# NAVAL POSTGRADUATE SCHOOL
## Monterey, California

# THESIS

# A HUMAN ERROR ANALYSIS AND MODEL OF NAVAL AVIATION MAINTENANCE RELATED MISHAPS

by

Dylan D. Schmorrow

September 1998

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# REPORT DOCUMENTATION PAGE

*Form Approved*
*OMB No. 0704-0188*

**1. AGENCY USE ONLY** ***(Leave blank)***

**2. REPORT DATE**
September 1998

**3. REPORT TYPE AND DATES COVERED**
Master's Thesis

**4. TITLE AND SUBTITLE**
**A HUMAN ERROR ANALYSIS AND MODEL OF NAVAL AVIATION MAINTENANCE RELATED MISHAPS**

**5. FUNDING NUMBERS**

**6. AUTHOR(S)**
Schmorrow, Dylan D.

**7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)**
Naval Postgraduate School
Monterey, CA 93943-5000

**8. PERFORMING ORGANIZATION REPORT NUMBER**

**9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)**

**10. SPONSORING / MONITORING AGENCY REPORT NUMBER**

**11. SUPPLEMENTARY NOTES**
The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

**12a. DISTRIBUTION / AVAILABILITY STATEMENT**
Approved for public release; distribution is unlimited.

**12b. DISTRIBUTION CODE**

**13. ABSTRACT** ***(maximum 200 words)***

Naval Aviation is in the midst of a major transformation as it attempts to come to terms with the demands of maintaining operational readiness in the face of diminishing budgets and reduced manning. Diminishing operating and procurement budgets mean that Naval Aviation is for the most part "making do" with existing aircraft. Over the past decade, one in four Naval Aviation mishaps were partially attributable to maintenance error. The present operating environment underscores the need to address maintenance error and its causes. The current study accomplishes three things. First, it evaluates 470 Naval Aviation mishaps with distinct maintenance error correlates. Second, it categorizes those errors using a taxonomy based upon current organizational and psychological theories of human error. Third, it mathematically models the consequences of these errors and uses the models to (a) predict the frequency with which maintenance-based mishaps will occur in the future and (b) approximate the potential cost savings from the reduction of each error type.

**14. SUBJECT TERMS**
Aviation Accidents, Aviation Mishaps, Accident Classification, Accident Prediction, Maintenance Mishaps, Human Factors, Human Error, Poisson Process, Cost Estimation

**15. NUMBER OF PAGES**
147

**16. PRICE CODE**

| | | | |
|---|---|---|---|
| **17. SECURITY CLASSIFICATION OF REPORT** | **18. SECURITY CLASSIFICATION OF THIS PAGE** | **19. SECURITY CLASSIFI- CATION OF ABSTRACT** | **20. LIMITATION OF ABSTRACT** |
| Unclassified | Unclassified | Unclassified | UL |

**NSN 7540-01-280-5500**

**Standard Form 298 (Rev. 2-89)**
**Prescribed by ANSI Std. 239-18**

# A HUMAN ERROR ANALYSIS AND MODEL OF NAVAL AVIATION MAINTENANCE RELATED MISHAPS

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Submitted in partial fulfillment of the
requirements for the degree of

**MASTER OF SCIENCE IN OPERATIONS RESEARCH**

from the

**NAVAL POSTGRADUATE SCHOOL**
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| | |
|---|---|
| AGM | Aircraft-Ground Mishap |
| AMB | Aircraft Mishap Board |
| DOD | Department of Defense |
| FM | Flight Mishap |
| FRM | Flight-Related Mishap |
| FY | Fiscal Year |
| MIR | Mishap Investigation Report |
| MRM | Maintenance-Related Mishap |
| NAVAIR | Naval Air Systems Command |

# EXECUTIVE SUMMARY

Naval Aviation is in the midst of a major transformation as it attempts to accommodate the demands of maintaining operational readiness in the face of diminishing budgets and reduced manning. The effects of Naval Aviation mishaps are significant in terms of loss of life, money, mission readiness, and mission capability. Over the past decade, one in four Naval Aviation mishaps were partially attributable to maintenance error. Throughout the past decade, Naval Aviation leadership has focused attention on the role of aircrew error and has seen a concomitant decrease in mishaps. However, leadership has not focussed on maintenance-related mishaps (MRMs) when, in point of fact, the maintenance of existing platforms will become increasingly important. Unless dramatic changes occur in the current operational environment, Naval Aviation will be confronted with a diminishing number of fleet aircraft that are rapidly aging.

The baseline methodological tool of this thesis is the Human Factors Accident Classification System (HFACS). The HFACS is a contemporary data collection and organizational instrument designed to aid in the analysis of Naval Aviation mishaps. It integrates theories and models derived from the psychological and organizational literature to produce a taxonomic tool with which an accident investigator can categorize the various forms of human error that may have been related to the mishap. The Maintenance Extension used in the present study is simply a variant of the HFACS. It is designed to focus the classification system on human error forms associated with maintenance.

The Maintenance Extension of the HFACS was used to evaluate human error directly associated with maintenance actions in 470 Naval Aviation MRMs. The analysis identified five human error categories out of ten that were most frequently associated with MRMs. These categories were *error*, *squadron*, *violation*, *unforeseen*, and *crew-resource management*. At least one of these five error types was present in over 95 percent of the 470 mishaps studied.

Information generated from the classification of human error was used to develop mathematical models which were then employed to develop a notional cost estimate associated with human errors in maintenance-related Naval Aviation mishaps. These models were, in turn, used with archival maintenance error data to gauge the potential impact of maintenance error reduction programs. Taken together, the taxonomic analysis and the model development accomplished two things. First, they identified the forms that maintenance error takes and the conditions under which they occur. Second, they identified the optimal point to employ intervention strategies to generate the most cost savings.

A variable Poisson process model was chosen as the simplest model that was suitable for predicting future mishaps. Probability tables for the number of future mishaps were derived from the density function associated with the means of the hypothetical Poisson process model. The average number of mishaps per year predicted by this model over the next five years ranged from 22 to 33 per year. Based on these values, the expected cost of MRMs for fiscal year 1998 was nearly 60 million dollars and well over 200 million for FY98 through FY02. An analysis of potential reductions associated with these error types revealed that cutting their occurrence by as low as 10 percent can save millions of dollars a year.

# ACKNOWLEDGEMENTS

The author would like to acknowledge and express appreciation to my thesis committee members, Captain George Conner, USN (retired), Captain Frank Petho, USN, and Commander John Schmidt, USN for their assistance, direction, and dedication throughout my course of study.

Appreciation is expressed also to Professors Samuel Buttrey and Lyn Whitaker for their support and assistance in statistical analysis. Appreciation is also due to Professor Patricia Jacobs for her direction concerning initial model construction and evaluation and to Professor Donald Gaver for providing modeling reference material. Gratitude is due to Lieutenant-Commander Tim Anderson, USN, for his guidance on cost estimation techniques.

Acknowledgment and gratitude is expressed to Monica Heidelberg for her love, support, sacrifice, and encouragement needed to bring this study to completion. Appreciation and gratitude is expressed also to my parents, Linda Nowland and David Schmorrow; my grandparents, Louis and Mary Schmorrow; and the rest of my family for their patience and encouragement throughout the duration of my studies.

# I. INTRODUCTION

## A. OVERVIEW

Naval Aviation is in the midst of a major transformation as it attempts to come to terms with the demands of maintaining operational readiness in the face of diminished budgets and reduced manning. Losing human or material assets because of an accident or mishap is amplified in today's operating environment. This is especially true for the U.S. Navy and Marine Corps whose strategy of "Forward Presence" require that they will be first on the scene in times of crisis. In particular, the record will show that Naval Aviation is most likely to be called upon to project force during crises. These operational requirements and Naval Aviation's response to them impact the aircraft, the aircrews, the maintainers who prepare the aircraft for flight, and the equipment those technicians use to maintain it (Nutwell and Sherman, 1997).

Naval Aviation's leadership has focused much attention on the role of aircrew error in mishaps over the past several years, and this has led to a dramatic reduction in the overall Class A Flight mishap rate[1] (Department of the Navy, 1997a). These reductions are attributable to several focused intervention programs and strategies aimed at reducing the causes of aircrew error; for example, the establishment of aircrew coordination training events and human factors councils. Unfortunately, such efforts do not address maintenance error and the conditions that cause it. Yet, during the past decade, maintenance error contributed to one in every four Naval Aviation mishaps.

Diminishing operating and procurement budgets mean that Naval Aviation must "make do" with existing aircraft. And, as operational requirements increase, these aircraft tend to be flown less to extend their life and reduce operating costs (Lockhardt, 1997). Additionally, older aircraft generally require more maintenance, more inspections, more major overhauls, and more operating limitations. This increased maintenance support is required to offset an aging fleet, which in turn underscores the need to address maintenance error and its causes. The need to preserve aviation assets and to address the problems associated with the aging aircraft fleet prompted Naval Aviation leadership to

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[1] Definitions can be found on page 6.

thoroughly examine aviation maintenance plans, policies, procedures, and practices.

Today's operational and budgetary climate demands management attention be focused on maintenance-related mishaps (MRMs). Naval Aviation must identify the types of maintenance errors associated with mishaps, and then implement intervention programs and strategies aimed at reducing the causes of these errors. The present study will take a step toward that goal. It will identify human error forms associated with past MRMs and then develop mathematical models to evaluate the most likely impact a program of focused maintenance error reduction might have.

When evaluating the general impact of human error on any given outcome variable, it is methodologically necessary to first differentiate between classes of error forms and then specify those forms associated with any particular mishap. Based upon that taxonomy, mathematical models can then be developed to predict the frequency of MRMs, project the magnitude of their associated costs, and forecast the impact various intervention strategies may have upon Naval Aviation assets. This thesis did the aforementioned and showed that reductions in certain maintenance errors by as little as 10 percent may save Naval Aviation millions of dollars annually.

## B. BACKGROUND

The current Commander of the Naval Air Systems Command (NAVAIR), Vice Admiral Lockhardt, stated that the average age of naval aircraft will continue to increase into the 21st century. He predicts that mission capability and readiness is directly coupled to this clear negative trend if left unchecked. To counter this negative trend, NAVAIR is investigating the potential impact of implementing new maintenance concepts including phased depot maintenance, the acceleration of depot work and inspection, and depot maintenance efficiencies from reliability centered maintenance actions. NAVAIR has also solicited the fleet for new ideas and has directed greater command focus on aviation maintenance issues. These efforts underscore the fact that NAVAIR must, and is, identifying and directing interventions to accommodate maintenance-related hazards and risks.

## C. PROBLEM STATEMENT

The present thesis will address Naval Aviation MRMs in a systematic fashion. Accordingly, it identifies the human-error types that contribute to MRMs and investigates the following areas:

1. The form of human errors, both direct and indirect, that lead to maintenance-related aviation mishaps;
2. The ability of stochastic models to predict future MRMs and mishap costs;
3. The type of intervention strategy or strategies – personnel training, improved policies and procedures, and command climate – that would "best" reduce MRMs; and
4. The impact reducing prevalent forms of maintenance errors by 10, 20, and 30 percent would have on future mishaps and overall costs to Naval Aviation.

## D. OBJECTIVE

The present study examines Naval Aviation MRMs to assess the nature of human error involvement and to determine potential cost savings of intervention strategies designed to reduce these errors. The primary objective is to determine which forms of human error are most prevalent, most costly in terms of loss of life, and most expensive in overall cost. A secondary objective is to present a methodology for modeling and assessing the potential benefits of proposed intervention strategies.

## E. DEFINITIONS

This study used the following definitions (Department of the Navy, 1997b):

Naval Aircraft. Refers U.S. Navy, U.S. Naval Reserve, U.S. Marine Corps, and U.S. Marine Corps aircraft.

Mishap. A naval mishap is an unplanned event or series of events directly involving naval aircraft, which result in 10 thousand dollars of greater cumulative damage to naval aircraft or personnel injury.

Mishap Class. Mishap severity classes are based on personnel injury and property damage.

a. Class A Severity. A mishap in which the total cost of property damage (including all aircraft damage) is $1,000,000 or greater; or a naval aircraft is destroyed or missing; or any fatality or permanent total disability occurs with direct involvement of naval aircraft.

b. Class B Severity. A mishap in which the total cost of property damage (including all aircraft damage) is $200,000 or more, but less than $1,000,000 and/or a permanent partial disability, and/or the hospitalization of five or more personnel.

c. Class C Severity. A mishap in which the total cost of property damage (including all aircraft damage) is $10,000 or more but less then $200,000 and/or injury results in one or more lost workdays.

Mishap Categories (Types). Naval aircraft mishap categories are defined below:

a. Flight Mishap (FM). Those mishaps in which there was $10,000 or greater DOD aircraft damage or loss of a DOD aircraft, and intent for flight for DOD aircraft existed at the time of the mishap. Other property damage, injury, or death may or may not have occurred.

b. Flight Related Mishap (FRM). Those mishaps in which there was less than $10,000 DOD aircraft damage, and intent for flight (for DOD aircraft) existed at the time of the mishap, and $10,000 or more total damage or a defined injury or death occurred.

c. Aircraft Ground Mishap (AGM). Those mishaps in which no intent for flight existed at the time of the mishap and DOD aircraft loss, or $10,000 or more aircraft damage, and/or property damage, or a defined injury occurred.

## F. SCOPE AND LIMITATIONS

This study examines Flight Mishaps (FM), Flight-Related Mishaps (FRM), and Aircraft-Ground Mishaps (AGM) which occurred from FY90 to FY97 and were caused, in part or wholly, by maintenance errors. The focus of the work is on maintenance operators. Personal injury accidents are not considered.

# II. LITERATURE REVIEW

## A. OVERVIEW

The literature review for this research included journals and textbooks covering the subjects of accident prevention, reporting, investigation, and causation. The purpose of this literature review is to provide an overview of the historic and current theories and practices concerning mishaps and to provide a rational basis to classify maintenance error.

## B. ACCIDENT PREVENTION

### 1. Origins and Practice

Interest in accident prevention did not begin until the beginning of the 20th century when employers realized that it was less expensive to prevent accidents than to pay for their consequences (Petersen, 1978). Organizations confronted with the challenge of how best to protect themselves and their employees from accidents have two options, namely, insurance and accident prevention programs (Pate-Cornell, 1996). Organizations typically employ both options (Kanis and Weegels, 1990), but the U.S. Navy does not purchase insurance and accordingly, must absorb the costs of any losses.

Accident prevention initiatives therefore, are the primary means Naval Aviation has to reduce costs associated with mishaps.

Accident prevention was initially based on the widely held notion that people committing unsafe acts, not their working conditions, were to blame for most accidents (Heinrich, 1941). This thinking fostered a preoccupation with assigning blame to people; a practice which hindered the development of systematic accident prevention well into the later half of this century (Manuele, 1981). Narrowly focusing on people and not on the environment in which they operate, tended to obscure a subset of associated causal factors. This is particularly true with systems that chronically expose individuals to hazards (Schmidt, 1987). Although there have been substantial advances in accident prevention in recent decades, the practice of blaming individuals for the accident, rather than the conditions associated with it, persists. This practice must be overcome and accidents must be analyzed in terms of the systems in which they occur.

### 2. Systems Engineering

The most effective accident prevention strategies employ systems engineering (Hawkins, 1987). The systems engineering approach was developed in the 1950's as part of the United States military's large-scale weapons programs. Systems engineering transforms operational needs into a description of system parameters and integrates them to optimize overall system effectiveness (Edwards, 1988). In addition, it focuses the level of analysis on the smallest identifiable system components and how these components interact (Bird, 1974). The strategy of focusing on the system through the development of well-defined system components exposes information that would have remained unknown without a system-level evaluation (Miller, 1988).

Systems engineering pays attention to the strengths and limitations of the human operator as an integral part of the system. The literature suggests that nearly 90 percent of accidents are attributable to human error (Heinrich, Petersen, and Roos, 1980; Hale and Glendon, 1987). Therefore, evaluating human factors associated with accidents can contribute to the understanding of systems and how they fail.

## 3. The SHEL Model

In the early 1970's the "SHEL Model" of system design was developed to provide a better way to evaluate failures in human-machine systems (Edwards, 1988). The "SHEL Model" identifies and defines four system dimensions: Software, Hardware, Environment, and Liveware. Edwards (1988) defines SHEL concepts as follows:

1. Software: the rules, regulations, laws, orders, standard operating procedures, customs, practices, and habits that govern the manner in which the system operates and in which the information within it is organized. Software is typically a collection of documents.
2. Hardware: the buildings, vehicles, equipment, and materials of which the system is comprised.
3. Environmental conditions: the physical, economic, political and social factors within which the software, hardware, and liveware operate.
4. Liveware: the human beings involved with the system.

These system dimensions and the relationships between them comprise the basis of Edward's "SHEL Model" which is depicted in Figure 1.

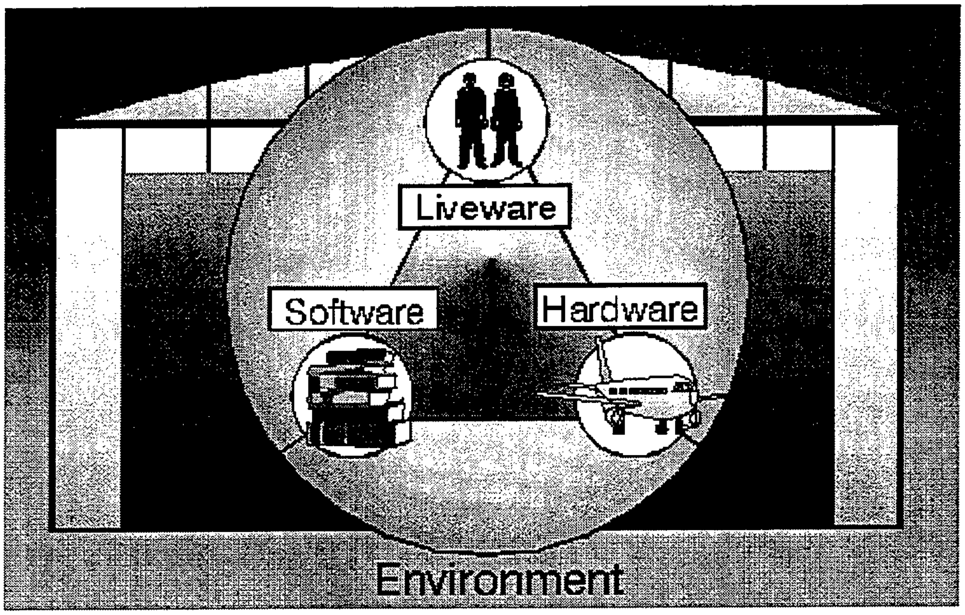

**Figure 1: SHEL Model of System Design**

The main assumption of the "SHEL Model" is that the system will fail when a failure occurs in any one of the four dimensions or in the connections between them. Edwards (1988) asserts that people are rarely the sole cause of accidents; but rather, accidents are caused by the interaction of several factors (Shappell and Wiegmann, 1997). The "SHEL Model" is a substantial departure from the commonly held belief that accidents are caused by single events (Edwards, 1981). The "SHEL Model" provides a method to describe systems, identify potential areas for concern within a system, and provide a general framework for accident investigation.

