/or phenomena responsible for this "non participation". Some limited but well-designed experiments might be devised to identify the needed characteristics of special programs aimed at improving operator involvement and performance. Finally, such efforts could lead to a better understanding of the alternatives and their relative merits : acceptance of current accident rates; greater regulation to improve safety at the expense of system entry requirements; programs that influence the safety-minded behavior of system operators.

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*U.S. GOVERNMENT PRINTING OFFICE : 1980 O-625-632/1969

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