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Aviation System Safety Risk Management Tool Analysis

Volume I: Summary Report

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U.S. Army risk management is a process used to minimize loss of life, injuries, and property damage. One step in the risk management process is risk assessment. Currently, risk assessment assigns a probability value for an identified hazard, based on a subjective evaluation. The need exists to assign objective probability values when assessing the risks imposed by aircraft component and part failures. This research extracted UH-60 and UH-1 helicopter part failure data for a 10-year period from the Army Safety Management Information System (ASMIS) data base. Data inconsistencies were corrected, the corrected data were organized into groups, and failure rates were calculated. The results established that component and part failure analyses can be successfully conducted using available data bases and that these data can be used to quantify hazard probabilities for failed aircraft components and parts. Volume I of this report describes the methodology used to obtain the failure rates, presents the results of the analyses, discusses potential uses for the data, and provides recommendations for further research. Volume II provides a table of part failure rates and a list of records for the UH-60 (see Appendix A) and for the UH-1 (see Appendix B).

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AVIATION SYSTEM SAFETY RISK MANAGEMENT TOOL ANALYSIS
VOLUME I: SUMMARY REPORT

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FOREWORD

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Army aviation's role on the modern battlefield has always contained inherent risks, and unexpected aircraft component and part failures increase that risk. Aircraft system managers can use risk management techniques to monitor the risk imposed by component and part failures, but the current Army definitions used to assign probability values to identified risks are ambiguous and lead to subjective probability evaluations.

This two-volume report contains the results of component and part failure analyses that established failure rates for every UH-60 and UH-1 part that was recorded in the Army Safety Management Information Systems data base between 1 October 1980 and 30 September 1990. These data can be used to identify those parts that fail at high rates so that appropriate measures can be implemented by the system managers to reverse unfavorable failure trends. These data can also be used to establish specific values for the probability terms used in the risk assessment matrix.

CONTENTS

TERMS, ACRONYMS, AND ABBREVIATIONS 3

EXECUTIVE SUMMARY 5

INTRODUCTION 7

Risk Assessment Matrix 7
Risk Management Implementation 9
Research Objectives 10

METHOD 10

Data Base Selection and Access 10
ASMIS Limitations 11
Data Editing and Organization 12
Data Transcription Reliability 13
Missing Data 13
Rate Calculations 14

RESULTS 14

Component Failure Analysis 14
Part Failure Analysis 15

DISCUSSION 19

Data Use 20
Data-Delivery System 21

RECOMMENDATIONS 22

REFERENCES 25

FIGURES

1. Risk Assessment Matrix 8
2. U.S. Army Aviation and Troop Command Risk Decision Authority Matrix 9
3. UH-60 Class A Through E Rate Graph 16
4. UH-1 Class A Through E Rate Graph 17
5. Example of the Failure Rate Table for the UH-60 Component Group Landing Gear 18
6. Example of the List of Records for the UH-60 Component Group Landing Gear 19

TABLES

1. Hazard Severity Categories, Descriptions, and Definitions 8
2. Hazard Probability Levels, Descriptions, and Definitions 9
3. UH-60 and UH-1 Fleet Exposure Data and Failure Rate Variables ... 14
4. UH-60 and UH-1 Component Groups and Number and Percent of Failures 15

5. UH-60 Parts That Failed More Than Three Times per 100,000 Flight Hours.......... 17
6. UH-1 Parts That Failed More Than Three Times per 100,000 Flight Hours.......... 18

TERMS, ACRONYMS, AND ABBREVIATIONS

AAE	-	Army Acquisition Executive
AMC	-	Army mishap classification
AR	-	Army regulation
ARPS	-	ASMIS retrieval and processing system
ASMIS	-	Army Safety Management Information System
ATCOM	-	U.S. Army Aviation and Troop Command
DA	-	Department of the Army
FY	-	fiscal year
HRED	-	Human Research and Engineering Directorate
PC	-	personal computer
PEO	-	Program Executive Office
PM	-	project manager
PRAM	-	Preliminary Report of Aircraft Mishap
RAC	-	risk assessment code
TM	-	technical manual
USASC	-	U.S. Army Safety Center

EXECUTIVE SUMMARY

REQUIREMENT

The research described in this report was conducted by Anacapa Sciences, Inc. under contract to the Human Research and Engineering Directorate (HRED) of the U.S. Army Research Laboratory. This research was conducted to meet U.S. Army Aviation and Troop Command requirements for three objectives. The first objective was to identify the system components and parts that either caused or contributed to Class A through E accidents for the UH-1 and UH-60 helicopter fleets for the 10-year period from 1 October 1980 through 30 September 1990. The second objective was to organize the data and determine the number of failures per year and calculate the failure rate per 100,000 flight hours for each failed component or part. The third objective was to analyze the data and to propose an automated data delivery system for such data if they can be collected and archived to the equipment part level.

Aircraft component and part failure analyses were conducted to determine the feasibility of extracting failure data from existing data bases and calculating failure rates from such data.

PROCEDURE

The Army Safety Management Information System (ASMIS) data base maintained by the U.S. Army Safety Center (USASC) was selected as the research data base. Army aviation accident data have been entered into ASMIS since 1956, making ASMIS the single largest source of Army aircraft component and part failure data. ASMIS also contained the exposure data required for the failure rate calculations.

Because data manipulation and editing were not possible within ASMIS, Anacapa Sciences, Inc., personnel developed a relational data base with the capability to capture selected data from ASMIS and transfer them to a personal computer. Once the data were transferred, several steps were required to edit and organize the data to obtain the desired results.

First, the data were organized into major component groups corresponding to those found in the aircraft part manuals. Then, inconsistent part names were edited to uniform nomenclatures so the parts would group together when the data were sorted. Third, each component group was searched for misplaced parts; when found, they were reassigned to the appropriate technical manual component group. Fourth, parts with the same part number but different part names were assigned a standard nomenclature. Fifth, case-by-case ASMIS queries were conducted to identify parts with nonspecific nomenclatures. Finally, the data base was reviewed for duplicate records and programmed to ignore those records during rate calculations.