## C. ACCIDENT INVESTIGATION

Understanding systems and the environment in which they operate provides a sound basis for accident investigation because when accidents occur they occur within their industrial and organizational context (Wagenaar, Groeneweg, and Hudson, 1994). The accident investigation process initially involves a retrospective analysis of past accidents to identify and focus upon areas of probable high risk. During this phase of the investigatory process, archival data are used to identify clusters of causal factors associated with the accident. These clusters are then used to help focus future safety efforts whose goal it is to recommend effective interventions that decrease the incidence of mishaps (McElroy, 1974).

Unfortunately, the perceptions of individual accident investigators can confound the goals of an accident investigation (Benner, 1982). Furthermore, despite the large number of accidents investigated, no generally accepted method of investigation exists (Benner, 1975). Accident investigators need to have well-defined objectives and a conceptual framework within which to work. Unless models of accident causation aid investigators in their analysis and serve as potential predictors of future accident scenarios, their usefulness will be limited (Hale, Stoop, and Hommels, 1990).

## D. ACCIDENT REPORTING

Accident reports have traditionally focused on frequencies of occurrence and observations per unit time. However, frequencies and rates alone do not provide a sound basis to understand accidents (Brown, 1990a). A typical accident report consists of a narrative describing the accident accompanied by supporting documentation. The conventional process of reporting accidents varies in scope, depth, quality, objectivity, and suffers from inconsistencies and varying degrees of completeness (Edwards, 1981). In addition, human factors information concerning accidents is often not present because the traditional reporting format does not typically capture this class of variables (Adams, Barlow, and Hiddlestone, 1981).

Accident reports can aid in the determination of cause and the prevention of accidents only if the methods used to collect, classify, and record data are accurate and reliable. Accident reports are most useful when the information they contain is free from bias, is based on the potential severity or frequency of occurrence, and is easily extractable (Adams and Hartwell, 1977).

Chapanis (1962) finds three elements essential for a good accident reporting system: properly trained investigators, a good accident report form, and centralized facilities for handling reports. Two of the most important functions of accident reporting systems are first, to prevent future accidents and second, to lessen the severity of the accidents that do occur (Brown, 1990b). Unfortunately, many accident-reporting methods do not meet these two design goals; instead, they tend to evolve without proper and coherent design objectives (Adams and Hartwell, 1977; Mayer and Ellingstad, 1992). This nonsystematic process causes subsequent data analysis to be very difficult (Primble and O'Toole, 1982) because the research design typically employed in analyzing the data generated by this process has been:

1. to gather data on past accidents within a population;
2. to divide the sample into groups with and without accidents;
3. to obtain measurements of individual characteristics on all subjects;

4. to statistically compare the measures for the two groups; and finally

5. to identify whether the two groups are significantly different, thereby concluding that the differential characteristic is strongly associated with accidents.

Many studies have used this general approach, but, the conclusions based on it are suspect. (Hale and Hale, 1972, Hansen, 1988; and Shaw and Sichel, 1971; as cited by Hansen 1989, p.81)

The outcome of an analysis based on this conventional method is suspect because the variable identified as a causal factor may not actually be responsible for the findings. Rather, the variable may be correlated to an unknown third variable which itself is the causal agent. However, over the past decade the tools available for reporting accidents have been refined and are now beginning to support more rigorous and structured methods of analysis (Leplat, 1989; Malaterre, 1990; Reason, 1990; Smith, 1997). The capacity of the accident report to provide data capable of distinguishing between causal and correlative variables determines the utility of possible interventions (Hill, Byers, Rothblum, and Booth, 1994).

## E. ACCIDENT CAUSATION

### 1. Theory

There are several theories of accident causation whose objectives are to determine how accidents occur. Models of accident causation based on these theories attempt to predict and prevent accidents (Goetsch, 1996). Which theory is most useful is contested, but the predominant theme across all of them is that a chain-of-events culminates in an event called an "accident" (Grenier, 1997).

"Domino Theory" captures the essence of chain-of-event theories. "Domino Theory" suggests that accidents can be viewed as a five step sequence (Department of the Navy, 1997b).

1. Safety and Management: This is a supervisory problem.
2. Basic Causes: This includes human factors, environmental factors, or job related factors.
3. Immediate Cause: This includes substandard practices and conditions.
4. Accident: This typically is a result of falls or the impact of moving objects.
5. Personal injury and property damage: This includes lacerations, fractures, death, and material damage.

Effective intervention within the "Domino Theory" framework involves removing any of the first three "dominos" to prevent accidents, injury, and damage.

### 2. The Reason Model

Reason (1990) developed a model of accident causation using the principles of "Domino Theory." This model of accident causation was largely the result of a comprehensive study of catastrophic failures of complex technical and industrial systems. Some of the catastrophic failures examined included the U.S. Space Shuttle Challenger explosion, the Soviet nuclear reactor meltdown in Chernobyl, and the release of deadly gas by Union Carbide in Bhopal, India. Reason's model is comprised of three parts: the organizational process, task and environmental conditions, and individual unsafe acts. This model has been widely used for analyzing the role of management policies and procedures and the actions of individuals (Sargeant and Cavenagh, 1994). This model considers the errors people make the result of a chain-of-events as depicted in Figure 2.

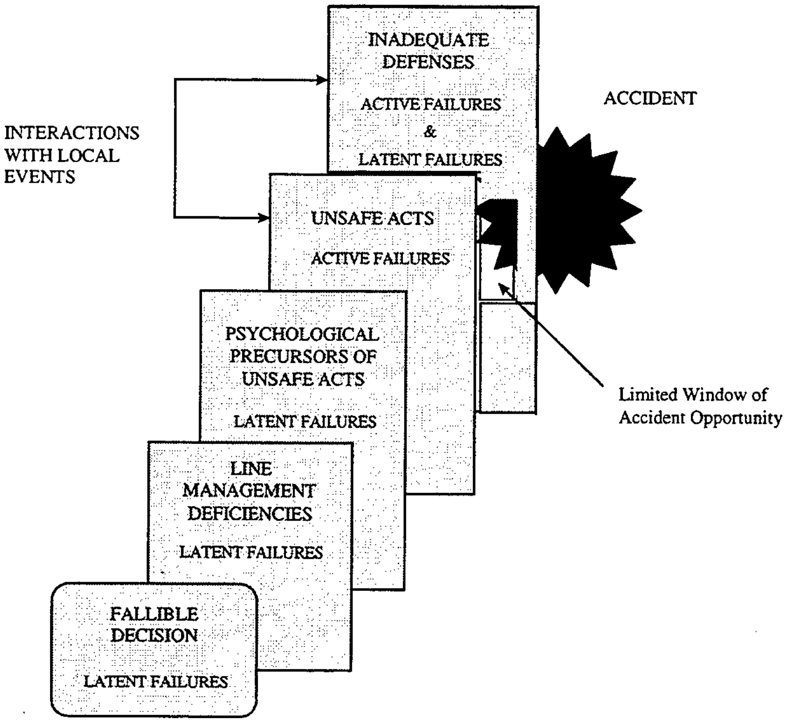

**Figure 2: Reason's Accident Causation Model**

Reason's model of accident causation examines accidents within the context of the organization in which they occur. Organizational actions that may contribute to mishaps are comprised of managerial decisions or actions that interact with environmental factors and individual unsafe acts to cause an accident (Reason, 1991). Unsafe acts that contribute to accidents are either *errors* or *violations*. *Errors* and *violations* are mediated by different psychological mechanisms (Reason, Manstead, Stradling, Baxter, and Campbell, 1990). Reason (1990) describes this differentiation as follows: "*Violations* require explanation in terms of social and motivational factors, whereas *errors* in the form of *slips*, *lapses*, and *mistakes* may be accounted for by reference to the information-processing characteristics of the individual (p.1315)." In general, this model illustrates how a combination of managerial decision-making, failures in technical expertise, and distorted communication increases the likelihood of a crisis in an organization (Smith, 1995).

Reason (1995) notes that, despite the differences in many disasters "…the root causes of these accidents have been traced to latent failures and organizational *errors* arising in the upper echelons of the system in question (p.1708)." The common elements of any accident which occurs in an organization include latent failures, local factors, active failures, and inadequate or absent defenses. Sargeant and Cavenagh (1994) define these elements as:

1. <u>Latent failures</u>: arising mainly from management decisions or actions whose repercussions may only become apparent when they combine with local triggering factors to breach the system's defenses. These latent failures are normally present well before the onset of a recognizable accident sequence, and may have remained unnoticed within the system for a considerable time.

2. Local factors: these are task, situational and environmental factors which directly influence performance in the workplace. Deficiencies in these factors can promote the occurrence of unsafe acts.

3. Active failures: are those *errors* or violations having an immediate adverse effect. These unsafe acts are typically associated with operational personnel.

4. Inadequate or absent defenses: which failed to identify and protect the system against technical and human failures arising from the three previous elements.

Accidents examined within an organizational context yields a more comprehensive understanding of the underlying accident process.

Within this organizational context, mistakes can be partitioned into two categories: mistakes caused by the lack of expertise and mistakes caused by a failure to actually apply expertise. Moreover, the organizational framework holds that the basis for these mistakes often remain inactive until they are activated by a "trigger event" (Smith, 1997). Psychosocial or managerially-related organizational features, when cojoined with seemingly unrelated and improbable events, can manifest their union in, yet again, an even more improbable event called an "accident." Reason (1990) contends that the focus of any intervention strategy must consider this conjunction between context and acts, which taken together, he calls *latent conditions*. Latent conditions are organized along seven general failure modes, which are shown in Table 1.

**Table 1: Latent Condition General Failure Types**

| Modes of Action | Modes of Failure |
|---|---|
| Goal | Incompatible Goals |
| Organize | Inappropriate Structure |
| Manage | Communications<br>Poor Planning<br>Inadequate Control and Monitoring |
| Design | Design Failures |
| Build | Unsuitable Materials |
| Operate | Poor Operating Procedures<br>Poor Training |
| Maintain | Poor Maintenance Scheduling<br>Poor Maintenance Procedures<br>Inadequate Regulation |

*Latent conditions* are a primary key in comprehending the underlying causes of accidents because *latent conditions* are the result of decisions made by individuals who are not in direct control of the system (Zotov, 1996). In general, these individuals are not front-line operators, but are maintenance personnel, construction workers, and managers associated with the system. *Active failures* on the other hand are those which are typically produced by front-line operators of the system (Grenier, 1997). *Active failures* differ from *latent failures* in that the person operating the system is responsible for causing them. Latent conditions and active failures both result from unsafe acts.

Reason's (1990) "Model of Unsafe Acts" differentiates *unsafe acts* into two primary categories, *intended* and *unintended*. Figure 3 depicts the "Model of Unsafe Acts."

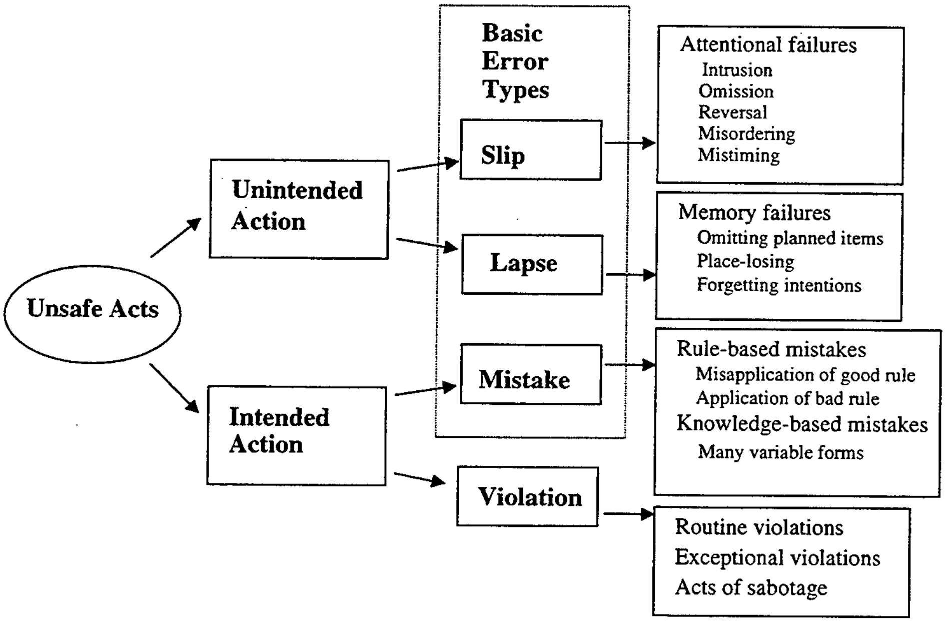

**Figure 3: Psychological Varieties of Unsafe Acts**

This model initially classifies the act according to whether it was *intended* or *unintended* and then distinguishes *errors* from *violations*. *Unintended acts* include *slips* that are the performance of an action that was not what was intended (Norman, 1981), and *lapses* that are due to memory failures (Reason, 1990). *Intended actions* included *mistakes* and *violations*. *Mistakes* occur when previously learned procedures or rules are misapplied unintentionally and *violations* are the willful disregard of established policy or procedures.

Reason's model provides a framework through which the cause of accidents can be studied. In fact, this model has been widely used as a basis to understand the causes of accidents, but it does not provide a comprehensive basis for that analysis (Shappell and Wiegmann, 1997; Zotov, 1996). Wiegmann and Shappell (1997) argue that the structure of Reason's "Model of Unsafe Acts" needs to be expanded and applied to *unsafe conditions of the operator and unsafe supervision*. Their resulting taxonomy of unsafe operations, which evolved into the Human Factors Accident Classification System (HFACS), identifies both *active* and *latent* human errors within three general categories: *unsafe acts*, *unsafe conditions of the operator*, and *unsafe supervision*.

### 3. The Human Factors Accident Classification System

#### a. Overview

The Human Factors Accident Classification System (HFACS) taxonomy was developed by Wiegmann and Shappell (1997) to help analyze Naval Aviation accidents. HFACS incorporates features of Bird's (1974) "Domino Theory," Edward's (1972) "SHEL Model," and Reason's (1990) "Unsafe Acts Model." In particular, using Edward's (1972) "SHEL Model," failures are partitioned into one of three levels of human-component failure and its associated organizational environment. Figure 4 shows the relationship of the three levels of human-component failure, which include:

- Level 1: unsafe supervision.
- Level 2: unsafe operator conditions.
- Level 3: unsafe acts of the operator.

These human-component failure categories enable an analyst to identify failures at each of the three levels historically related to accidents. This classification can then be used to target the most appropriate intervention.

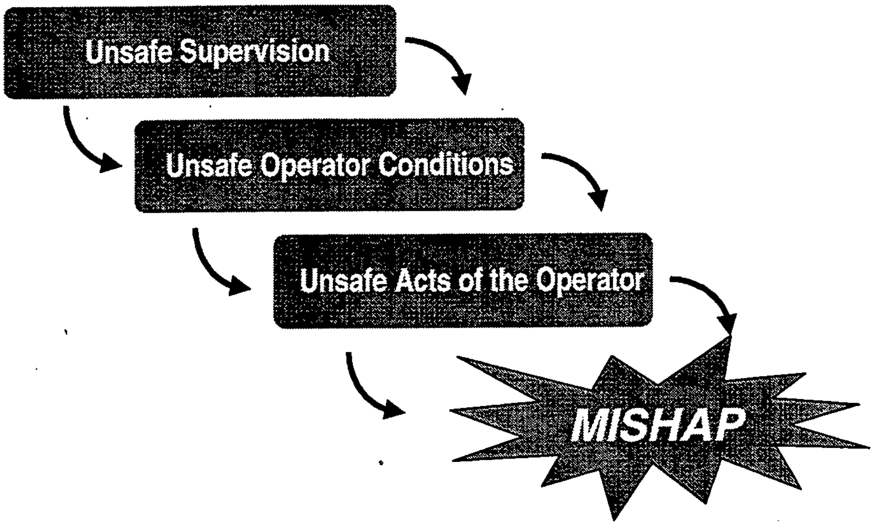

**Figure 4: Levels of Human-Component Failure**

### b. Organizational Influences

Human-component failures are always affected by organizational influences. HFACS classifies organizational influences into three broad areas: *resource management*, *organizational climate*, and *operational processes*. Table 2 provides a summary of the HFACS classifications involving organizational influence.

**Table 2: Classification of Organizational Influence**

| Resource Management | Organizational Climate | Operational Processes |
|---|---|---|
| Human | Structure | Operations |
| Monetary | Policies | Procedures |
| Equipment &Facility | Culture | Oversight |

*Organizational influence* refers to *latent failures* induced by upper-level management that directly affect all three levels of human-component failure. *Latent failures* are partitioned into three classes: *resource management*, *organizational climate*, and *operational processes*. *Resource management* includes human, monetary, and equipment resources; for example, failures induced by excessive cost cutting or lack of funding. *Organizational climate* refers to the prevailing culture within an organization. *Operational processes* include the formal methods by which things are accomplished in an organization (Shappell and Wiegmann, 1997).

### c. Unsafe Supervision

Failures associated with *unsafe supervision* can be partitioned into two subsets. Those that are *unforeseen* and those that are *known* (Shappell and Wiegmann, 1997). *"Known" unsafe supervision* includes inadequate supervision, planned inappropriate operations, failure to correct known problems, and supervisory violations. Supervisory violations include circumstances in which front-line or middle-level management do not agree with stated policies or openly disparage supervisors. *Known unsafe supervisory* actions often include situations in which the supervisor's intent may not be purposefully malicious, but simply imperious; that is, the supervisor may simply believe that "I know best."

*"Unforeseen" unsafe supervision* includes the failure to recognize unsafe operations, a lack of documentation, and inadequate design. Supervisors may have to manage several individuals who are completing tasks simultaneously. The workload imposed by this management condition can overwhelm a supervisor and diminish their situational awareness. Furthermore, supervisors will occasionally face unanticipated personal issues that adversely impact their overall effectiveness. Unanticipated equipment design problems or a lack of technical specifications, instructions, and regulations can also contribute to failures. Challenges such as these will always exist and will often contribute to the sequence of events leading to accidents. Table 3 provides a summary of the *unsafe supervision classification.*

**Table 3: Classification of Unsafe Supervision**

| Known Unsafe Supervision | Unforeseen Unsafe Supervision |
|---|---|
| Inadequate Supervision<br>Failure to administer proper training<br>Lack of professional guidance | Failure to Recognize Unsafe Operations<br>Loss of supervisory Situational awareness<br>Unseen unsafe Conditions/hazards<br>Unrecognized adverse medical Conditions<br>Life changes (e.g. divorce, Family, death, legal, Financial, or personal Problems) |
| Planned Inappropriate Operations<br>Improper work tempo | |
| Failed to Correct Known Problem<br>Failure to correct inappropriate behavior<br>Failure to correct Safety hazard | Lack of Documentation<br>Lack of technical specifications, instructions, regulations, etc. |
| Supervisory Violations<br>Not adhering to rules and regulations<br>Willful disregard for authority by supervisors | Inadequate Design<br>Equipment design that contributes to accident |

Shappell and Wiegmann (1997)

### d. Unsafe Conditions of the Operator

The *unsafe condition* and *unsafe acts* categories are closely related. *Substandard conditions of the operator* include adverse physiological states, adverse mental states, and physical or mental limitations. Operator errors manifest themselves as a function of increasing workload and can not be avoided, but adverse physiological states can greatly increase the likelihood of an accident and indeed, can be avoided (Groeger, 1990). The second category, adverse mental states, involves psychological or mental problems affecting the operator. These states, such as overconfidence and complacency, deficient situational awareness, and fatigue-related problems induced by circadian dysrhythmia and general drowsiness must be considered by an investigator to provide a more complete understanding of failures (Lourens, 1990). The third category of *unsafe conditions of the operator* involves diminished physical or mental capabilities of the operator. This category also includes special aspects of the environment that can adversely impact performance; for example, the debilitating effects of a sensorially impoverished or satiated environment.

*Substandard practices* are partitioned into three categories: mistakes and misjudgments, crew resource mismanagement, and readiness violations. Mistakes and misjudgments often involve behaviors that do not violate existing rules and regulations, yet still impair job performance. These behaviors include poor dietary practices and overexertion while off duty. Crew resource mismanagement includes not working as a team, poor crew coordination, improper task briefing, and inadequate task coordination. Crew resource management focuses on individuals directly engaged in a group task. It does not include high-level management personnel. The category of *substandard practices of the operator*, is *readiness violation*. A *readiness violation* is assumed when regulations regarding crew rest, alcohol consumption, or medications are not adhered to. Table 4 provides a general summary of the dimensions of unsafe condition of the operator.

**Table 4: Classification of Unsafe Conditions of the Operator**

| Substandard Conditions | Substandard Practices |
|---|---|
| Adverse Physiological States | Mistakes and/or Misjudgments |
| Spatial disorientation | Poor dietary practices |
| Hypoxia | Overexertion while off duty |
| Intoxication | |
| Visual illusions | Crew Resource Mismanagement |
| Physical fatigue | Not working as a team |
| Motion sickness | Poor aircrew coordination |
| Medical illness | Improper briefing before a Mission |
| Adverse Mental States | |
| Loss of situational awareness | Readiness Violation |
| Circadian dysrhythmia | Not adhering to regulations regarding crew rest, alcohol consumption, or medications |
| Complacency | |
| Alertness (Drowsiness) | |
| Overconfidence | |
| Physical and/or Mental Limitation | |
| Lack of sensory input | |
| Limited reaction time | |
| Insufficient physical capabilities | |
| Insufficient intelligence | |

Shappell and Wiegmann (1997)

### e. Unsafe Acts of the Operator

The classification of *unsafe acts of the operator* is partitioned into *unintended* and *intended acts*. *Intended unsafe acts* are defined as acts in which an operator deviates from a plan and is unaware of the deviation. A deviation from planned action is due either to a failure in execution or a failure of memory. Both failures occur at the skill-based level of processing. Failures in execution are referred to as *slips* and these include errors of intrusion, omission, reversal, misordering, and mistiming. *Slips* are due to attentional *lapses*. Memory failures typically involve the omission of planned items including losing ones' place and forgetting intentions. Operators are usually unaware of *slips* and *lapses*.

*Intended unsafe acts* are either *mistakes* or *violations*. *Mistakes* include the misapplication of a good rule or the application of a bad rule. *Mistakes* may be knowledge-based errors that involve an inaccurate or incomplete mental model of the problem space. In contrast, knowledge-based errors are the result of an operator having insufficient familiarity with the system or task. Individuals who are not experts in their field or experts not fully familiar with a new system are prone to errors of this type.

The HFACS taxonomy of *unsafe acts* defines *violations* as intended actions that may be either routine or exceptional. *Routine violations* are habitual departures from rules and regulations that are generally condoned by management. These *violations* are commonly viewed by operators and management as being acceptable departures from rules or regulations. Table 5 provides a summary of this classification (Shappell and Wiegmann, 1997).

**Table 5: Classification of Unsafe Acts of the Operator**

| Unintended Actions | Intended Actions |
|---|---|
| Slips: Attention Failures | Mistakes |
| | Rule-based |
| Intrusion | Misapplication of a good rule |
| Omission | Application of a bad rule |
| Misordering | Knowledge-based |
| Reversal | Inaccurate or incomplete mental model of the problem space |
| Mistiming | |
| Lapses: Memory Failures | Violations |
| | Routine |
| Omitting planned items | Habitual departures from rules and regulations condoned by management |
| Place-losing | Isolated departures from rules and regulations not condoned by management |
| Forgetting | |
| Intentions | |
| | Exceptional |

Shappell and Wiegmann (1997)

## F. THE HFACS MAINTENANCE EXTENSION

The *HFACS Maintenance Extension* taxonomy was used in the present work to classify causal factors that contribute to maintenance related mishaps. This addition to the HFACS consists of four broad human error categories: *Supervisory Conditions*, *Working Conditions*, *Maintainer Conditions*, and *Maintainer Acts* (see Figure 5).

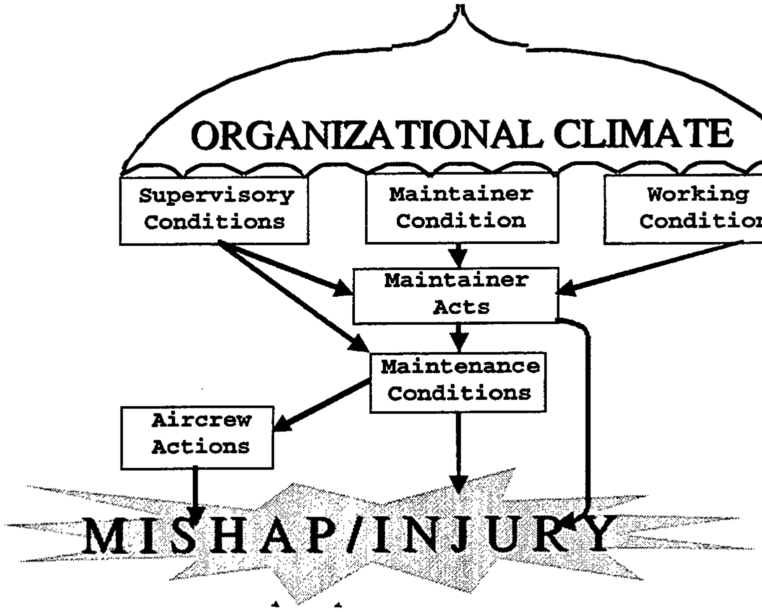

**Figure 5: HFACS Maintenance Extension**

*Supervisory Conditions*, *Working Conditions*, and *Maintainer Conditions* are *latent conditions* that can impact a maintainer's performance and can contribute to an *active failure*. A maintainer's *active failure* may lead directly to a mishap or injury; for example, a maintainer who runs a forklift into the side of an aircraft. The *active failure* could also become a *latent condition* with which the aircrew would have to accommodate in flight. *Maintenance Conditions* can directly lead to mishap or injury through no fault of the aircrew; for example, an improperly rigged landing gear that collapses on touchdown.

*Maintenance Conditions* can also cause an emergency that the aircrew must ultimately accommodate in flight. The end result would at least be minor damage or injury or in the worst case, could lead to loss of an aircraft and loss of life; for example, a fire caused by an over-torqued hydraulics line that ruptures in flight. It is important to note that *Supervisory Conditions* related to aircraft design for maintainability, prescribed maintenance procedures, and standard maintenance operations could be inadequate and lead directly to a *Maintenance Condition*. The three orders of maintenance error — first order, second order, and third order — reflect a decomposition of the error type from a molar to a micro perspective. These three orders are summarized in Table 6.

**Table 6: HFACS Maintenance Extension Categories**

| First Order | Second Order | Third Order |
|---|---|---|
| Supervisory Conditions | Unforeseen | Unrecognized Unsafe Operations<br>Inadequate Documentation<br>Inadequate Design |
| | Squadron | Inadequate Supervision<br>Planned Inappropriate Operations<br>Failed to Correct Problem<br>Supervisory Violation |
| Maintainer Conditions | Medical | Mental State<br>Physical State<br>Physical/Mental Limitation |
| | Crew Resource Management | Communication<br>Assertiveness<br>Adaptability/Flexibility |
| | Personal Readiness | Preparation/Training<br>Qualification/Certification<br>Violation |
| Working Conditions | Environment | Lighting/Light<br>Exposure/Weather<br>Environmental Hazards |
| | Equipment | Damaged<br>Unavailable<br>Dated/Uncertified |
| | Workspace | Confining<br>Obstructed<br>Inaccessible |
| Maintainer Acts | Error | Attention<br>Memory<br>Rule/Knowledge<br>Skill |
| | Violation | Routine<br>Exceptional |

Schmidt (1998)

The classification of latent *Supervisory Conditions* that can contribute to an active failure includes both unforeseen and squadron error types. Examples of situations potentially leading to *unforeseen supervisory conditions* include:

- An engine that falls off an engine-stand during change-out evolution due to an unforeseen hazard of a high sea state (Unrecognized Unsafe Operation).
- A maintenance plan that omits a necessary step in a maintenance procedure, such as leaving out an o-ring that causes a fuel leak (Inadequate Documentation).
- The poor layout of system components that do not permit direct observation of maintenance being performed (Inadequate Design).

Examples of situations potentially leading to squadron *Supervisory Conditions* include:

- A supervisor who does not ensure that maintenance personnel are wearing required personal protective gear (Inadequate Supervision).
- A supervisor who directs a maintainer to perform an operation without considering associated risks, such as driving a truck through an aircraft hanger (Planned Inappropriate Operations).
- A supervisor who neglects to correct maintainers who routinely bend the rules when they perform a routine check (Failed to Correct Problem).
- A supervisor who willfully orders a maintainer to wash an aircraft without proper safety gear (Supervisory Violation).

*Latent Maintainer Conditions* that can contribute to an active failure include medical, crew resource management, and personal readiness. Examples of maintainer medical conditions include:

- A maintainer who has a marital problem and can not focus on a maintenance action being taken (Mental State).
- A maintainer who worked 20 hours straight and suffers from mental and physical fatigue (Physical State).

- A maintainer who is short and can not visually inspect aircraft before it is prepared for a catapult launch (Physical Limitation).

Examples of maintenance crew resource management conditions include:

- A maintainer who leads an aircraft being taxied into another parked aircraft because improper hand signals were used (Communication).
- A maintainer who performs a maintenance action not in accordance with standard maintenance procedures because the maintainer was overly submissive to a superior (Assertiveness).
- A maintainer who dismisses an apparent downing discrepancy to meet the flight schedule (Adaptability).

Examples of maintenance personal readiness conditions include:

- A maintainer working on an aircraft although the maintainer did not review proper training material (Training).
- A maintainer engages in a procedure that they are not qualified to perform (Qualification).
- A maintainer intoxicated on the job (Violation).

*Latent Working Conditions* such as poor environmental factors, inadequate equipment, and uncomfortable workspaces all impact maintainer acts. For example, a maintainer who must work in a confined workspace or on the deck of an aircraft carrier during bad weather and heavy seas will likely perform poorly. Similarly, a maintainer who unknowingly uses outdated maintenance publications or damaged ground support equipment can adversely impact the quality of the maintenance. *Working Conditions* include the physical environment in which the maintainer works and the tools they use in the course of their work.

*Active failures* in the form of *Maintainer Acts* include both *errors* and *violations*. *Active failure* can directly cause damage and injury, or lead to a *latent* maintenance condition. *Active failures* include:

- A maintainer who misses a hand signal and backs a forklift into an aircraft (Attention).
- A mechanic who may be very familiar with a certain sequence of multiple steps that must be taken, but may inadvertently reverse the ordering of two of the steps within the sequence and unwittingly contribute to an accident (Memory).
- A maintainer who inflates an aircraft tire to a pressure required for a different type of aircraft tire (Rule).
- A mechanic who roughly handles a delicate engine valve and breaks a piece off (Skill).

The HFACS Maintenance Extension defines *violations* as intended actions that may be either routine or exceptional. *Routine violations* are practices that are habitual departures from rules and regulations that are generally condoned by management. These *violations* are commonly viewed by operators and management as being acceptable departures from rules or regulations. An example of a routine violation might include a situation where a forklift operator knowingly exceeds a speed limit in an aircraft hanger by three to five miles per hour, and management is aware of this violation yet does not intervene. In comparison, an exceptional violation would include a situation where the forklift operator exceeds the aircraft-hanger speed limit by twenty miles per hour.

## G. SUMMARY

A human error taxonomy is a tool used to evaluate accidents. The HFACS Maintenance Extension is a taxonomy designed specifically for the analysis of aviation maintenance-related mishaps. This taxonomy was developed within the framework of the HFACS taxonomy that proved useful in the analysis of pilot error associated with aviation mishaps. Furthermore, the HFACS Maintenance Extension is based upon established theories of human error and system design. Accordingly, the HFACS Maintenance Extension was chosen for use in the present study to aid in the analysis of Naval Aviation MRMs.

# III. METHODOLOGY

## A. RESEARCH APPROACH

This research involved the adaptation and analysis of an existing accident mishap database maintained by the U.S. Naval Safety Center. This mishap database includes all Naval Aviation Class A, B, and C Flight, Flight-Related, and Aircraft Ground mishaps. The database consists of data taken from mishap investigation reports (MIRs) submitted by Aircraft Mishap Boards (AMBs). Each MIR follows a prescribed format and includes a brief summary of the mishap event, characteristics of the mishap, and a summary of causal factors (Department of the Navy, 1997b).

The analysis of this data consists of four phases. The first phase examines the operational environment in which the mishaps used in this study occurred, then it describes the mishaps themselves. The second phase develops and evaluates mathematical models that represent the underlying mishap arrival process. The third phase identifies and summarizes human errors associated with each mishap. The final phase presents cost savings estimates based on potential reductions of human error in aviation maintenance. The cost saving estimates are based on the specific human errors associated with various maintenance actions and the mathematical models developed to represent them.

## B. DATA COLLECTION

The Naval Safety Center aviation mishap database was queried to identify all Naval Aviation MRMs. A total of 470 MRMs from FY90 through FY97 were obtained. Data included the mishap date, Type (e.g., FM, FRM, and AGM), Class (e.g., Class A, B, and C), associated casual factors, and the cost. Additionally, data were obtained from the Naval Safety Center and the Chief of Naval Air Warfare (N88) on the number of flight-hours flown per month, the number of fleet aircraft in operation per month, and the average age of those aircraft. Monthly totals of the mishaps were used and treated as point-event data to infer the data's pattern and properties. Causal factors associated with the mishaps were coded according the HFACS Maintenance Extension to account for the range of human error types.

## C. DATA ANALYSIS

### 1. Data Tabulation

The occurrences of MRMs and associated error types, and additional relevant data were entered into a spreadsheet for subsequent analysis. Monthly totals of these data were calculated and served as the basis for this analysis.

### 2. Analysis

The frequency of mishaps by Class and Type were determined. Various mathematical models were fitted to the data to find the one that best fit it. Human errors associated with the mishaps were identified and an estimate of dollar savings resulting from the reduction of each error type was produced. Procedural and policy recommendations are based on these results.

# IV. RESULTS

## A. BACKGROUND

The rate of Naval Aviation MRMs of all Classes and Types per 100,000 flight-hours has generally decreased during FY90 through FY97. In particular, Figure 6 shows the number of Naval Aviation MRMs has decreased from an average of 3.1 mishaps for FY90-FY94 to an average of 1.7 for FY95-FY97. In addition, the MRM rate as a percentage of the overall Naval Aviation mishap rate has dropped 23 percent during this time-period. The MRM rate dropped from an average of 30 percent of total mishaps before FY95 to a subsequent average of 23 percent.

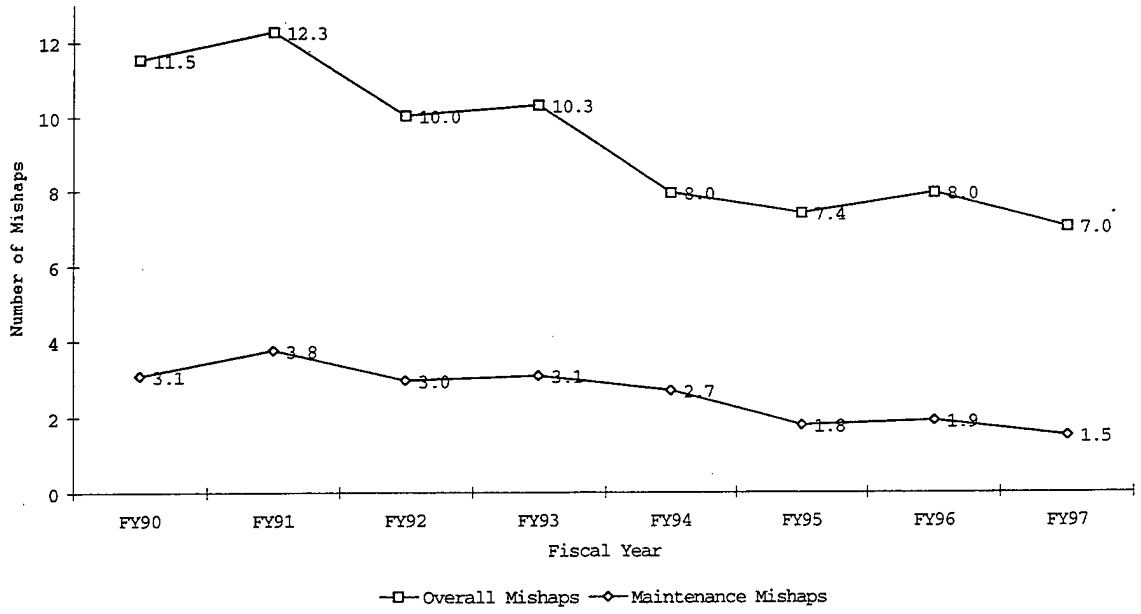

**Figure 6: Naval Aviation Mishap and MRM Rates**

From October 1989 through September 1997, Naval Aviation operated in an environment which had three significant trends: a reduction in the overall number of flight-hours flown, a reduction in the number of planes available, and an increase in the overall average age of the planes available. Figure 7 shows these trends.