Additionally, a random sample of 20% of the Class A through D accident cases was reviewed to determine the rate of transcription errors in the ASMIS data base. The review also identified the extent of missing data in the source documents.

FINDINGS

Queries from ASMIS yielded 2,222 records for the UH-60 fleet and 8,961 records for the UH-1 fleet. After 12 duplicate UH-60 records and 17 duplicate UH-1 records were removed, rate calculations were based on 2,210 UH-60 records and 8,944 UH-1 records.

Analysis of these data resulted in the following observations in the UH-60 data base per 100,000 flight hours:

1. Four hundred twenty-three (423) parts failed. The number of failures per part ranged from 1 to 117; the corresponding failure rates ranged form 0.09 to 10.54.

2. One failure was recorded by 223 parts (failure rate 0.09); 159 other parts failed 2 to 11 times (failure rate greater than 0.09 but less than 1.0). Twenty-one parts failed 12 to 22 times (failure rate greater than 1.0 but less than 2.0). Eight parts failed 23 to 33 times (failure rate greater than 2.0 but less than 3.0).

3. Only 12 parts failed frequently enough to record a failure rate greater than 3.0.

Analysis of the UH-1 data resulted in the following observations per 100,000 flight hours:

1. Five hundred eight (508) parts failed. The number of failures per part ranged from 1 to 734; the corresponding failure rates ranged form 0.01 to 10.24.

2. One failure was recorded by 206 parts (failure rate 0.01); 268 other parts failed 2 to 71 times (failure rate greater than 0.01 but less than 1.0). Twenty-four parts failed 72 to 140 times (failure rate greater than 1.0 but less than 2.0). Three parts failed 141 to 214 times (failure rate greater than 2.0 but less than 3.0).

3. Only seven parts failed frequently enough to record a failure rate greater than 3.0.

USE OF FINDINGS

The analysis identified parts with relatively high failure rates. Aviation system managers can use these data to identify problematic components or parts, to monitor component and part failure trends, and to develop countermeasures to reverse unfavorable component and part failure rates.

These data can also provide the basis for assigning quantified parameters to the five categories of probability that are used to assign risk assessment codes to identified hazards. The current verbal definitions used by the Army to assign hazard probabilities are ambiguous and lead to subjective probability evaluations. By analyzing actual part failure data, one can establish quantified limits for the five probability categories. This procedure enables objective assignment of hazard probabilities when risk assessment is performed.

AVIATION SYSTEM SAFETY RISK MANAGEMENT TOOL ANALYSIS

VOLUME I: SUMMARY REPORT

INTRODUCTION

Since its inception, the role of Army aviation has evolved from simple artillery observation to an integrated and essential member of the combined arms team. In the last decade, the mission of Army aviation has increased in complexity, largely because of the increased capabilities of new, technologically advanced aviation systems. Today's changing world has also increased the challenge to the Army of safely performing its mission. The Army no longer considers its primary mission that of defending allied territory in a relatively simple and static scenario. Rather, the Army will probably continue to be called upon to respond anywhere in the world to a wide variety of military, humanitarian, and peace-keeping missions. Army aviation's role has always contained inherent risks, but today's demands to operate in a variety of environments increases that risk. To maintain Army aviation's enviable safety record and thus conserve valuable combat resources will require constant vigilance and the application of sound safety management techniques.

One of the safety management techniques used by the Army is risk management, a decision-making process designed to minimize loss of life, personal injury, and property damage. Risk management acknowledges that Army operations contain various levels of risk and provides a process with which to manage these risks. The five steps of the risk management process are risk identification, risk assessment, risk decision (deciding whether to accept the risk), implementation of controls to reduce or eliminate hazards, and supervision directed at providing feedback, based on the success of the controls that were implemented.

Risks or hazards that require the application of risk management techniques are identified by occupational health or safety personnel during surveys or inspections and by accident investigation boards. Army leaders are also trained to apply risk management techniques before they conduct inherently risky operations such as river crossings or terrain flight using night vision goggles. Once a hazard or risk is identified, risk assessment is made by either the staff safety professional or in the case of small unit tactical operations, the unit leader.

Risk Assessment Matrix

Army Regulation (AR) 385-10 (1988) provides a matrix (see Figure 1) that is used by safety personnel and commanders to perform the assessment step of the risk management process. This matrix provides a tool for assigning a risk assessment code (RAC) to each hazard evaluated based on its probability of occurrence and the estimated severity of its consequences. RAC values range from 1 to 5, with 1 representing hazards with the most risk and 5 representing those with the least risk. Hazards and their associated RACs are documented in hazard abatement plans, and the elimination of RAC 1 and 2 hazards receives priority in operating plans and budgets.

To determine the RAC, the hazard must be evaluated and assigned a severity category and a probability level. The four severity categories used in hazard evaluation and their respective severity descriptions and definitions are given in Table 1.

		Accident Probability				
		Frequent	Probable	Occasional	Remote	Improbable
Severity		A	B	C	D	E
Catastrophic	I	1	1	2	3	5
Critical	II	1	2	3	4	5
Marginal	III	2	3	4	5	5
Negligible	IV	3	4	5	5	5

Figure 1. Risk assessment matrix.

Table 1

Hazard Severity Categories, Descriptions, and Definitions

Category	Description	Definition
I	Catastrophic	Death or permanent total disability; system loss; major property damage
II	Critical	Permanent partial disability; temporary partial disability exceeding 3 months; major system damage; significant property damage
III	Marginal	Minor injury; lost work day accident, compensable injury or illness; minor system damage; minor property damage
IV	Negligible	First aid or minor supportive medical treatment; minor system impairment

The five hazard probability levels are shown in Table 2. The description of each probability level and the phrase used to define it (Department of the Army, 1988) are also given in Table 2.