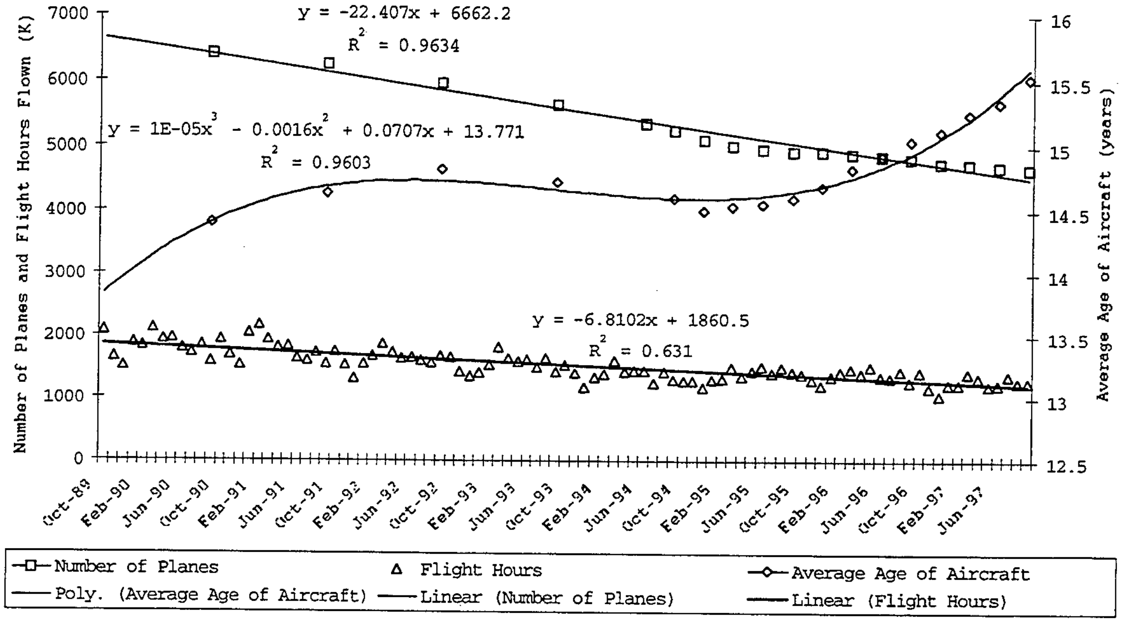

**Figure 7: Trends in Naval Aviation**

Historically, the number of flight-hours flown is considered a major factor in the analysis of aviation mishaps because increased flight operations increase maintenance requirements. Figure 8 shows that the number of MRMs per month increase as the number of flight-hours flown per month increase.

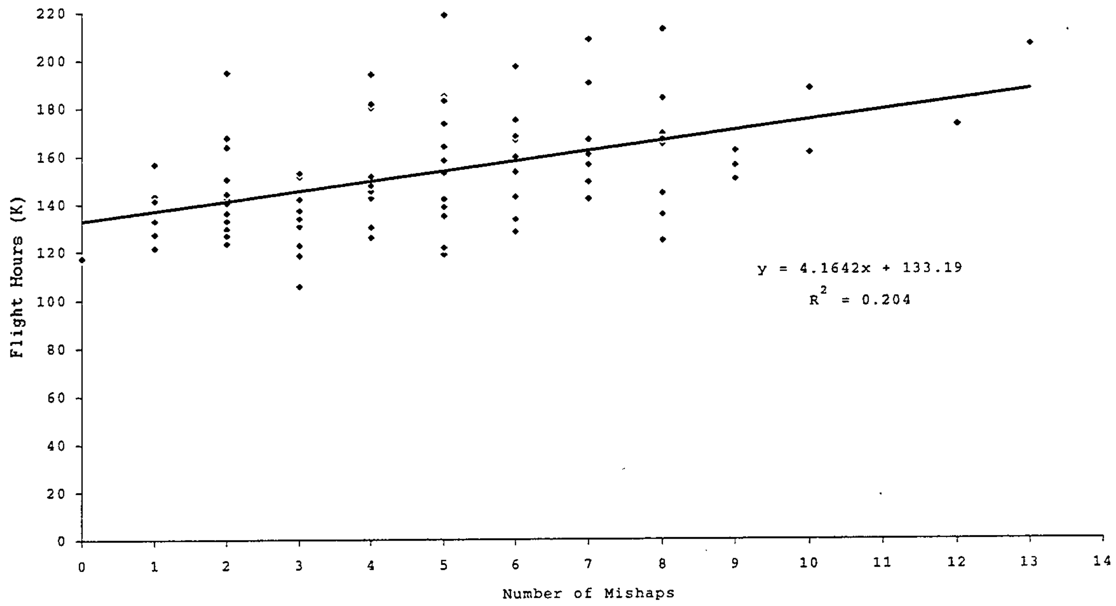

Figure 8: Flight-Hours Flown Versus Number of MRMs

Patterns in MRMs can be more clearly seen by examining them by Class and Type. Figure 9 reveals that MRMs are unevenly distributed across Class and Type and that Class C mishaps and Aircraft-Ground mishaps (AGMs) comprise the largest percentage of mishap Class and Type. Table 7 shows that nearly 50 percent of all the MRMs are Class C, Aircraft-Ground mishaps (AGMs) mishaps.

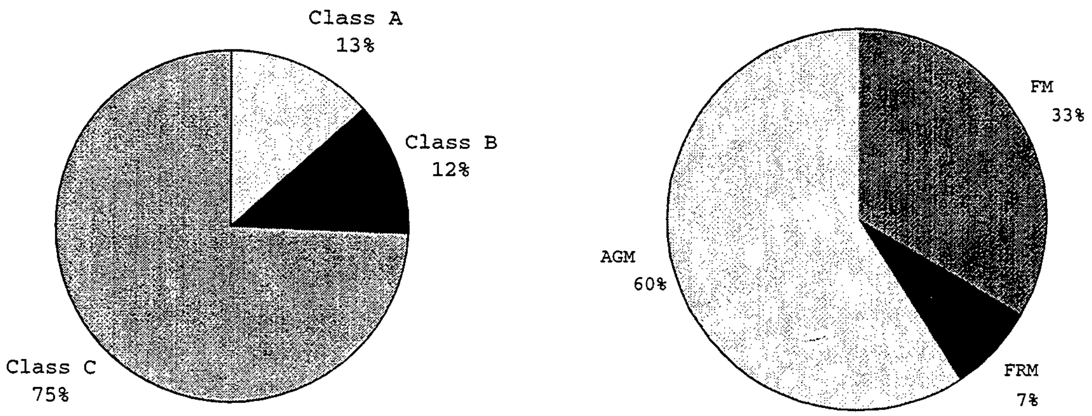

**Figure 9: FY90-FY97 MRMs by Class and Type**

**Table 7: FY90-FY97 Maintenance-Related Mishaps**

| | Flight | Flight-Related | Aircraft -Ground | Total |
|---|---|---|---|---|
| Class-A | 50 | 0 | 13 | 63 |
| Class-B | 17 | 6 | 34 | 57 |
| Class-C | 90 | 29 | 231 | 350 |
| Total | 157 | 35 | 278 | 470 |

Fifty-one people died in these mishaps: 40 were attributed to FMs and 11 to AGMs. In terms of direct financial costs, MRMs cost Naval Aviation over $800 million during the period under study; that is, from FY90 through FY97. Although Class A Flight mishaps make-up only 13 percent of all mishaps, Table 8 shows that they are the largest contributor to overall cost. Table 9 contains the average costs of MRMs by Class and Type for FY90 through 1997. Costs were normalized to FY98 dollars using aircraft procurement and weapons procurement inflation indices.

**Table 8: FY90-FY97 Total MRM Costs (FY98$M)**

| | FM | FRM | AGM | Total |
|---|---|---|---|---|
| Class-A | 796 | 0 | 3 | 799 |
| Class-B | 8 | 2 | 11 | 22 |
| Class-C | 6 | 2 | 9 | 16 |
| Total | 810 | 4 | 23 | 837 |

**Table 9: FY90-FY97 Average MRM Costs (FY98$K)**

| | FM | FRM | AGM | Total |
|---|---|---|---|---|
| Class-A | 16579 | 0 | 260 | 13537 |
| Class-B | 514 | 393 | 362 | 412 |
| Class-C | 164 | 56 | 43 | 59 |
| Total | 8261 | 116 | 91 | 2168 |

## B. DATA EXPLORATION

The frequency with which accidents occur can provide valuable information to reveal the accident's underlying arrival process. Events, such as accidents, and their associated times of occurrence are point-event data. One analytic method for point-event data is to group the data into finite time intervals then evaluate their distribution. Figures 10 and 11 show the distribution of the 96 months of MRM data by Class and Type.

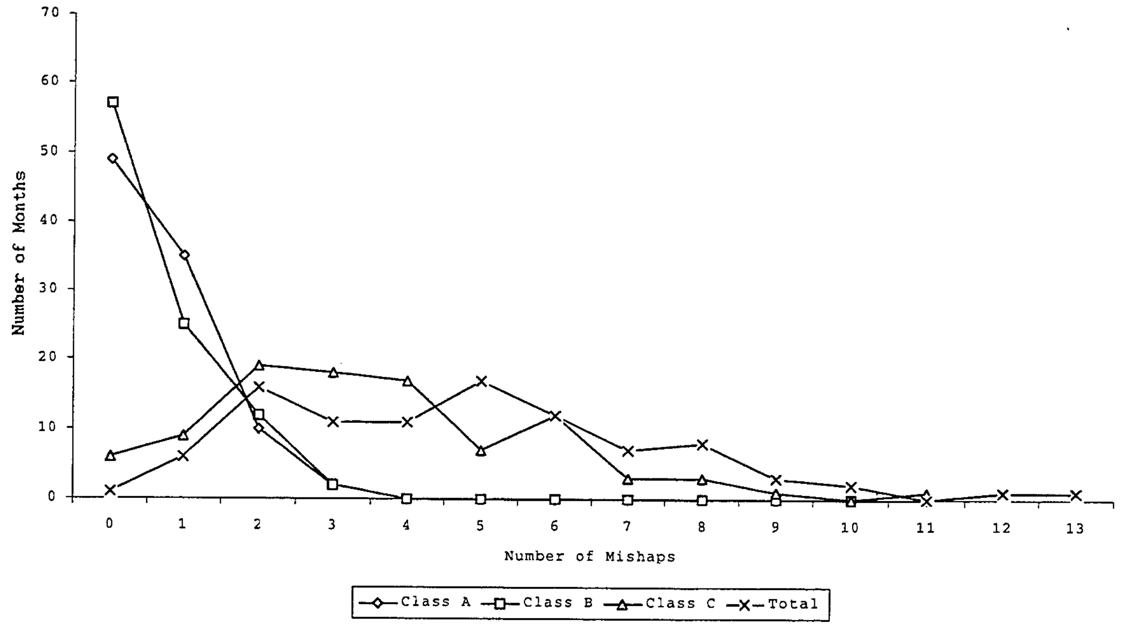

Figure 10: Distribution of Monthly Mishaps by Class

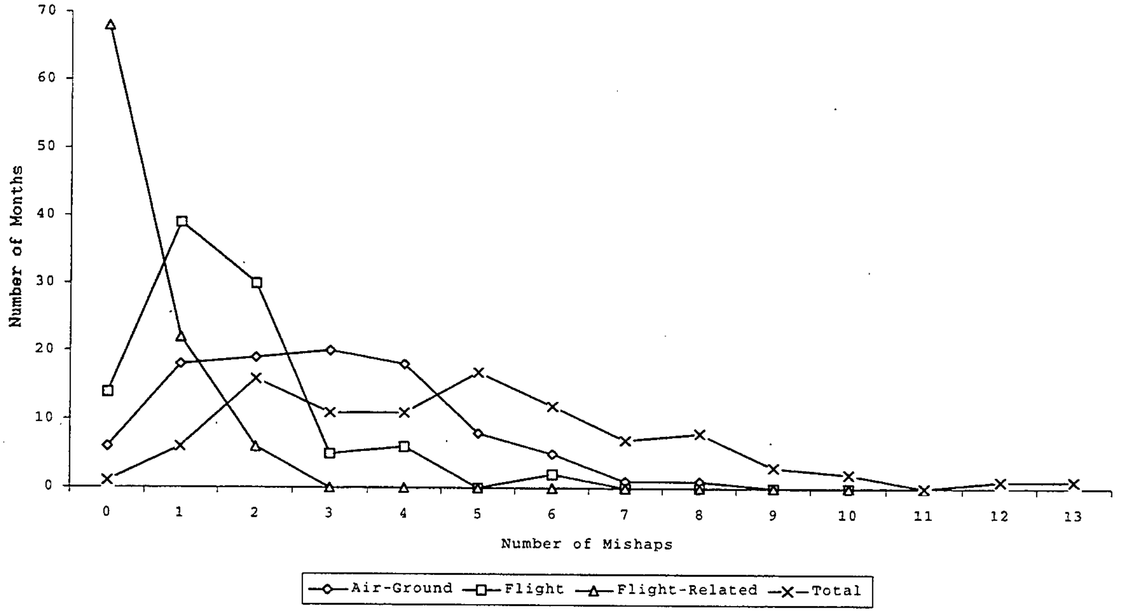

Figure 11: Distribution of Monthly Mishaps by Type

Data were grouped by month and fiscal year in this study. Table 10 shows the overall number of undifferentiated MRMs by month of occurrence. Tables of the monthly numbers of MRMs partitioned by Class and Type are at Appendix A.

**Table 10: Total MRMs by FY**

| Time Period | 90 | 91 | 92 | 93 | 94 | 95 | 96 | 97 | Total |
|---|---|---|---|---|---|---|---|---|---|
| October | 7 | 2 | 6 | 8 | 3 | 6 | 5 | 6 | 43 |
| November | 6 | 8 | 5 | 1 | 5 | 2 | 2 | 0 | 29 |
| December | 3 | 6 | 2 | 5 | 3 | 5 | 1 | 3 | 28 |
| January | 7 | 13 | 7 | 5 | 6 | 4 | 8 | 3 | 53 |
| February | 8 | 5 | 2 | 6 | 5 | 1 | 6 | 3 | 36 |
| March | 8 | 4 | 10 | 5 | 7 | 7 | 4 | 2 | 47 |
| April | 4 | 4 | 5 | 2 | 3 | 2 | 1 | 3 | 24 |
| May | 6 | 5 | 8 | 6 | 4 | 4 | 4 | 5 | 42 |
| June | 4 | 5 | 7 | 9 | 8 | 2 | 2 | 2 | 39 |
| July | 5 | 10 | 6 | 9 | 8 | 2 | 3 | 3 | 46 |
| August | 5 | 12 | 1 | 5 | 4 | 2 | 2 | 2 | 33 |
| September | 5 | 9 | 6 | 7 | 3 | 2 | 4 | 1 | 37 |
| Total | 68 | 83 | 65 | 68 | 59 | 39 | 42 | 33 | 457 |

General indications suggest there is an overall decreasing trend in MRMs. However, Figures 12 and 13 show that this overall-decreasing trend is primarily due to a drop in Class C mishaps, FMs, and AGMs. Class A, Class B, and FRMs remained constant during this same period.

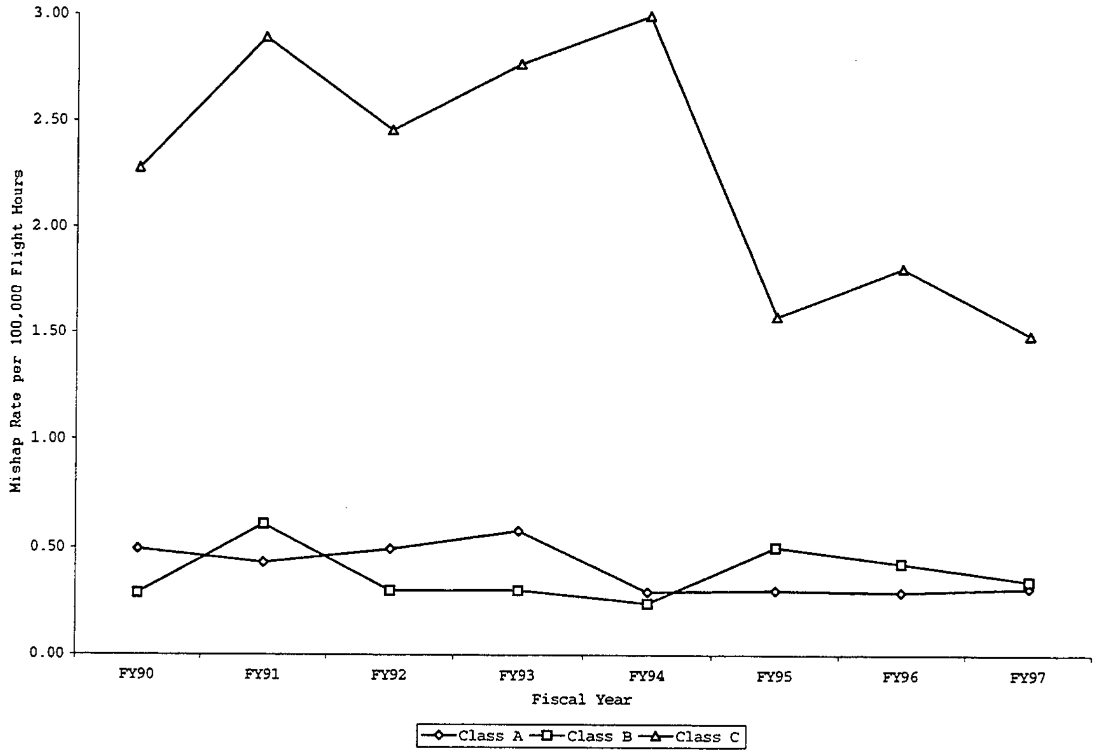

Figure 12: Mishap Rate by Class

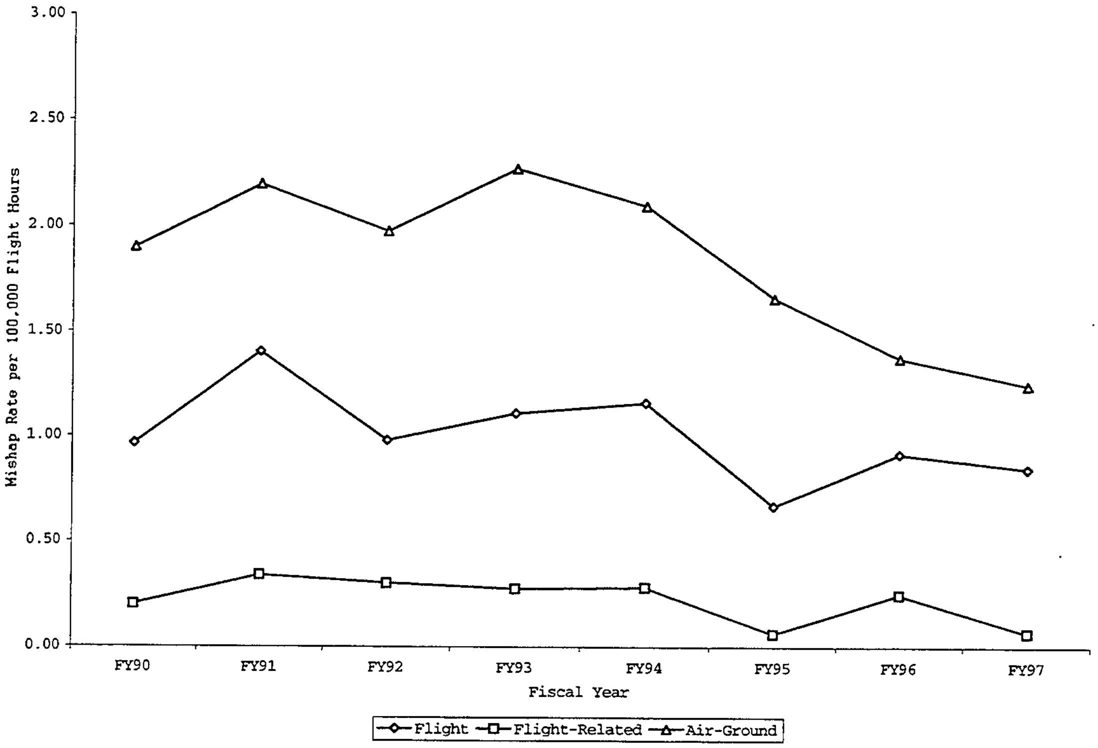

Figure 13: Mishap Rate by Type

## C. STOCHASTIC MODELING

Model fitting was used to reveal MRM's underlying arrival process. Gaver (1996) argues that if a model is considered successful it will describe similar patterns in future data. Furthermore, he specifies models for the occurrence of point event arrivals as relatively simple mathematical formulas, which are specified by one or two parameters inferred from the data.

Initial attempts to study the underlying mishap process focused on the identification of suitable, simple mathematical models that summarize the mishap data. The models considered included the Poisson process with homogenous and non-homogenous piece-wise constant rates, a moving average estimator, and a variable Poisson process. The specific question posed was: "Does strong evidence exist that the distributions of the number of arrivals per unit of time differ from one another?"

Gaver (1996) reasons that "… models are not supposed to be perfect representations of the data sets to which they are fitted, but to represent the situation of concern well enough to be useful (p.3)." The models considered were tested using a modified denominator-free

$\chi^2$ statistical test, which is superior to the classical $\chi^2$ statistical test when the data values are small and include zeros (Freeman and Tukey, 1950). It was determined on an a priori basis that models with probabilities lower than 0.05 would not be used.

The variable Poisson process model was found to be most adequate statistically in describing the MRMs. The variable Poisson process model is a method to generate an estimator based on a function fitted to historical data (Cox and Lewis, 1968). A curve is fitted to the historical data and is used to predict the mean of the hypothetical Poisson process that produces the failures. The variable Poisson process model was the simplest model found to be suitable based on initial evaluation and subsequent cross-validation. Therefore, this model forms the basis for subsequent analysis of the MRMs. Appendix B details alternative models that were rejected.

The variable Poisson process model generates monthly hypothetical MRM means for the mishap data. The value at some month $t$ is assumed to come from a Poisson process with mean $\lambda_t$, and further it is assumed that $\lambda_t$ follows the exponential decay equation $\lambda_t = a * \exp(-b * t)$. The values a and b are estimated by maximum likelihood. The likelihood function is given by

$$L(a,b) = \exp(-\sum_{t=1}^{n} a * \exp(-bt)) - \prod_{i=1}^{t} [a * \exp(-bt)]^{Y_t} .$$

where $Y_t$ is the number of mishaps at time t. The log likelihood is

$$\ell = -\sum_{t=1}^{n} a * \exp(-bt) + \sum_{t=1}^{n} Y_t * \log[a * \exp(-bt)] .$$

This yields the derivatives

$$\frac{\partial \ell}{\partial a} = -\sum_{t=1}^{n} \exp(-bt) + \sum_{t=1}^{n} \frac{Y_t * \exp(-bt)}{a * \exp(-bt)}$$

$$= -\sum_{t=1}^{n} \exp(-bt) + \sum_{t=1}^{n} \frac{Y_t}{a} \quad = \sum_{t=1}^{n} \left[ \frac{Y_t}{a} - \exp(-bt) \right]$$

and

$$\frac{\partial \ell}{\partial b} = -\sum_{t=1}^{n} a(-t) * \exp(-bt) + \sum_{t=1}^{n} \frac{Y_t * a(-t) * \exp(-bt)}{a(-t) * \exp(-bt)}$$

$$= \sum_{t=1}^{n} at * \exp(-bt) - \sum_{t=1}^{n} tY_t \quad = \sum_{t=1}^{n} \left( t * [a * \exp(-bt) - Y_t] \right) .$$

An S-plus computer program was developed to generate the values of $\hat{a}$ and $\hat{b}$ that makes the sum

$$\left( \sum_{t=1}^{n} \left[ \frac{Y_t}{\hat{a}} - \exp(-\hat{b}t) \right] \right)^2 + \left( \sum_{t=1}^{n} \left( t * [\hat{a} * \exp(-\hat{b}t) - Y_t] \right) \right)^2$$

equal to zero. This computer program can be found in Appendix C.

Once the equation that meets the criterion of least squares is obtained; the predicted values at each month *t* are calculated and compared to the data. Figure 14 presents the equation fitted to the total MRM data. Figures for mishap Class and Type can be found in Appendix D.

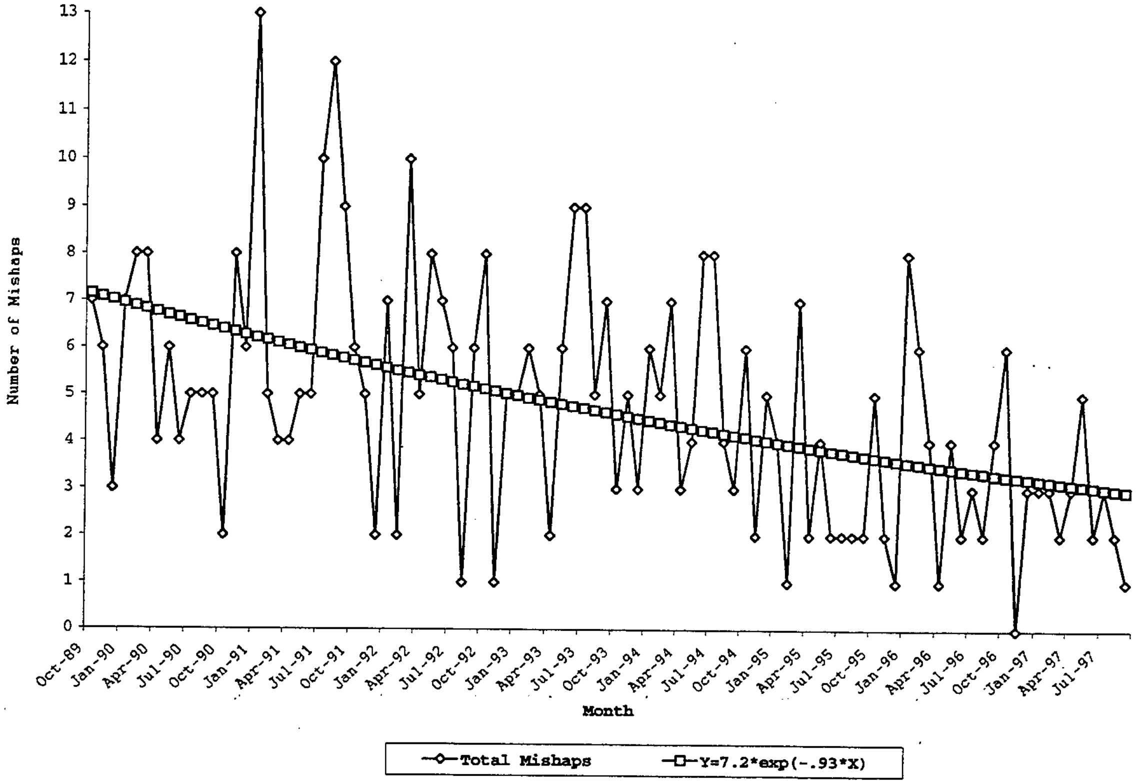

**Figure 14: Variable Poisson Process for Total MRMs**

The distribution of the number of MRMs for each month is assumed Poisson with mean $\lambda_m$. The estimate of $\lambda_m$ is $\hat{\lambda}_t = \hat{a} * \exp(-\hat{b} * t)$. The modified denominator-free $\chi^2$ test was used to determine the suitability of the estimates. This goodness of fit test compared $\sum_{i=1}^{96}\left(\sqrt{m_i}+\sqrt{m_i+1}-\sqrt{4*\hat{\lambda}_i+1}\right)^2$ to a $\chi^2_{95}$ obtaining a probability, $P\{\chi^2_{95} \geq \hat{\lambda}\}$. Table 11 shows the values of $\hat{a}$ and $\hat{b}$ that were calculated, the probabilities obtained, and the suitability of the models.

**Table 11: Variable Poisson Process Model Validation**

| Mishap Classification | $\hat{a}$ | $\hat{b}$ | $P\{\chi^2_{95} \geq \hat{\lambda}\}$ | Suitability |
|---|---|---|---|---|
| Flight | 2.3 | 0.93 | 0.962 | Not Unusual |
| Flight-Related | 0.7 | 0.91 | 0.999 | Not Unusual |
| Aircraft-Ground | 4.3 | 0.85 | 0.725 | Not Unusual |
| Class A | 1.0 | 1.43 | 0.989 | Not Unusual |
| Class B | 0.7 | 1.08 | 0.940 | Not Unusual |
| Class C | 6.9 | 0.46 | 0.079 | Not Unusual |
| Total | 7.2 | 1.38 | 0.327 | Not Unusual |

The variable Poisson process model goodness of fit test results are above the 0.05 threshold initially established for the suitability of the models. Therefore, the variable Poisson process model adequately statistically describes FMs, FRMs, AGMs, Class A, Class B, and Class C, and total mishaps. An assessment of the model for predicting MRM data was tested using additional MRM data. Table 12 contains this new mishap data.

**Table 12: October 1997 - March 1998 Monthly MRMs**

| Mishap Classification | OCT | NOV | DEC | JAN | FEB | MAR |
|---|---|---|---|---|---|---|
| Flight | 2 | 2 | 1 | 0 | 1 | 1 |
| Flight-Related | 1 | 0 | 0 | 0 | 0 | 0 |
| Air-Ground | 0 | 1 | 2 | 0 | 1 | 0 |
| Class-A | 1 | 1 | 0 | 0 | 0 | 0 |
| Class-B | 1 | 0 | 0 | 0 | 1 | 0 |
| Class-C | 1 | 2 | 3 | 0 | 1 | 1 |
| Total | 3 | 3 | 3 | 0 | 2 | 1 |

The variable Poisson process models that were fit to the original data were tested to determine if they adequately predicted the new data not used in the initial model. The modified denominator-free $\chi^2$ test was used to determine the suitability of the estimates in this cross-validation. Table 13 shows model probabilities and the suitability of the models in predicting the new data. Since no estimation was involved, results were referenced to a $\chi_6^2$ random. Cross-validation demonstrated that this model was suitable for predicting MRM probability distribution.

**Table 13: Variable Poisson Process Model Cross-Validation**

| Mishap Classification | $P\{\chi_6^2 \geq \hat{\lambda}\}$ | Suitability |
|---|---|---|
| Flight | .57 | Not Unusual |
| Flight-Related | .93 | Not Unusual |
| Aircraft-Ground | .30 | Not Unusual |
| Class A | .80 | Not Unusual |
| Class B | .82 | Not Unusual |
| Class C | .23 | Not Unusual |
| Total | .24 | Not Unusual |

## D. PROBABILITIES AND EXPECTED FUTURE COSTS

Probability tables based on equations calculated by the variable Poisson process model were developed. The values obtained from the equations are means of hypothetical Poisson processes that produce the mishaps. These means were used to predict the likelihood of future mishaps. Probability tables for FY98 and the five-year period including FY98 through FY02 provide insight into a possible environment facing Naval Aviation in the near future. Table 14 presents a summary of the FY98 probability table found in Appendix E.

**Table 14: FY98 Average Monthly MRM Probabilities**

| Mishap Classification | Number of Maintenance-Related Mishaps 0 | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|---|
| Flight | .38 | .37 | .18 | .06 | .01 | .00 | .00 |
| Flight-Related | .86 | .13 | .01 | .00 | .00 | .00 | .00 |
| Aircraft-Ground | .19 | .31 | .26 | .15 | .06 | .02 | .01 |
| Class A | .71 | .24 | .04 | .01 | .00 | .00 | .00 |
| Class B | .64 | .29 | .06 | .01 | .00 | .00 | .00 |
| Class C | .19 | .31 | .26 | .15 | .06 | .02 | .01 |
| Total | .06 | .17 | .24 | .22 | .16 | .09 | .04 |

The hypothetical expected number of MRMs per year were calculated using the variable Poisson process model. Values are obtained by summing the hypothetical monthly means that were generated by the variable Poisson process model. Table 15 presents the expected number of mishaps for FY98 through FY02.

**Table 15: Expected MRMs for FY98 - FY02**

| Mishap Classification | 98 | 99 | 00 | 01 | 02 |
|---|---|---|---|---|---|
| Flight | 11.6 | 10.4 | 9.4 | 8.5 | 7.7 |
| Flight-Related | 1.8 | 1.5 | 1.3 | 1.1 | 0.9 |
| Aircraft-Ground | 20.2 | 18.1 | 16.2 | 14.6 | 13.0 |
| Class-A | 4.1 | 3.6 | 3.2 | 2.8 | 2.4 |
| Class-B | 5.3 | 5.0 | 4.8 | 4.5 | 4.3 |
| Class-C | 20.0 | 17.0 | 14.4 | 12.2 | 10.3 |
| Total | 33.5 | 30.0 | 26.8 | 24.0 | 21.5 |

Expected costs of MRMs for FY98 and for the five-year period including FY98 through F02 were calculated. Costs are assumed independent and identically distributed. Mishaps, N, are assumed Poisson and independent of cost. Cost is given by $Cost = \sum_{i=1}^{N} C_i$ and expected cost was calculated as follows:

$$\begin{aligned} E[Cost] &= E[E[Cost \mid N]] \\ &= E[N * E[C_i]] \\ &= E[N] * E[C_i] \end{aligned}$$

The variance of this expected cost is given by

$$
\begin{aligned}
Var[Cost] &= Var[E[Cost \mid N]] + E[Var[Cost \mid N]] \\
&= Var[N * E[C_i]] + E[N * Var[C_i]] \\
&= E[C_i]^2 * Var[N] + E[N] * Var[C_i]
\end{aligned}
$$

and the standard deviation is

$$SD = \sqrt{Var[Cost]}$$

Cost values were calculated using the expanded probability tables in Appendix F and the average costs of the MRMs for FY90 through FY97. The expected cost of Naval Aviation MRMs for FY98 and the five-year period from FY98 through FY02 are in Table 16. The total dollar value shown is an average of the cost totals for mishap Type, mishap Class, and mishap total. Cost calculated directly using the total mishap variable Poisson model was not used alone because cost is highly dependent on the Class and Type of the mishap.

**Table 16: Expected Costs of Naval Aviation MRMs in FY98$M**

| Mishap Classification | FY98 Expected Cost | FY98 Standard Deviation | FY98-FY02 Expected Cost | FY98-FY02 Standard Deviation |
|---|---|---|---|---|
| Flight | 95.54 | 13.72 | 394.04 | 87.86 |
| Flight-Related | .21 | 0.26 | 0.77 | 21.34 |
| Air-Ground | 1.84 | 0.81 | 7.49 | 74.91 |
| Class-A | 55.26 | 35.59 | 216.99 | 55.97 |
| Class-B | .19 | 1.15 | 9.84 | 40.41 |
| Class-C | 1.19 | 0.35 | 4.37 | 71.00 |
| Total | 72.62 | 12.55 | 294.41 | 96.29 |

## E. HUMAN ERROR IDENTIFICATION

The Naval Aviation MRMs are categorized according to the Human Factors Accident Classification System Maintenance Extension. The number of mishaps in which a second order human error causal factor is present was identified. These human error causal factors are categorized by the corresponding HFACS Maintenance Extension second order error types in Table 17.

**Table 17: Frequency of Error Type by Accident Type and Class**

| | Unforeseen | Squadron | Environment | Equipment | Workspace | Medical | Personal Readiness | Crew-Resource Management | Error | Violation |
|---|---|---|---|---|---|---|---|---|---|---|
| FM | 68 | 80 | 0 | 4 | 0 | 0 | 0 | 13 | 126 | 52 |
| FRM | 8 | 17 | 0 | 0 | 0 | 1 | 1 | 2 | 27 | 9 |
| AGM | 75 | 185 | 6 | 16 | 2 | 22 | 2 | 63 | 217 | 121 |
| Class A | 30 | 42 | 0 | 2 | 0 | 2 | 1 | 10 | 47 | 25 |
| Class B | 25 | 41 | 1 | 3 | 0 | 3 | 0 | 6 | 44 | 21 |
| Class C | 96 | 199 | 5 | 15 | 2 | 18 | 2 | 62 | 279 | 136 |
| Total | 151 | 282 | 6 | 20 | 2 | 23 | 3 | 78 | 370 | 182 |

Table 17 shows that over 95 percent of the human error casual factors identified can be attributed to five error types. These five error types in descending number are *error*, *squadron*, *violation*, *unforeseen*, and *crew-resource management*. These error types, with the exception of *unforeseen*, were examined further to determine the impact their reductions may have on MRMs.