Table 2

Hazard Probability Levels, Descriptions, and Definitions

Level	Description	Definition
A	Frequent	Continuously experienced
B	Probable	Will occur frequently
C	Occasional	Will occur several times
D	Remote	Unlikely, but can reasonably be expected to occur
E	Improbable	Unlikely to occur, but possible

Risk Management Implementation

Department of Defense Instructions 5000.2, Section 6 (1991) adds authority levels to the risk assessment matrix and specifies which authority level makes the decision to accept a risk level once it is established. At the U.S. Army Aviation and Troop Command (ATCOM), the risk decision authority for aviation systems resides with the system project manager (PM) for lower risk levels, with the Aviation Program Executive Office (PEO) for intermediate risk levels, and with the Army Acquisition Executive (AAE), a Secretary of the Army-level office, for higher risk levels (see Figure 2). Theoretically, the risk decision that is made for the higher risk levels has a greater potential for a negative effect on operational readiness.

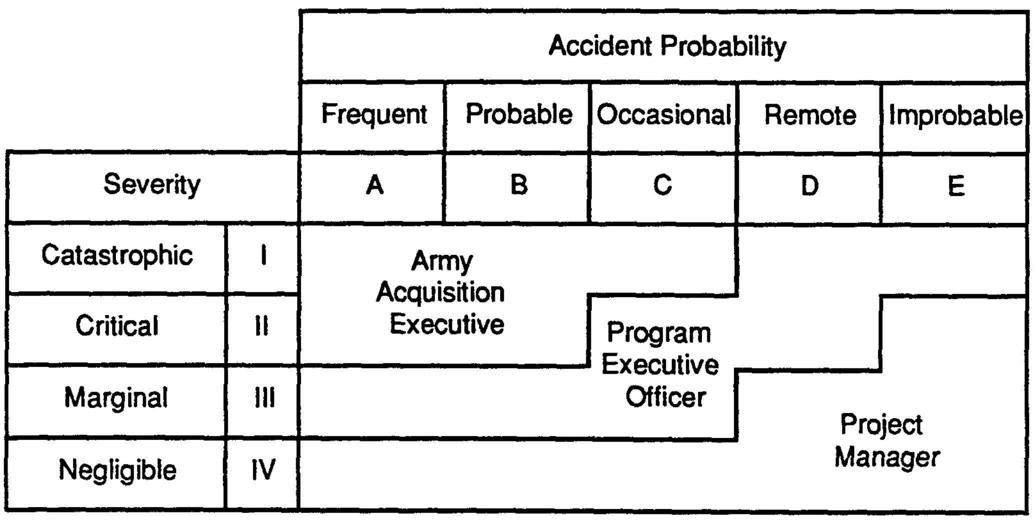

Figure 2. U.S. Army Aviation and Troop Command risk decision authority matrix.

Research Objectives

The definitions used to describe the four hazard severity categories allow the objective assignment of one of the categories based on the type of injury that the hazard would probably produce. Property damage parameters also could be assigned specific dollar values upon which to base severity category assignment. However, the definitions used to describe the five hazard probability levels (improbable, remote, occasional, probable, or frequent) are not specific. The persons assessing the probability, and ultimately the risk, presently do so solely on the basis of their judgment rather than on quantified probabilities or rates. For example, when assessing the risk presented by the failure of a UH-1 main rotor blade in flight, it is reasonable to assume that the consequences would be severe. However, without examining actual failure rates, the risk assessor could assign a probability of improbable, remote, or perhaps occasional, depending on the assessor's background, experience, and perceptions.

A need exists to improve the risk assessment tool and thereby reduce or eliminate the subjective decision making. Objectivity is important when assessing the risk posed to a fleet of aircraft by failure of aircraft components or parts. In some cases, component or part failures result in decisions that adversely affect Army readiness, such as restricting the operation of an aircraft system or grounding the fleet.

In Army aviation, historical accident data exist that may be used to quantify the risk assessment probability categories. This research was designed to examine part of one data base to determine its usefulness in assessing risk probabilities. Three technical objectives of the research project were to (a) identify the system components or parts that either caused or contributed to accidents for the UH-1 and UH-60 helicopter fleets, (b) organize and analyze the data to determine the number of failures per year and failure rate per 100,000 flight hours for each system component and part, and (c) propose an automated data delivery system for such data if they can be collected and archived to the equipment part level.

Establishing quantified failure rates could allow system managers to more accurately assess the level of risk imposed by the failure of a particular aircraft component or part. This may result in a better risk decision, and it will begin the evolution of risk assessment into risk determination.

METHOD

Data Base Selection and Access

The Army safety management information system (ASMIS) data base, maintained by the U.S. Army Safety Center (USASC), was selected as the research data base. Army aviation accident data have been entered into ASMIS since 1956, making it the single largest source of Army aircraft component and part failure data. ASMIS also contains the exposure data required for rate calculations.

For aviation mishaps, Army mishap classifications (AMC) range from A through E, with Class A mishaps being the most severe (more than $1,000,000 damage, aircraft totally destroyed, or injuries resulting in death or total disability). Class E mishaps are the least severe, resulting in less than $2,000 damage and no injuries. Many Class E mishaps are not actually accidents but are reported as occurrences that result in no damage, such as a precautionary landing or an aborted mission. In many cases, aviation mishaps are caused by the failure or malfunction of aircraft components or parts.

In accordance with AR 385-40 (1987), component and part failure data resulting in an aviation mishap is recorded on two source documents. The Department of the Army (DA) 2397 series forms are used by accident investigation boards to report the more serious Class A through C mishaps. The Preliminary Report of Aircraft Mishap (PRAM) is used by unit safety officers to electronically transmit the less severe Class D and E aircraft accident information to USASC. Component and part failure data from both sources are then entered into the ASMIS data base.

The ASMIS data base was accessed using the ASMIS retrieval and processing system (ARPS). ARPS is a multifunctional query system that offers a variety of options for data retrieval, including retrieval from the aviation accident data base and the accident exposure data base. ARPS queries first require the establishment of specific criteria for selecting the accident reports containing the desired data. Then, key words are selected and arguments constructed in accordance with the ARPS aviation user's guide to retrieve specific data fields.

The criteria for selecting the accident reports needed for this research specified aviation accidents for a 10-fiscal-year (FY) period from 1 October 1980 through 30 September 1990. Key words and arguments were constructed that specified all accident cases, Class A through E, in which component or part failure was a definite or suspected cause. Because of the number of records expected, two separate queries were conducted: one for the UH-1 helicopter fleet and one for the UH-60 helicopter fleet. (UH-1 and UH-60 accident case data and exposure data also include the EH and MH helicopters within the series.) The selection of the UH-1 and the UH-60 provided a large data base because these two fleets collectively flew approximately 50% of the total Army flying hour program during the period selected for the research. The fields selected for display were (a) case number, (b) Army mishap classification, (c) FY, (d) failed component group name, (e) failed part name, and (f) failed part number. An additional query for each fleet requested exposure data (flight hours) for each of the 10 FYs.

ASMIS Limitations

The initial research plan was to manipulate the data within ASMIS, but limitations of the system prevented using this procedure. First, the data had to be sorted by both the component group field and the part name field. Within ASMIS, the maximum length of fields that can be sorted is 30 characters. The component name and part name fields contain 40 characters, making it impossible to sort them simultaneously. Second, ASMIS can sort a maximum of only 8500 records at one time, a total exceeded by the UH-1 data base. Third, an initial review of the data obtained from ASMIS indicated numerous inconsistencies in component and part name entries that would result in inaccurate groupings of like components and parts. ASMIS does not allow users to edit the fields to correct such inconsistencies. Finally, ASMIS does not have the capability to calculate component and part failure rates based on exposure data.

To overcome these limitations, the ASMIS data were transferred to another data base for editing, manipulation, and calculation of rates. Because the NO STOP feature was used in the terminal processing mode during the argument phase of the inquiry, the required ASMIS data were transferred as an American standard code for information interchange (ASCII) text file into a custom-developed relational data base in a personal computer (PC). Because of space limitations imposed by the PC software, the component name and part name fields were limited to 10 characters. ASMIS exposure data were also transferred to the relational data base.

Data Editing and Organization

The first step in editing the data was to establish logical categories within the failed component field. Component and part name data were entered into ASMIS from the source document DA Form 2397-7R or the PRAM. Instructions for entering information on these source documents are given in DA Pamphlet 385-95 (1983). The instructions do not require the failed aircraft components entered on the form to coincide with the major functional component groups listed in the aircraft-specific technical manuals (TMs). However, a review of the ASMIS data indicated that failed components were generally grouped according to the TM functional groups. Therefore, the failed component field in the relational data base was edited to include only the TM major component functional groups within ASMIS. Component failures that were listed in ASMIS that did not correspond with a TM component group were removed from the component group field and added to the part field within the appropriate TM component group.

The second step in organizing the data was to correct the nomenclature errors in the failed part field. Five substeps were performed to organize these failed part data. First, the failed parts list within each component group was examined for nomenclature consistency. Frequently, identical parts did not group together because of inconsistent spelling. For example, the main rotor blade was listed in the UH-60 data base with the following entries: Blace [sic] M/R, Blade, Blade Assy, Blade M/B, Blade M/R, Blade MR, M/R Blade, and MR Blade. A standard spelling (e.g., M/R Blade) was established for each part and misspelled entries were edited.

Third, some failed parts were listed in more than one component group. Each component group was searched, and misplaced parts were reassigned to the appropriate component group. Examples of such misplacement included instrument indicators (instrument component group) listed in the electrical system group and servos (flight control group) listed in the hydraulic system group. Third, data sorts by part number indicated that some parts with the same number were assigned different names. A standard nomenclature was established and recorded for parts having the same part number.

Fourth, because it was limited to 10 characters, the part name did not always indicate the complete name of the part that failed and therefore did not fully define the part function. This limitation resulted in large part groups that actually consisted of several smaller, more definitive part groups. For example, within the instrument system component group of the UH-1 data base, one failed part (indicator) was listed 635 times. However, several groups of part numbers were associated with the part name. After ARPS was queried for individual case numbers and requesting narrative information, many of the entries for the indicator were redesignated as exhaust gas temperature indicator, fuel pressure indicator, fuel quantity indicator, oil pressure indicator, oil temperature indicator, radio magnetic indicator, and torque indicator.

Finally, the data base was reviewed for duplicate entries (i.e., a case number listed more than once with identical or nearly identical component name, part name, and part number information). The duplicate entries were annotated within the data base so they would not be included in subsequent rate calculations.

Data Transcription Reliability

Inconsistencies in the ASMIS data base could be caused by inaccurate information from the source documents or by data transcription errors when source documents information was entered into ASMIS. To determine the reason for the data inconsistencies, a random sample (20%) of the source documents from the Class A through D accident cases from both the UH-60 and the UH-1 data bases was reviewed and compared to the data base entries.

Of the 118 Class A through D accident cases in the UH-60 data base, 24 were randomly selected for detailed review. Two of the 24 cases contained inconsistencies between the source documents and ASMIS data. Of the 232 Class A through D accident cases in the UH-1 data base, only 1 of 46 randomly selected cases contained a discrepancy between the source document and the ASMIS data. All three errors were caused by inaccurate entry into ASMIS.

Thus, the 20% samples indicate that the probability of a data entry error is .08 for the UH-60 accident data base and .02 for the UH-1 accident data base. That is, there are probably about eight errors in the remaining 94 UH-60 cases and about four errors in the remaining 186 UH-1 cases.

Although the sample statistics are the best point estimates, the error rates may be different for the remainder of the respective data bases. Sample variability is always a concern in estimating population parameters, but it is especially important when the incidence rates are low. For example, if the UH-60 sample had contained one less error, the estimated probability would be .04 instead of .08; if it contained one more error, the estimated probability would be .12. A more reliable estimate is to determine the range of probable errors in each data base at a specified confidence level (e.g., the 90% confidence interval).

The hypergeometric distribution was used to estimate the 90% confidence interval of probable data entry errors in each data base. The hypergeometric distribution is appropriate because the population of accident cases for each aircraft is finite and the relative size of each sample is known (20% of the population). With 90% confidence, the remainder of the UH-60 data base contains between 0 and 16 errors, and the remainder of the UH-1 data base contains between 0 and 11 errors.