Figures 15 and 16 show the percentages of these error types in terms of a percentage of the total 470 mishaps analyzed.

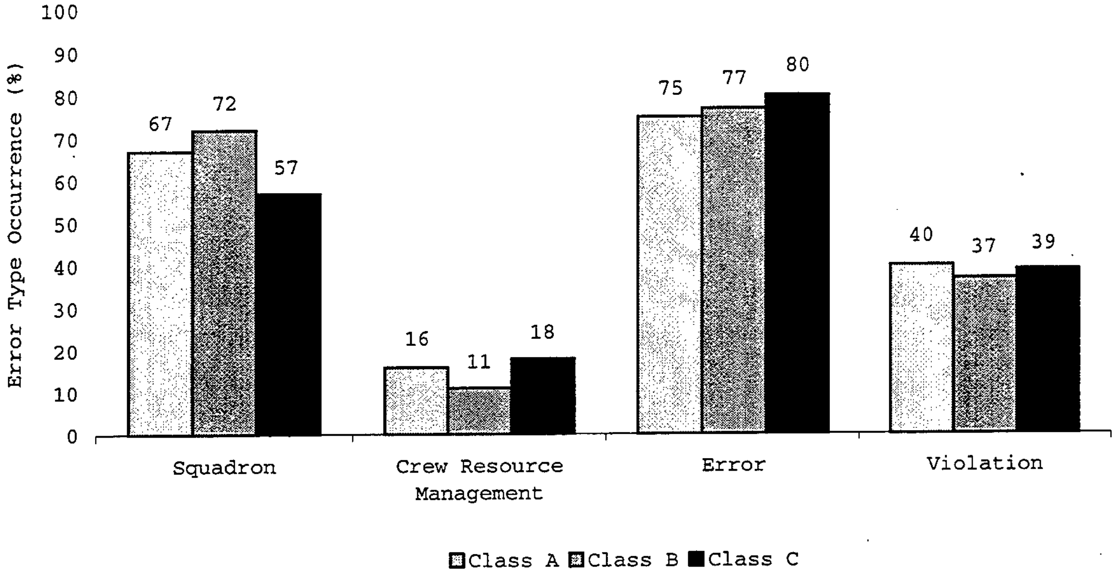

**Figure 15: Percent of Human Error by Class**

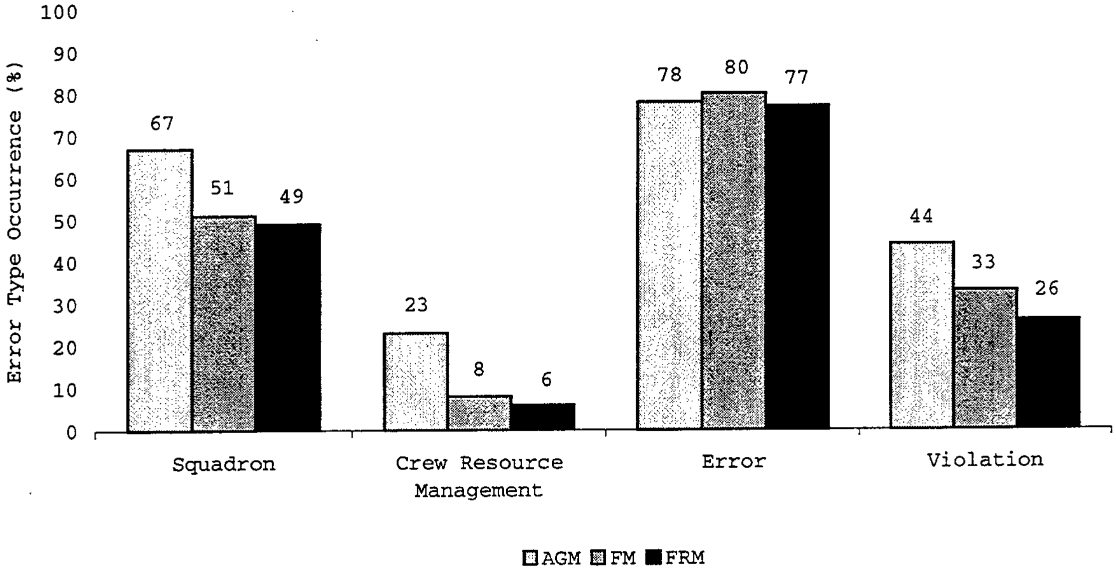

**Figure 16: Percent of Human Error by Type**

Figure 17 illustrates the rate of these five human error types per 100,000 flight-hours. The classifications of *squadron* and *error* have consistently been factors with the highest rates. However, rates of all four human error types per 100,000 flight-hours have dropped between 18 and 42 percent during the time-period studied.

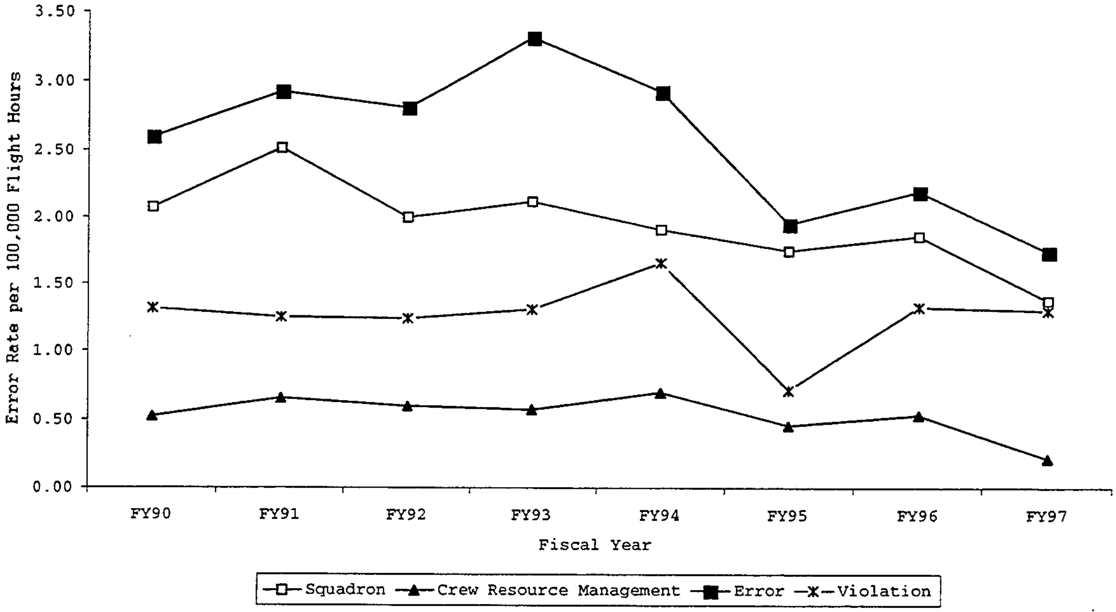

**Figure 17: Error Rate per 100,000 Flight-Hours**

## F. HUMAN ERROR IMPROVEMENT COST SAVINGS CALCULATIONS

Cost savings were based upon (a) the expected number of mishaps in the future, (b) the associated costs of those mishaps, and (c) the likelihood that human error played a role in the expected mishaps. Estimates based upon reductions of the occurrence of human error by 10, 20, and 30 percent were estimated. Cost savings estimates were calculated as follows:

$$E[\text{Cost savings}] = E[N] * E[C_i] * \%\text{Error} * \%\text{Reduction}$$

Table 18 and Figure 18 show potential cost savings over both a one-year and five-year period.

**Table 18: Potential Cost Savings (FY98$M)**

| Percent | Years | Supervisory | Crew Resource Management | Error | Violation |
|---|---|---|---|---|---|
| 10 | 1 | 4.4 | 0.9 | 6.0 | 2.8 |
|  | 5 | 18.1 | 3.5 | 24.8 | 11.3 |
| 20 | 1 | 8.8 | 1.7 | 12.1 | 5.5 |
|  | 5 | 36.1 | 7.0 | 49.6 | 22.6 |
| 30 | 1 | 13.2 | 2.6 | 18.1 | 8.3 |
|  | 5 | 54.2 | 10.5 | 74.3 | 33.9 |

Figure 18: Five Year Cost-Savings FY98$M

# V. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

## A. SUMMARY

The effects of Naval Aviation mishaps are significant in terms of fatalities, costs, readiness, and mission capability. Throughout this past decade, Naval Aviation leadership has focused much attention on the role of aircrew error and this has contributed to an overall decrease in aviation mishaps. However, similar efforts have not been taken to address MRMs. During the 1990's, one in every four Naval Aviation mishaps were maintenance-related. Unless significant changes occur in the current operational environment, Naval Aviation will continue to rely on a diminishing number of fleet aircraft that are rapidly aging. The demands for aviation maintenance will continue to increase well into the 21st century, as will the opportunities for maintenance error.

Accident prevention programs are the primary means Naval Aviation has to reduce costs associated with aviation mishaps. Accidents historically were thought to be the result of single events, a belief that is still held by some. Only through an understanding of the systems that fail and the context in which these failures occur can this belief be put to rest. This study shows that accidents are results of a complex combination of errors. Naval Aviation must address the issue of maintenance error. The only question that remains is where to target intervention strategies to reduce maintenance error. This study provides insights into maintenance error that, if acted upon, may mitigate the emerging maintenance problem.

The present research employed the Human Factors Accident Classification System (HFACS) maintenance extension. HFACS applies human error theories to aviation mishaps. The HFACS Maintenance Extension is an extension of the original HFACS taxonomy that includes human error associated directly with maintenance actions. The HFACS Maintenance Extension was used to classify 470 Naval Aviation MRMs according to specific human error types. Models were developed on the same mishap data to provide insight into the underlying processes that comprise Naval Aviation MRMs. The information obtained through this classification and modeling provided the basis to estimate the costs associated with human errors in Naval Aviation MRMs.

## B. CONCLUSIONS

This study examined Naval Aviation mishaps in a systematic manner. The occurrence of maintenance error in past MRMs and mathematical models of mishaps were used to evaluate potential effects of maintenance error reduction programs. The HFACS Maintenance Extension was used to identify the most likely forms that maintenance error takes and the conditions associated with those errors. It then highlighted where to employ intervention strategies and gave the potential cost savings associated with that intervention.

The methodologies used in this study were well adapted to the mishaps examined. In particular, the variable Poisson process model provided the means to predict future mishaps and future costs. This particular model was chosen as the simplest model that was suitable for predicting future mishaps. The model predicts a *mean* number of MRMs based on a hypothetical Poisson process. Probability tables for the number of future mishaps were derived from the density function associated with the means of the hypothetical Poisson process model. This model was cross validated on six-months of additional data. The model was found to adequately statistically describe mishaps by Type, Class, and total number of mishaps. The variable Poisson process model used in conjunction with the HFACS Maintenance Extension allowed for the prediction of cost saving estimates for human error reduction strategies.

The average number of mishaps predicted by this model per year over the next five years ranged from 22 to 33 per year. Based on these values, the expected cost of MRMs for FY98 was nearly 60 million dollars and well over 200 million for FY98 through FY02.

The HFACS Maintenance Extension categories of *error*, *squadron*, *violation*, *unforeseen*, and *crew-resource management* were the most significant contributors to cost. At least one of these five error dimensions occurred in over 95 percent of the 470 mishaps studied. An analysis of potential reductions in these error types revealed that reductions as low as 10 percent for a single error type can produce cost savings of over one million dollars annually.

## C. RECOMMENDATIONS

The use of the HFACS Maintenance Extension is recommended to make the study of MRMs more rigorous. Using the Maintenance Extension, particularly its taxonomy, allows human error intervention strategies to be identified and prioritized. This taxonomy is appropriate for the study of aviation maintenance mishaps, as well as other accidents that have associated maintenance error as causal factors.

It is recommended that the Naval Safety Center and the Naval Air Systems Command work toward revising the current procedures for aviation accident investigation and mishap reporting to include the HFACS Maintenance Extension. Adding the extension would increase the usefulness of the existing aviation mishap database by standardizing the reporting of MRMs and would aid investigators in assessing factors associated with mishaps.

Further, it is recommended that the Naval Safety Center and Naval Air Systems Command lead an effort to study trends in Naval Aviation mishaps using simple mathematical models as well as more advanced techniques not employed here. Human error theory suggests that the complex interactions of several factors result in accidents. This suggests that multivariate mathematical techniques that directly consider factors such as flight-hours flown, number of fleet aircraft, and average age of aircraft, would be appropriate.

Valid models of accident causation must predict future accident scenarios. Additional research evaluating other possible models is recommended. The analysis of different mathematical models for the prediction of Naval Aviation mishaps and mishap costs may identify models that are more suitable than those used in this research.

# APPENDIX A: MONTHLY NUMBER OF MAINTENANCE-RELATED MISHAPS BY TYPE AND CLASS FOR FY90-FY98

## Table A1: Flight Mishaps by FY

| Time Period | 90 | 91 | 92 | 93 | 94 | 95 | 96 | 97 | Total |
|---|---|---|---|---|---|---|---|---|---|
| October | 1 | 0 | 2 | 4 | 0 | 2 | 1 | 2 | 12 |
| November | 2 | 4 | 1 | 1 | 2 | 1 | 1 | 0 | 12 |
| December | 2 | 1 | 0 | 1 | 2 | 1 | 1 | 1 | 9 |
| January | 4 | 6 | 1 | 1 | 2 | 1 | 2 | 2 | 19 |
| February | 3 | 2 | 1 | 1 | 1 | 0 | 2 | 0 | 10 |
| March | 1 | 1 | 4 | 2 | 2 | 3 | 2 | 1 | 16 |
| April | 2 | 1 | 2 | 1 | 0 | 0 | 0 | 1 | 7 |
| May | 1 | 2 | 2 | 3 | 2 | 2 | 1 | 2 | 15 |
| June | 1 | 2 | 4 | 3 | 2 | 0 | 1 | 1 | 14 |
| July | 1 | 4 | 1 | 1 | 3 | 0 | 1 | 2 | 13 |
| August | 2 | 6 | 0 | 1 | 2 | 1 | 1 | 1 | 14 |
| September | 1 | 1 | 2 | 2 | 1 | 0 | 2 | 0 | 9 |
| Total | 21 | 30 | 20 | 21 | 19 | 11 | 15 | 13 | 150 |

## Table A2: Flight-Related Mishaps by FY

| Time Period | 90 | 91 | 92 | 93 | 94 | 95 | 96 | 97 | Total |
|---|---|---|---|---|---|---|---|---|---|
| October | 2 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 4 |
| November | 0 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 3 |
| December | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 2 |
| January | 0 | 2 | 0 | 0 | 0 | 0 | 1 | 1 | 4 |
| February | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 2 |
| March | 2 | 0 | 1 | 0 | 2 | 0 | 0 | 0 | 5 |
| April | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 |
| May | 1 | 0 | 1 | 2 | 0 | 0 | 0 | 0 | 4 |
| June | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 3 |
| July | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| August | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| September | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 5 |
| Total | 5 | 7 | 6 | 5 | 5 | 1 | 4 | 1 | 34 |

## Table A3: Aircraft-Ground Mishaps by FY

| Time Period | 90 | 91 | 92 | 93 | 94 | 95 | 96 | 97 | Total |
|---|---|---|---|---|---|---|---|---|---|
| October | 4 | 2 | 4 | 3 | 2 | 4 | 4 | 4 | 27 |
| November | 4 | 2 | 3 | 0 | 3 | 1 | 1 | 0 | 14 |
| December | 1 | 4 | 2 | 3 | 1 | 4 | 0 | 2 | 17 |
| January | 3 | 5 | 6 | 4 | 4 | 3 | 5 | 0 | 30 |
| February | 5 | 3 | 1 | 5 | 4 | 0 | 3 | 3 | 24 |
| March | 5 | 3 | 5 | 3 | 3 | 4 | 2 | 1 | 26 |
| April | 2 | 3 | 3 | 1 | 2 | 2 | 1 | 2 | 16 |
| May | 4 | 3 | 5 | 1 | 2 | 2 | 3 | 3 | 23 |
| June | 3 | 2 | 2 | 6 | 6 | 2 | 0 | 1 | 22 |
| July | 4 | 6 | 4 | 8 | 5 | 2 | 2 | 1 | 32 |
| August | 3 | 6 | 1 | 4 | 2 | 1 | 1 | 1 | 19 |
| September | 4 | 7 | 3 | 4 | 1 | 2 | 1 | 1 | 23 |
| Total | 42 | 46 | 39 | 42 | 35 | 27 | 23 | 19 | 273 |

## Table A4: Class A Mishaps by FY

| Time Period | 90 | 91 | 92 | 93 | 94 | 95 | 96 | 97 | Total |
|---|---|---|---|---|---|---|---|---|---|
| October | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 2 | 7 |
| November | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 5 |
| December | 1 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 3 |
| January | 3 | 2 | 2 | 0 | 0 | 1 | 0 | 0 | 8 |
| February | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 |
| March | 0 | 0 | 2 | 2 | 0 | 1 | 1 | 0 | 6 |
| April | 2 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 3 |
| May | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 6 |
| June | 1 | 0 | 1 | 2 | 1 | 0 | 0 | 0 | 5 |
| July | 0 | 1 | 2 | 3 | 0 | 0 | 0 | 0 | 6 |
| August | 1 | 2 | 0 | 0 | 1 | 1 | 0 | 1 | 6 |
| September | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 5 |
| Total | 11 | 9 | 10 | 11 | 5 | 5 | 5 | 5 | 61 |

## Table A5: Class B Mishaps by FY

| Time Period | 90 | 91 | 92 | 93 | 94 | 95 | 96 | 97 | Total |
|---|---|---|---|---|---|---|---|---|---|
| October | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 5 |
| November | 3 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 5 |
| December | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 2 | 4 |
| January | 0 | 0 | 1 | 0 | 0 | 1 | 2 | 0 | 4 |
| February | 0 | 2 | 0 | 0 | 0 | 1 | 0 | 0 | 3 |
| March | 0 | 0 | 0 | 0 | 1 | 2 | 0 | 1 | 4 |
| April | 0 | 2 | 1 | 2 | 0 | 1 | 1 | 1 | 8 |
| May | 0 | 2 | 1 | 0 | 0 | 0 | 1 | 1 | 5 |
| June | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 3 |
| July | 1 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 3 |
| August | 0 | 3 | 0 | 2 | 0 | 0 | 0 | 0 | 5 |
| September | 1 | 2 | 1 | 0 | 0 | 0 | 2 | 0 | 6 |
| Total | 6 | 13 | 6 | 6 | 4 | 8 | 7 | 5 | 55 |

## Table A6: Class C Mishaps by FY

| Time Period | 90 | 91 | 92 | 93 | 94 | 95 | 96 | 97 | Total |
|---|---|---|---|---|---|---|---|---|---|
| October | 5 | 2 | 4 | 6 | 3 | 4 | 3 | 4 | 31 |
| November | 2 | 6 | 4 | 0 | 4 | 1 | 2 | 0 | 19 |
| December | 2 | 4 | 2 | 5 | 3 | 3 | 1 | 1 | 21 |
| January | 4 | 11 | 4 | 5 | 6 | 2 | 6 | 3 | 41 |
| February | 8 | 3 | 2 | 6 | 5 | 0 | 5 | 3 | 32 |
| March | 8 | 4 | 8 | 3 | 6 | 4 | 3 | 1 | 37 |
| April | 2 | 2 | 3 | 0 | 3 | 1 | 0 | 2 | 13 |
| May | 5 | 2 | 7 | 5 | 3 | 4 | 2 | 3 | 31 |
| June | 3 | 4 | 6 | 6 | 6 | 2 | 2 | 2 | 31 |
| July | 4 | 9 | 4 | 6 | 6 | 2 | 3 | 3 | 37 |
| August | 4 | 7 | 1 | 3 | 3 | 1 | 2 | 1 | 22 |
| September | 4 | 7 | 4 | 6 | 2 | 2 | 1 | 0 | 26 |
| Total | 51 | 61 | 49 | 51 | 50 | 26 | 30 | 23 | 341 |

# APPENDIX B: ALTERNATIVE MODELS FOR THE PREDICITION OF HYPOTHETICAL MEANS OF POISSON RANDOM VARIABLES

### The Homogeneous Poisson Process Model

The homogeneous Poisson process model is a relatively simple mathematical model. This model attempts to fit a single parameter to a set of data. The underlying arrival process that produced the data is considered Poisson with mean λy. λy is assumed to be the mean value of a Poisson distribution of random variables. The MRM data was examined by year, by twelve-month period, and by month. Figures B1 and B2 show the number of MRMs by fiscal year.