Missing Data

Some data were not recorded on the source documents and therefore were not available in ASMIS. In the UH-60 data base, component names in 17 records (0.8%), part names in 15 records (0.7%), and part numbers in 655 records (29.5%) were not recorded. In the UH-1 data base, component names in 28 records (0.3%), part names in 32 records (0.4%), and part numbers in 2,196 records (24.5%) were not recorded. Unrecorded component and part names had little effect on the analyses because of their infrequent occurrence. Unrecorded part numbers had no effect because the data were sorted by the component and part name fields. The part number field, when available, was only used as a secondary means of identifying the part name when the nomenclature was inconsistent or not recorded.

Rate Calculations

ARPS queries from the exposure data option provided accident exposure data as annual flight hours for each fleet for the 10-year period selected. A rate variable, 100,000 divided by hours flown, was computed and entered into the relational data base for both the UH-1 and UH-60 fleets (see Table 3). The failure rate for each part was computed by multiplying the number of times the part failed by the failure rate variable for each FY and for the cumulative 10-year period.

Table 3

UH-60 and UH-1 Fleet Exposure Data and Failure Rate Variables

	UH-60 fleet exposure		UH-1 fleet exposure	
FY	Flight hours	Rate variable	Flight hours	Rate variable
81	33,748	2.9631	819,040	0.1221
82	50,983	1.9614	746,174	0.1340
83	62,398	1.6026	758,258	0.1319
84	76,299	1.3106	704,405	0.1420
85	77,471	1.2908	692,752	0.1444
86	109,489	0.9133	709,805	0.1209
87	153,572	0.6512	695,702	0.1437
88	177,105	0.5646	704,431	0.1420
89	183,458	0.5451	681,333	0.1468
90	185,676	0.5386	657,192	0.1522
81-90	1,110,199	0.0901	7,169,092	0.0139

RESULTS

Component Failure Analysis

The ARPS queries from the aviation accident data base option yielded 2,222 records for the UH-60 fleet and 8,961 records for the UH-1 fleet. Review of the data bases found 12 duplicate records for the UH-60 and 17 duplicate records for the UH-1. These records were retained in the data base but were not used to calculate part failure rates. Eliminating duplicate records reduced the usable data base to 2,210 records for the UH-60 and 8,944 records for the UH-1.

Fourteen component groups were identified for the UH-60, and 15 component groups were identified for the UH-1 (see Table 4). Component groups for the two data bases were essentially identical except for the armament component group in the UH-1 data base. The pneudraulic component group (UH-60) is essentially the same as the hydraulic component group (UH-1); the nomenclature difference is specified by the parts TM for each aircraft system.

The flight control and rotor and transmission (rotor/xmsn) component groups for the UH-60 data base each had 457 (20.6%) part failures. The engine component group had 440 (19.8%) part failures. The remaining 12 component groups collectively accounted for less than 40% of the total part failures (see Table 4).

Table 4

UH-60 and UH-1 Component Groups and Number and Percent of Failures

UH-60 component groups			UH-1 component groups		
Component	N	Percent	Component	N	Percent
Flight controls	457	20.6	Engine	2913	32.5
Rotor/xmsn	457	20.6	Rotor/xmsn	1571	17.5
Engine	440	19.8	Hydraulic	1192	13.3
Pneudraulic	238	10.7	Electrical	961	10.7
Electrical	178	8.0	Fuel system	789	8.8
Utility	159	7.2	Instrument	777	8.7
Airframe	80	3.6	Utility	220	2.5
Instrument	78	3.5	Airframe	170	1.9
Fuel system	41	1.8	Flight control	138	1.5
Landing gear	25	1.1	Avionics	96	1.1
Avionics	20	<1.0	Landing gear	42	<1.0
Cargo/pers	16	<1.0	Cargo/pers	30	<1.0
Not recorded	16	<1.0	Not recorded	28	<1.0
Special tools	5	<1.0	Armament	12	<1.0
			Special tools	5	<1.0
Total	2,210		Total	8,944	

Note. Rotor/xmsn = rotor/transmission; cargo/pers = cargo and personnel handling.

For the UH-1, the engine component group had 2,913 (32.5%) part failures. The data in Table 4 show that rotor/xmsn, hydraulic, and electrical were the only other component groups that accounted for more than 10% of the UH-1 part failures.

Part Failure Analysis

The UH-60 data base contained 423 part failures. The number of failures per part ranged from 1 to 117; the corresponding rates ranged from 0.09 to 10.54 (see Figure 3).

Only one failure was recorded for each of 223 parts (a 10-year failure rate of 0.09 per 100,000 flight hours for each part). One hundred fifty-nine (159) other parts had failure rates greater than 0.09 but less than 1.0 per 100,000 flight hours (2 to 11 failures per part). Twenty-one parts had failure rates greater than 1.0 but less than 2.0 (12 to 22 failures per part). Eight parts had failure rates greater than 2.0 but less than 3.0 (23 to 33 failures per part). To record a failure rate greater than 3.0, a part had to fail at least 34 times during the period; only 12 parts met that criterion.

Those UH-60 parts with failure rates greater than 3.0 are shown in Table 5. The highest failure rate was for the engine (10.54). However, the specific part of the engine component group that failed was not identified in ASMIS.

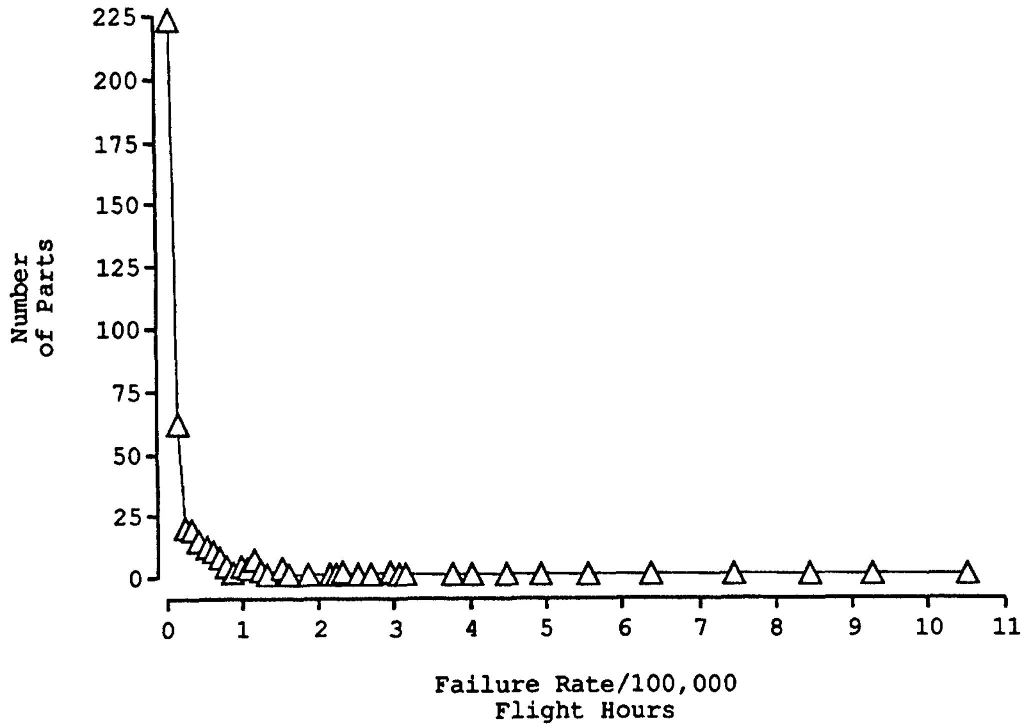

Figure 3. UH-60 Class A through E rate graph.

In the UH-1 data base, 508 parts failed one or more times. The number of failures per part ranged from 1 to 734; the corresponding rates ranged from 0.01 to 10.24 (see Figure 4).

Only one failure was recorded for each of 206 parts (a 10-year failure rate of 0.01 per 100,000 flight hours). Two hundred sixty-eight (268) other parts had failure rates greater than 0.01 but less than 1.0 (2 to 71 failures per part). Twenty-four parts had failure rates greater than 1.0 but less than 2.0 (72 to 140 failures per part). Three parts had failure rates greater than 2.0 but less than 3.0 (141 to 214 failures per part). To record a failure rate greater than 3.0, a part had to fail at least 215 times during the period; only seven parts failed that frequently (see Table 6). The highest failure rate for the UH-1 was for the engine (10.24). As with the UH-60, the specific part of the engine component group that failed was not identified in ASMIS.

Table 5

UH-60 Parts That Failed More Than Three Times per 100,000 Flight Hours

Part name	Component group	No. of failures	Rate
Engine	Engine	117	10.54
Actuator, servo	Flight control	103	9.28
Electronic control unit	Engine	94	8.47
Antiflap device	Rotor/xmsn	83	7.48
Gearbox, main module	Rotor/xmsn	71	6.40
Pump assembly	Pneudraulic	62	5.58
Amplifier	Flight control	55	4.95
Starter, pneumatic	Pneudraulic	50	4.50
Auxiliary power unit	Utility	45	4.05
Accessory gearbox	Rotor/xmsn	42	3.78
Fire detector	Utility	35	3.15
Stabilator	Flight control	34	3.06

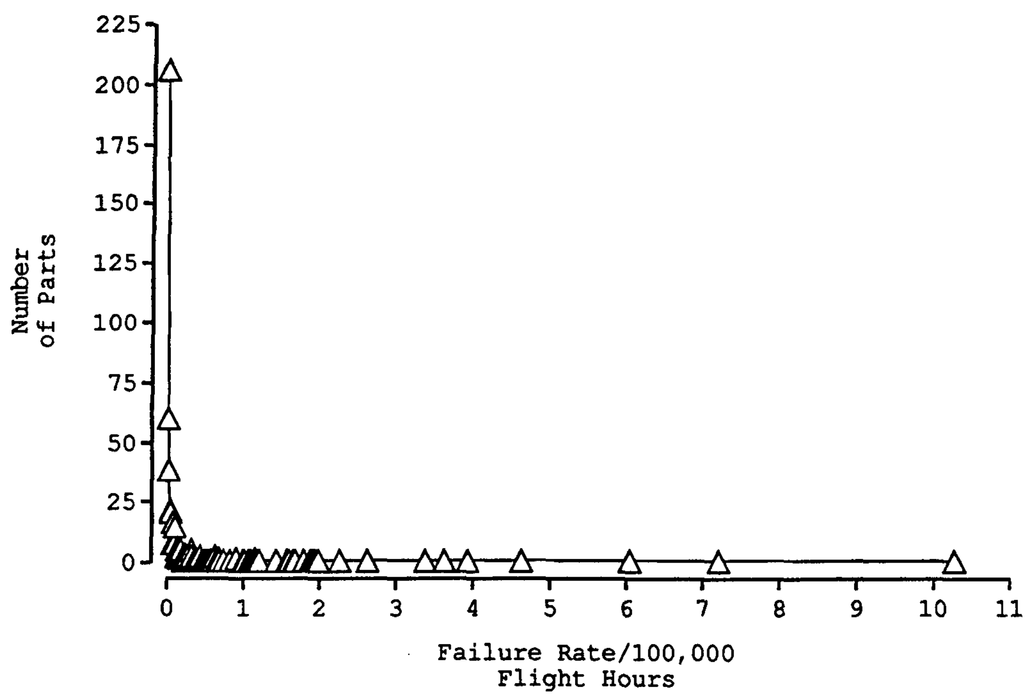

Figure 4. UH-1 Class A through E rate graph.

Table 6

UH-1 Parts That Failed More Than Three Times per 100,000 Flight Hours

Part name	Component group	No. of failures	Rate
Engine	Engine	734	10.24
Pump, submerged	Fuel system	517	7.21
Generator	Engine	434	6.05
Fuel control	Engine	332	4.63
Panel assembly	Electrical	282	3.93
Servo cylinder	Hydraulic	261	3.64
Oil pressure indicator	Instrument	242	3.38

Appendix A lists the failed UH-60 parts sorted by component group; Appendix B lists the failed UH-1 parts sorted by component group. For each failed part name, the tables display the number of failures and the failure rate for each FY from 1981 to 1990 and for the 10-year period (see Figure 5). A list of all records within the component group follows each table. The list displays the failed part name, part number, fiscal year of occurrence, AMC, and accident case number (see Figure 6). Duplicate records are annotated by an X in the block in the right-hand column of the list. The list allows cross-referencing of failed part nomenclature with the appropriate part number, if available, for positive part identification.