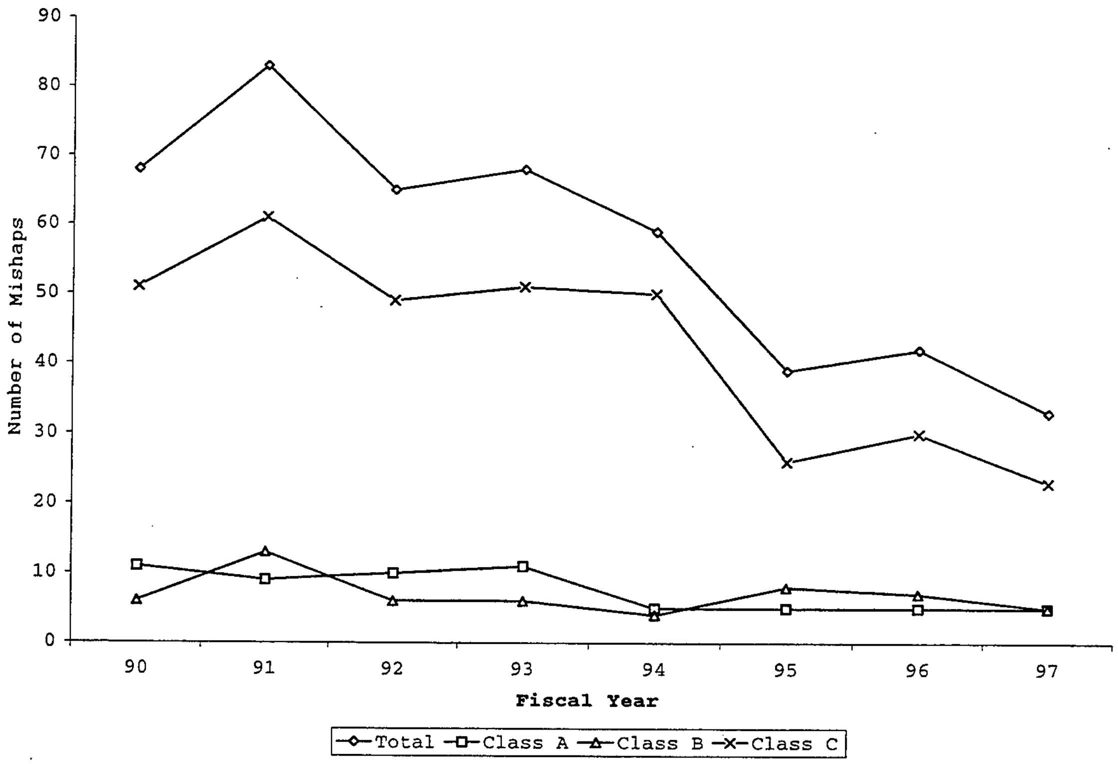

Figure B1: Maintenance-Related Mishap Class by FY

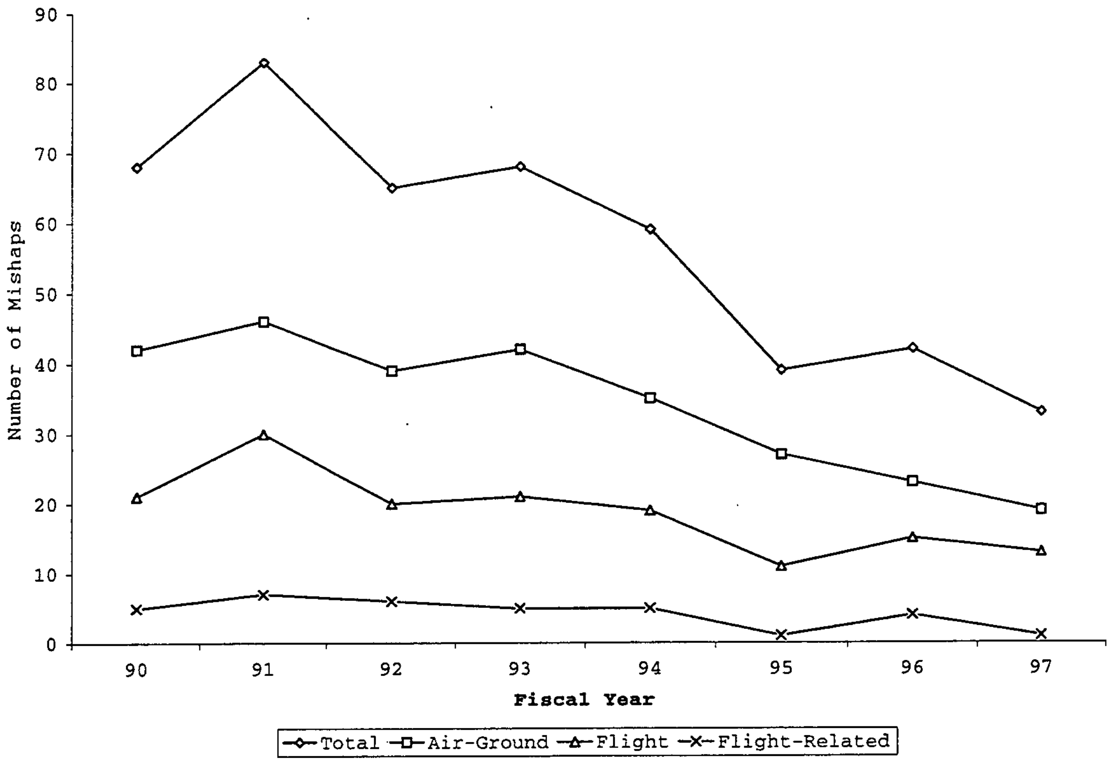

**Figure B2: Maintenance-Related Mishap Type by FY**

The estimate of $\lambda_y$ is $\hat{\lambda}_y = \frac{\sum_{i=1990}^{1997} y_i}{n}$. A $\hat{\lambda}_y$ was calculated for all Classes and Types of mishap as well for the total number of mishaps. The classical $\chi^2$ test was used to determine the suitability of this estimate. The goodness of fit test compared $\sum_{i=1990}^{1997} \frac{(y_i - \hat{\lambda}_y)^2}{\hat{\lambda}_y}$ to a $\chi_7^2$ distribution obtaining a probability, $P\{\chi_7^2 \geq \hat{\lambda}_y\}$.

**Table B1: FY Homogenous Poisson Process Model**

| Mishap Classification | $\hat{\lambda}_y$ | $P\{\chi_7^2 \geq \hat{\lambda}_y\}$ | Suitability |
|---|---|---|---|
| Flight | 18.8 | 0.005 | Unlikely |
| Flight-Related | 4.6 | 0.070 | Not unusual |
| Air-Ground | 34.1 | 0.343 | Not unusual |
| Class A | 7.6 | 0.370 | Not unusual |
| Class B | 6.9 | 0.361 | Not unusual |
| Class C | 42.6 | <0.001 | Unlikely |
| Total | 57.1 | <0.001 | Unlikely |

The homogeneous Poisson process model adequately statistically describes the yearly data for FRMs, AGMs, Class A mishaps, and Class B mishaps. However, the homogenous Poisson process model is not appropriate for modeling the yearly total number of MRMs or Class C mishaps.

Figures B3 and B4 show the number of MRMs by twelve-month period.

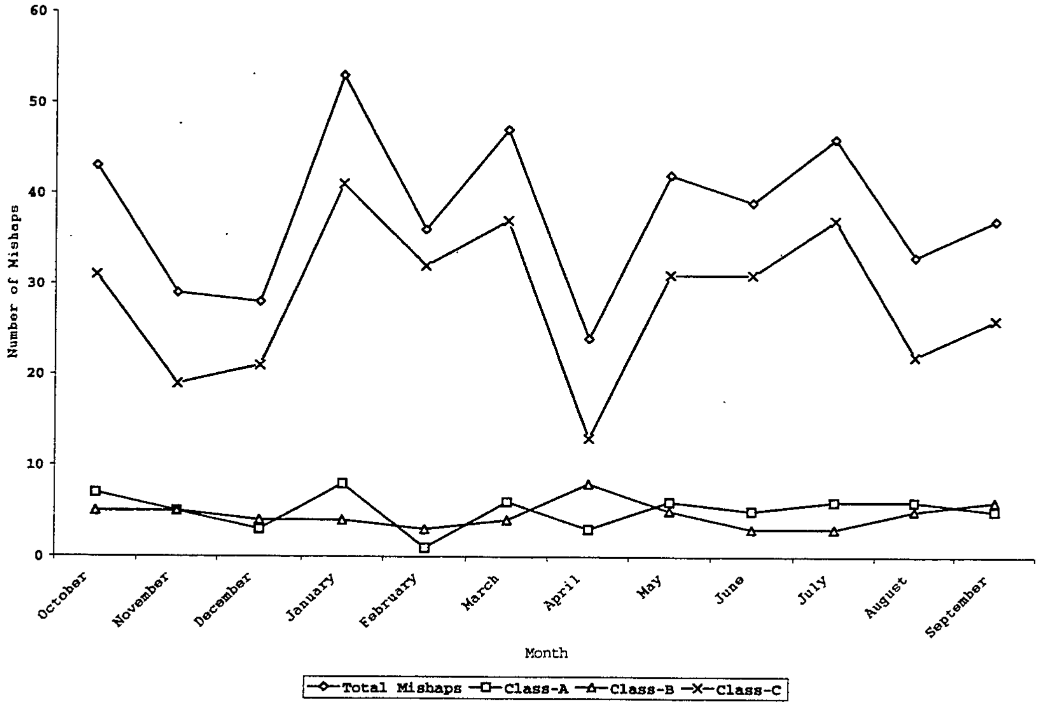

Figure B3: Twelve-Month Mishap Class by Month

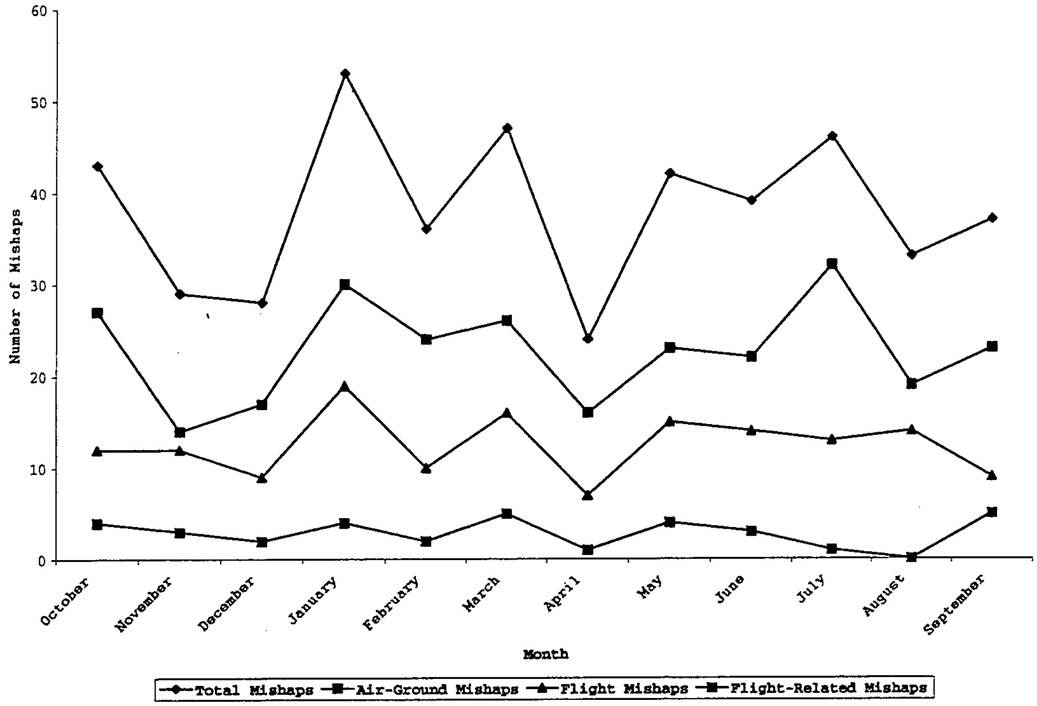

**Figure B4: Twelve-Month Mishap Type by Month**

The estimate of $\lambda_m$ is $\hat{\lambda}_m = \frac{\sum_{i=October}^{September} m_i}{12}$. A $\hat{\lambda}_y$ was calculated for all Classes and Types of mishap as well for the total number of mishaps. The classical $\chi^2$ test was used to determine the suitability of this estimate. The goodness of fit test compared $\sum_{i=October}^{September} \frac{(m_i - \hat{\lambda}_m)^2}{\hat{\lambda}_m}$ to a $\chi^2_{11}$ distribution obtaining a probability, $P\{\chi^2_{11} \geq \hat{\lambda}_m\}$.

**Table B2: Twelve-Month Homogenous Poisson Process Model**

| Mishap Classification | $\hat{\lambda}_y$ | $P\{\chi^2_7 \geq \hat{\lambda}_y\}$ | Suitability |
|---|---|---|---|
| Flight | 12.5 | 0.516 | Not unusual |
| Flight-Related | 2.8 | 0.489 | Not unusual |
| Air-Ground | 22.8 | 0.189 | Not unusual |
| Class-A | 5.1 | 0.709 | Not unusual |
| Class-B | 4.6 | 0.931 | Not unusual |
| Class-C | 28.4 | 0.005 | Unlikely |
| Total | 38.1 | 0.029 | Unlikely |

The homogeneous Poisson process model adequately statistically describes the twelve-month data for FMs, FRMs, AGMs, Class A mishaps, and Class B mishaps. The twelve-month total number of MRMs and Class C mishaps for each month may not be adequately described by a homogeneous Poisson random variable.

The estimate of $\lambda_a$ is $\hat{\lambda}_a = \frac{\sum_{i=October1989}^{September1997} a_i}{96}$. A $\hat{\lambda}_a$ was calculated for all Classes and Types of mishap as well for the total number of mishaps. The modified denominator-free $\chi^2$ test was used for mishap data separated by type and class. This goodness of fit test compared $\sum_{i=October1989}^{September1997}\left(\sqrt{a_i}+\sqrt{a_i+1}-\sqrt{4*\hat{\lambda}_a+1}\right)^2$ to a $\chi^2_{95}$ distribution obtaining a probability, $P\{\chi^2_{95} \geq \hat{\lambda}_a\}$.

**Table B3: Continuous-Month Homogenous Poisson Process Model**

| Mishap Classification | $\hat{\lambda}_a$ | $P\{\chi^2_{95} \geq \hat{\lambda}_a\}$ | Suitability |
|---|---|---|---|
| Flight | 1.6 | 0.855 | Likely |
| Flight-Related | 0.4 | 0.999 | Likely |
| Air-Ground | 2.8 | 0.221 | Likely |
| Class-A | 0.6 | 0.970 | Likely |
| Class-B | 0.6 | 0.931 | Likely |
| Class-C | 3.6 | 0.003 | Unlikely |
| Total | 4.8 | 0.005 | Unlikely |

The homogeneous Poisson process model adequately statistically describes the continuous-month data for FM, FRM, AGM, Class A, and Class B mishaps. However, the homogeneous Poisson process model is not appropriate for modeling the continuous-month total number of MRMs or Class C mishaps.

### The Non-Homogeneous Poisson Process Model

The total number of MRMs and Class C mishaps were not adequately described by any of the three homogeneous Poisson process models proposed. Although the model was unlikely, the continuous-month homogeneous Poisson process model had the highest likelihood of being an adequate estimator. Based on this, and trends noted in the data, a continuous month non-homogenous piece-wise constant rate function was examined.

The variance of Poisson random variables equals its mean. Therefore in data, of which there is a significant range in the size of counts per time unit, problems may arise because the larger the count the greater the variability. An examination of the square root of the count data can be beneficial in decreasing the effects of this problem. Figure B5 shows the square root of the monthly counts.