UH-60 Component Analysis

Component: LAND GEAR											
Part	*1981*	*1982*	*1983*	*1984*	*1985*	*1986*	*1987*	*1988*	*1989*	*1990*	*Total*
CONNECTOR										1 .54	1 .09
PISTON LIN										1 .54	1 .09
STRUT ASSY			1 1.6		1 1.29	1 .91	2 1.3	1 .56	3 1.64	5 2.69	14 1.26
TIRE	1 2.96	1 1.96	2 3.21	1 1.31		1 .91			1 .55		7 .63
YOKE ASSY			1 1.6					1 .56			2 .18
Total	1 2.96	1 1.96	4 6.41	1 1.31	1 1.29	2 1.83	2 1.3	2 1.13	4 2.18	7 3.77	25 2.25

Figure 5. Example of the failure rate table for the UH-60 component group landing gear.

UH-60 Accident Records

Component: LAND GEAR				
Part	**Number**	**FY**	**AMC**	**Case Number**
TIRE	7025012049101	81	E	801117081 ☐
TIRE	7025012049101	82	E	820507141 ☐
TIRE	7025012049101	83	E	821023041 ☐
TIRE	7025012049102	84	E	840921141 ☐
STRUT ASSY	7025012051043	85	D	850324051 ☐
STRUT ASSY	7025012051043	90	E	900928081 ☐
STRUT ASSY	7025012051043	90	E	891011161 ☐
STRUT ASSY	7025012051045	87	E	870629101 ☐
STRUT ASSY	7025012051045	90	E	900820101 ☐
PISTON LIN	7025012067102	90	C	900807141 ☐
STRUT ASSY	7025013101041	90	C	900409151 ☐
STRUT ASSY	7025013101042	86	D	860128081 ☐
STRUT ASSY	7025013101042	87	D	870202071 ☐
STRUT ASSY	7025013101042	88	D	880602021 ☐
STRUT ASSY	7025013101042	89	D	890601111 ☐
STRUT ASSY	7025013101042	89	D	881130161 ☐
STRUT ASSY	7025013101042	83	E	830802191 ☐
STRUT ASSY	7025013101043	89	E	890710151 ☐
YOKE ASSY	7025013158042	83	C	830405141 ☐
YOKE ASSY	7025013158042	88	D	880125091 ☐
TIRE	7025013173101	83	E	830302141 ☐
CONNECTOR	NOT REC	90	E	900220081 ☐
STRUT ASSY	NOT REC	90	D	900620011 ☐
TIRE	NOT REC	86	D	860605021 ☐
TIRE	NOT REC	89	E	881211031 ☐

Figure 6. Example of the list of records for the UH-60 component group landing gear.

DISCUSSION

This research determined that extensive data about UH-60 and UH-1 component and part failures exist in the ASMIS data base. However, extensive review and editing will be required to make the ASMIS data useful for calculating failure rates for aircraft components and parts. The component failure analysis tables in Appendices A and B represent a reasonably accurate and comprehensive tabulation of part failures and corresponding failure rates for the UH-60 and UH-1 helicopters during the 10-year period evaluated.

Two caveats must be considered when using these data. First, ASMIS contains records of accidents caused by materiel failure in which component and part failure data were not recorded during the original investigation. That is, the data are missing from the source documents. Second, all Army aircraft component and part failure data are not required to be entered into ASMIS. Additional aircraft part failure data are also reported through logistical channels (e.g., quality deficiency reports and equipment improvement reports). However, failures reported through these channels are unlikely to affect flight safety. Such data may be more useful during detailed investigations of parts identified as high risk by an ASMIS analysis.

The remainder of this report is divided into three parts. First, two immediate uses for the data are described. Second, suggestions for a data-delivery system are discussed. Third, recommendations for future research are proposed.

Data Use

The edited ASMIS data can be used for at least two immediate purposes. First, the authors' analysis identified some parts with relatively high failure rates (see Tables 5 and 6). Although such part failure rates were generally low, the UH-60 and UH-1 system managers may wish to consider the reasons for high failure rates of certain parts. Failure rates per 100,000 flight hours ranged from a low of .09 to 10.54 (UH-60) and .01 to 10.24 (UH-1). Making the assumption that one flight hour equals one mission, the probability for failure in the UH-60 data base ranges from a high of .0001 to a low of .0000009 per mission. In the UH-1 data base, the ranges are from a high of .0001 to a low of .00000014.

Second, the quantified failure rates for the UH-1 and UH-60 systems may be used to assign specific values to the probability terms used in the risk assessment matrix (i.e., improbable, remote, occasional, probable, or frequent). Although the determination of the failure rate definition for a hazard probability level is still subjective, it will be based on empirical data and can be communicated in mathematical terms. The failure rate definition, once established by the responsible authority, will not be subject to different interpretations, which can occur with the current verbal definitions. The following paragraphs provide an example of one way that failure rate data could be used to define the hazard probability levels. The responsible authority must determine the actual failure rate parameters. The failure rate graphs (see Figures 3 and 4) are the basis for this discussion.

The definition of the term improbable states that the event is "unlikely to occur, but possible." Presumably, it is possible for any part to fail, even if it never has. Therefore, the term improbable could be defined as parts that have not failed during the preceding period or those that have not yet failed. The exact number of these parts is unknown because the ASMIS data base only includes failed parts. Consequently, there is no data point for them in Figures 3 and 4, but all parts that are not listed have a failure rate of zero.

The term remote is defined as "unlikely, but can reasonably be expected to occur." Parts that failed only once have a demonstrated likelihood of failure, but it is definitely remote. One failure could represent a random event or even a misattribution, but the likelihood of failure should be considered more than improbable unless there is irrefutable evidence (e.g., no failures in the last 5 years). If the remote hazard level were defined as a single failure, approximately 53% of the UH-60 part failures and 41% of the UH-1 part failures would belong to this category. Parts that have failed more than once but very rarely (i.e., two or three times) or not recently could also be considered remote. The upper boundary for the remote level must ultimately be determined by the responsible authority and then communicated to the aviation community.

The same empirical data and logic can be applied when defining the three higher levels of hazard probability. The occasional level ("will occur several times") could be defined as parts that failed more than the remote category parts but not more than 3 failures per 100,000 hours. Both Figures 3 and 4 show a break in the failure rate distributions at or just above 3.0. Approximately 44% of the UH-60 parts and 58% of the UH-1 parts fall within those boundaries.

The probable level ("will occur frequently") could be defined as those parts with failure rates between 3.0 and either 6.0, 7.0, or 8.0. There are approximately equal breaks in the distributions at all these points, but this is partly because so few parts had failure rates that high. The most consistent break on both graphs is at 7.0. Finally, the frequent level ("continuously experienced") could be defined as the parts with failure rates greater than the upper boundary of the probable category. Because of its effect on the RAC code assigned, very few parts (either four or two in Figures 3 and 4) would be assigned to the frequent level.

Data-Delivery System

For use in making risk assessment decisions, component and part failure data must be accurate and comprehensive, readily accessible, and current. A computerized data base should be developed from the ASMIS information (and possibly other data bases) to contain the required information. The ASMIS data could be used directly, but this procedure would be inefficient. ASMIS contains many more data fields than are needed for component failure analysis, the data must be reviewed and edited for risk assessment analysis, and ASMIS has limited data manipulation capabilities. The UH-60 and UH-1 data bases in this research were entered into a personal computer and manipulated using a commercially available computer application.

The data format used in this research for the UH-60 and UH-1 data bases is adequate for an ongoing risk assessment data base. It contains all the relevant information and can be sorted in different ways for analysis. For example, the data can be sorted so that only Class A through C accidents are considered in a component and part failure analysis of the more severe accidents.

In addition, further research and development could produce computer formulas or routines that could be applied to the data in their current format. There are two obvious examples. First, once the responsible authorities determine the mathematical definitions of the hazard probability levels, a computer program routine could be developed that would determine the level for each part and automatically enter it into the data base. As additional data for the part were added to the data base, the probability level would be automatically updated. The same update would occur if the probability level definition were changed.

Second, routines could be developed to determine if newly added data create a significant change in the failure rate for a part. That is, statistical confidence intervals can be computed from the historical data that will determine whether a different failure rate for the current assessment period represents a normal variation in failures or an increased hazard (if the rate goes up) or an improved part or maintenance procedure (if the rate goes down).

A critical element in the utility of the proposed data base is its maintenance. There are actually two maintenance issues. One is the period of time that data are retained for the analyses; that is, are failure rates that occurred 10 years ago relevant to the current components and parts? Should only the last 5 years of data be considered or should all available data (i.e., from the beginning of the system life cycle) be considered?

There are both logical and statistical solutions to this issue, but separate solutions would probably be needed for each part, component, or at least each aircraft type. First, a logical analysis should be conducted to determine if there have been significant modifications of a part or component. If modifications have been made, previous failure data are probably not relevant. Second, failure rates for specific time periods should be correlated to determine if older data are still predictive of future occurrences. For example, data collected during the early years of a part's use might not be predictive of its current failure probability (i.e., wear and tear effects). Both approaches should be used to determine the relevant data base time periods for each part or component and entered into the RAC computations.

The second maintenance issue is how frequently the data base should be updated. One extreme would be to have the data entered directly (i.e., bypass ASMIS) into the risk assessment data base as each failure occurs. This procedure would be cumbersome and labor intensive. It would also have little analytical benefit unless the same part failed several times during a very short period; that is, each separate incident could not be analyzed for a departure from historical rates. The update period should be at least once a year. This will minimize the effort required to edit the data for accuracy and consistency, but it may not provide timely information in detecting a widespread part or component deficiency. It is recommended that a quarterly or a semiannual update be conducted.

Resource and statistical approaches for determining the optimal update periods may both be different for different parts, components, or aircraft. First, the resources available for processing and managing the data will dictate how often the data base can be updated. Within those constraints, however, statistical analyses can be conducted to determine how often failures are likely to occur, which indicate a significant change in a part's or a component's reliability.

Because the data base can reside in a personal computer, it could be made available to any user who needs the information for managing his or her aviation risks. Updates could be performed at a central location and distributed to the subscribers on floppy disk.

RECOMMENDATIONS

The results of this research about the benefit of using aircraft component and part failure data to support the Army's risk management program lead to four major recommendations:

1. Collect and edit the part and component failure data for all aircraft in the U.S. Army inventory. Although the results of the UH-60 and the UH-1 data were very similar, other aircraft have different components and

parts, are used to fly different missions, and are in different stages of the aircraft life cycle. These data are needed not only to provide aircraft-specific data but also to support the determination of mathematically defined hazard levels.

2. Use the failure data to develop an objective definition of each hazard level. Such objective definitions will facilitate both the assessment of risk by authorized personnel and the communication of the risk level to subordinate units.

3. Develop a computerized data base system to provide timely and accurate information for analyzing aviation risks. This recommendation was discussed in detail in the preceding section. However, additional research to develop appropriate data manipulation and interpretation routines and to determine the optimal time periods for updating the data base are highly recommended to ensure the data base provides the best possible analytical information.

4. Review the equipment improvement report, the quality deficiency report, and the flight safety parts data bases for component and part failure data that are not currently in ASMIS. Any additional data that are reliable should be incorporated into the risk assessment data base to increase its comprehensiveness.

REFERENCES

Headquarters, Department of the Army (1988). The Army safety program (Army Regulation 385-10). Washington, DC: Author.

U.S. Department of Defense (1991). Department of Defense Instructions 5000.2, Section 6. Washington, DC: Author.

Headquarters, Department of the Army (1987). Accident reporting and records (Army Regulation 385-40). Washington, DC: Author.

U.S. Government Printing Office (1992). Aviation safety management information system (ASMIS) retrieval and processing system aviation user's guide. Washington, DC: Author.

Headquarters, Department of the Army (1983). Aircraft accident investigation and reporting (Department of the Army Pamphlet 385-95). Washington, DC: Author.