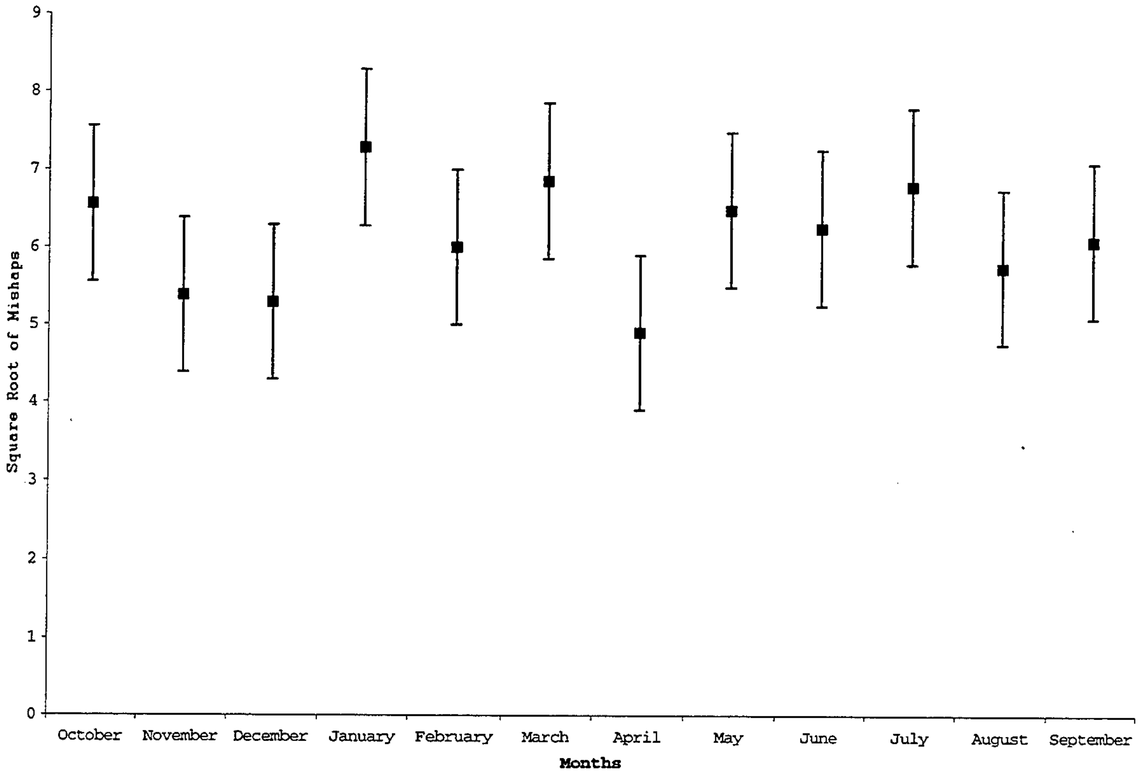

**Figure B5: Square Roots of Mishaps by Month**

An examination of Figure B5 confirms that a non-homogeneous Poisson process may be appropriate. In order to fit a non-homogenous Poisson process with a piece-wise constant rate function, months were partitioned into two groups. The proposed model, $\lambda_i = \lambda_L$ for the six months with the lowest average number of mishaps (November, December, February, April, August, and September) and $\lambda_i = \lambda_H$ the other months, was then tested.

The means $\lambda_L$ and $\lambda_H$ were estimated to determine whether the distribution of the total number of MRMs for each month can be described by a non-homogeneous Poisson process. The estimate of $\lambda_L$ is $\hat{\lambda}_L = \frac{29+28+36+24+33+37}{6} = 31.17$ and the estimate of $\lambda_H$ is

$\hat{\lambda}_H = \frac{43+53+47+42+39+46}{6} = 45$. The classical $\chi^2$goodness of fit test resulted in $\sum_{i=1}^{6(LowMonths)} \frac{(m_i - \hat{\lambda}_l)^2}{\hat{\lambda}_l} + \sum_{i=1}^{6(HighMonths)} \frac{(m_i - \hat{\lambda}_h)^2}{\hat{\lambda}_h} =$ 6.69. This value compared to a $\chi^2_{10}$ distribution, $P\{\chi^2_{10} \geq 6.69\}$, obtains a probability of 0.754. Therefore, the values of 31.17 and 45 for $\lambda_L$ and $\lambda_H$, respectively are not that unusual.

The means $\lambda_L$ and $\lambda_H$ were estimated to determine whether the distribution of Class C mishaps for each month can be described by a non-homogeneous Poisson process. The estimate of $\lambda_L$ is $\hat{\lambda}_L = \frac{19+21+32+13+22+26}{6} = 22.17$ and the estimate of $\lambda_H$ is $\hat{\lambda}_H = \frac{31+41+37+31+31+37}{6} = 34.67$. The classical $\chi^2$goodness of fit test resulted in $\sum_{i=1}^{6(LowMonths)} \frac{(m_i - \hat{\lambda}_l)^2}{\hat{\lambda}_l} + \sum_{i=1}^{6(HighMonths)} \frac{(m_i - \hat{\lambda}_h)^2}{\hat{\lambda}_h} =$ 11.97. This value compared to a $\chi^2_{10}$ distribution, $P\{\chi^2_{10} \geq 11.97\}$, obtains a probability of 0.287. Therefore, the values of 22.17 and 34.47 for $\lambda_L$ and $\lambda_H$, respectively are not that unusual. The non-homogenous Poisson process model adequately statistically describes the total number of MRMs and Class C mishaps.

### Cross-validation of Homogeneous and Nonhomogeneous Poisson Process Models

Mishap data for October 1997 through March of 1998 were obtained and used to cross-validate the models based on the fiscal year 1990 through 1997 data. The homogeneous and nonhomogeneous Poisson process fitted models which best fit the original data. This was suggested by their associated probability values; they were tested to determine if they adequately described the new data. The two models tested were the:

- nonhomogenous Poisson process model for the total number of mishaps and Class C mishaps with rates $\hat{\lambda}_L$ and $\hat{\lambda}_H$.
- and the continual-month homogeneous Poisson process models for FMs, FRMs, and AGMs, Class A mishaps, and Class B mishaps with rate $\hat{\lambda}_a$.

The classical $\chi^2$ test was used for the total number of mishaps and Class C data and the denominator-free goodness of fit test was used for the other data. Since no estimation was involved, both results were referenced to a $\chi^2_6$ random variable.

**Table B4. Cross-Validation of Homogeneous and Nonhomogeneous Poisson Process Models**

| Mishap Classification | $P\{\chi^2_6 \geq \hat{\lambda}\}$ | Suitability |
|---|---|---|
| Flight | 0.744 | Not unusual |
| Flight-Related | 0.895 | Not unusual |
| Aircraft-Ground | 0.001 | Unlikely |
| Class A | 0.720 | Not unusual |
| Class B | 0.760 | Not unusual |
| Class C | 0.006 | Unlikely |
| Total | <0.001 | Unlikely |

Homogeneous Poisson process models adequately statistically describe FMs, FRMs, Class A mishaps, and Class B mishaps. However, a homogeneous Poisson process model may not be appropriate for modeling AGMs and the non-homogeneous Poisson process model may not be appropriate for the total number of MRMs and Class C mishaps.

**Moving Average Method**

The moving average estimation technique is a method to generate an estimator based on the average of historical data. In this technique it is assumed that the overall number of mishaps on month *i* is a realization of a Poisson random variable with mean $\lambda_i$. The expected value $\lambda_{i+1}$ in month span+1 is predicted by the average of a preceding span of months' values, $\hat{\lambda}_{Span+1} = \frac{\sum_{i=1}^{Span} m_i}{Span}$. The mean squared error over all the predictions from month span+1, up to and including the last month of analysis is calculated. This is completed for every value of span from one up to the maximum span of eighty-four. For each span an associated average sum of squared error is calculated. The span with the smallest average sum of squared error is then chosen as the estimator for this mathematical model.

The first step in the moving average method is to determine the optimal span which produced the minimum average squared error. An SPLUS program was written and executed which produced the average squared error for span lengths ranging from two through eighty-four. The

Span length that on average produced a minimal amount of mean squared error and was used as a basis to calculate estimators. The spans that had the minimal amount of mean squared error for FM, FRM, AGM, Class A, Class B, and Class C mishaps were 38, 44, 46, 46, 24, and 38 respectively.

The estimate of $\lambda_m$ is $\hat{\lambda}_m = \frac{\sum_{i=1}^{Span} m_i}{Span}$. The modified denominator-free $\chi^2$ test was used to evaluate the model. This goodness of fit test compared $\sum_{i=1}^{96-Span}\left(\sqrt{m_i}+\sqrt{m_i+1}-\sqrt{4*\hat{\lambda}_m+1}\right)^2$ to a $\chi^2_{96-Span}$ distribution obtaining a probability, $P\left\{\chi^2_{96-Span} \geq \hat{\lambda}_m\right\}$.

**Table B5: Moving average Model**

| Mishap Classification | Span | $P\left\{\chi^2_{96-Span} \geq \hat{\lambda}_m\right\}$ | Suitability |
|---|---|---|---|
| Flight | 38 | 0.946 | Not unusual |
| Flight-Related | 44 | 0.999 | Not unusual |
| Air-Ground | 46 | 0.179 | Not unusual |
| Class A | 46 | 0.974 | Not unusual |
| Class B | 24 | 0.937 | Not unusual |
| Class C | 38 | 0.059 | Not unusual |
| Total | 38 | 0.204 | Not unusual |

The moving average model adequately statistically describes the monthly data for total MRMs, FMs, FRMs, AGMs, Class A mishaps, Class B mishaps, and Class C mishaps.

## Cross-validation of the moving average model

The moving average models that were fit to the original data were tested to determine if they adequately described the six-months of new data. The denominator-free goodness of fit test was used for all data. Since no estimation was involved, both results were referenced to a $\chi_6^2$ random variable.

**Table B6: Cross-validation of the moving average model**

| Mishap Classification | $P\{\chi_6^2 \geq \hat{\lambda}\}$ | Suitability |
|---|---|---|
| Flight | 0.946 | Not unusual |
| Flight-Related | 0.999 | Not unusual |
| Air-Ground | 0.042 | Unlikely |
| Class A | 0.803 | Not unusual |
| Class B | 0.790 | Not unusual |
| Class C | 0.413 | Not unusual |
| Total | 0.198 | Not unusual |

The moving average model adequately statistically describes the total number of mishaps, FMs, FRMs, AGMs, Class A, Class B, and Class C mishaps.

# APPENDIX C: VARIABLE POISSON PROCESS COMPUTER PROGRAM

**MAIN**

```
function(data, a.start = 15, b.start = 1, scale = 1/100){
#
# Main function to fit the Poisson/exponential model.
#
# Arguments: data, the set of putative Poisson counts
#            a.start, b.start: starting values
#            scale: Scale factor for numerics
# Return value: output from nlmin
#
# Step one: put data and scale into frame 1 for FUNC
#
     assign("data", data, frame = 1)
     assign("scale", scale, frame = 1)  #
#
# Call nlmin
#
     out <- nlmin(d.func, c(a.start, b.start),
     max.iter = 100)#
     plot(data, main = paste("Poisson Model for",
          substitute(data)), xlab = "Month", ylab
           = "Mishaps", type = "b")
     y.seq <- out$x[1] * exp( - out$x[2] * (1:length(
          data)) * scale)
     lines(1:length(data), y.seq, col = 8)
     return(out)
}
```

**FUNC**

```
function(param){
#
# FUNC: function for doing ML estimation in the
# Poisson/exponential model.
#
# Arguments: param, vector of parameters
# (The data is "data" in frame 1.)
#
# 1: get parameters and data
     a <- param[1]
     b <- param[2]
     data <- get("data", frame = 1)
     scale <- get("scale", frame = 1)    #
# 2: Set up the "t" vector with multipler of "scale".
#
     tt <- (1:length(data)) * scale#
#
# Compute the two terms in the likelihood; square, add them.
#
     first <- sum(data/a - exp( - b * tt))
     second <- sum(tt * (a * exp( - b * tt) - data))
     return(first^2 + second^2)
}
```

# APPENDIX D: FITTED VARIABLE POISSON PROCESS MODELS FOR MISHAP TYPE AND CLASS

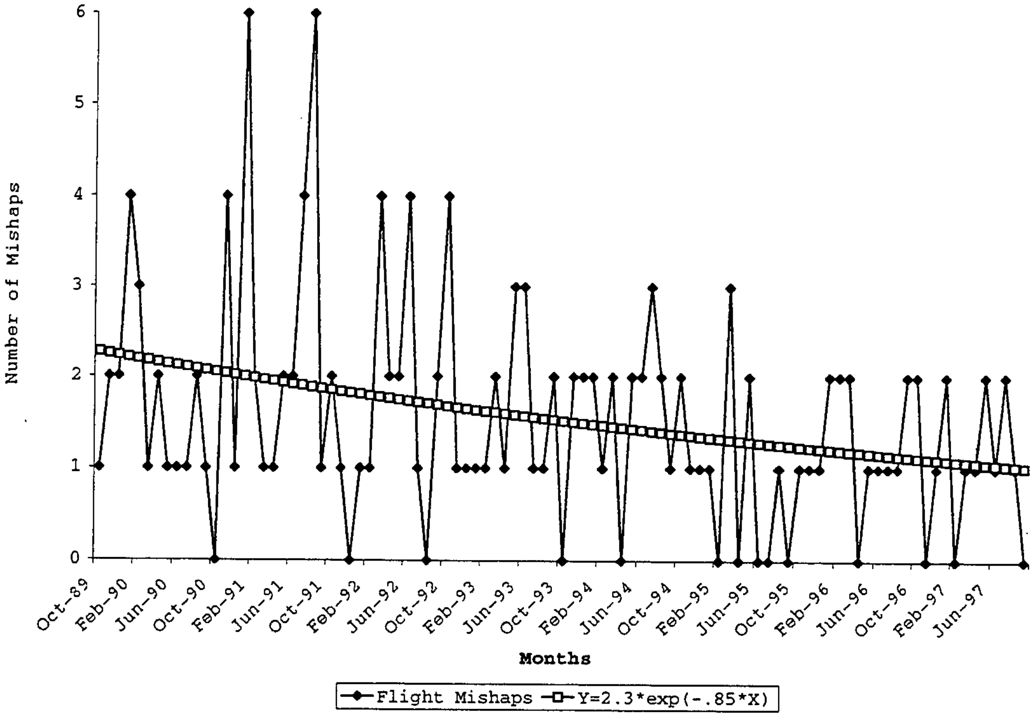

**Figure D1: Variable Poisson Process for MRM FMs**

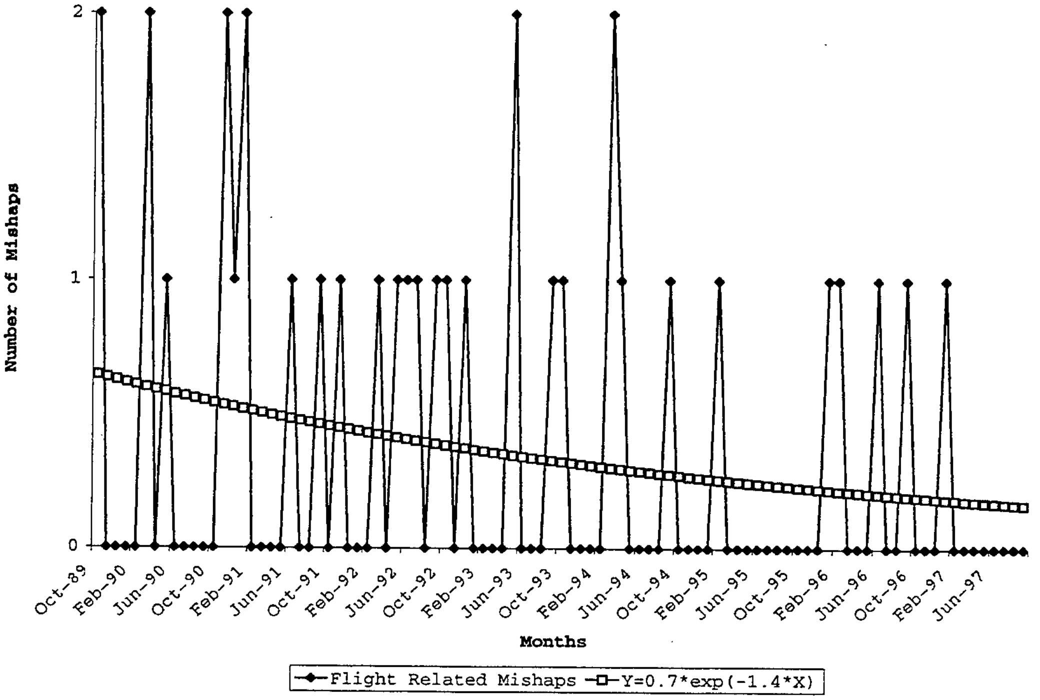

**Figure D2: Variable Poisson Process for MRM FRMs**

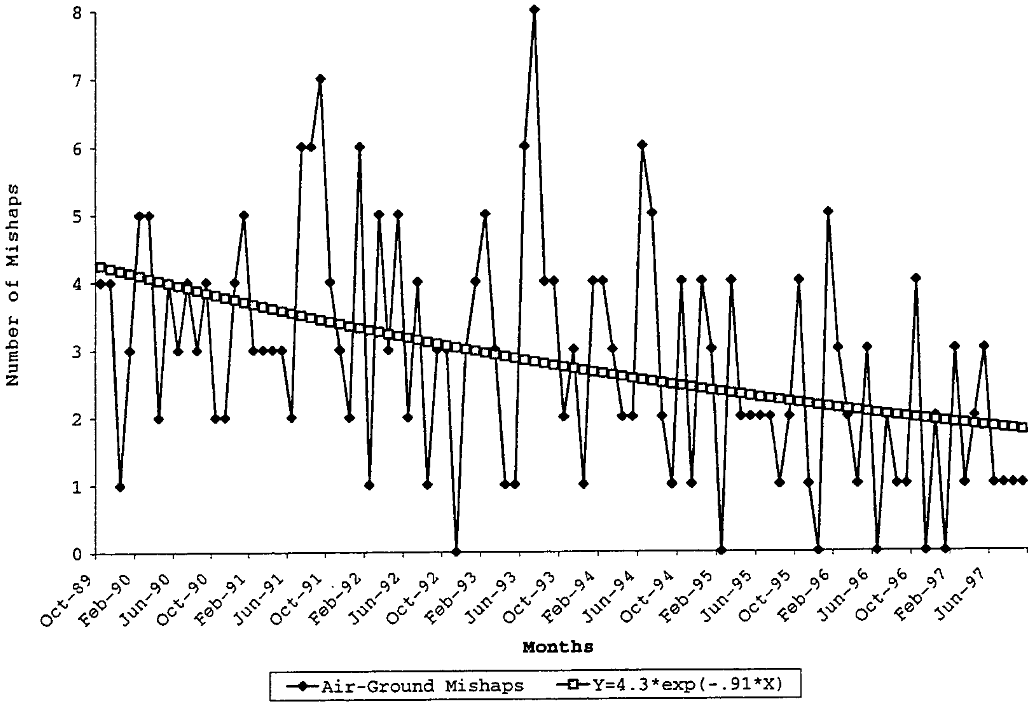

Figure D3: Variable Poisson Process for MRM AGM

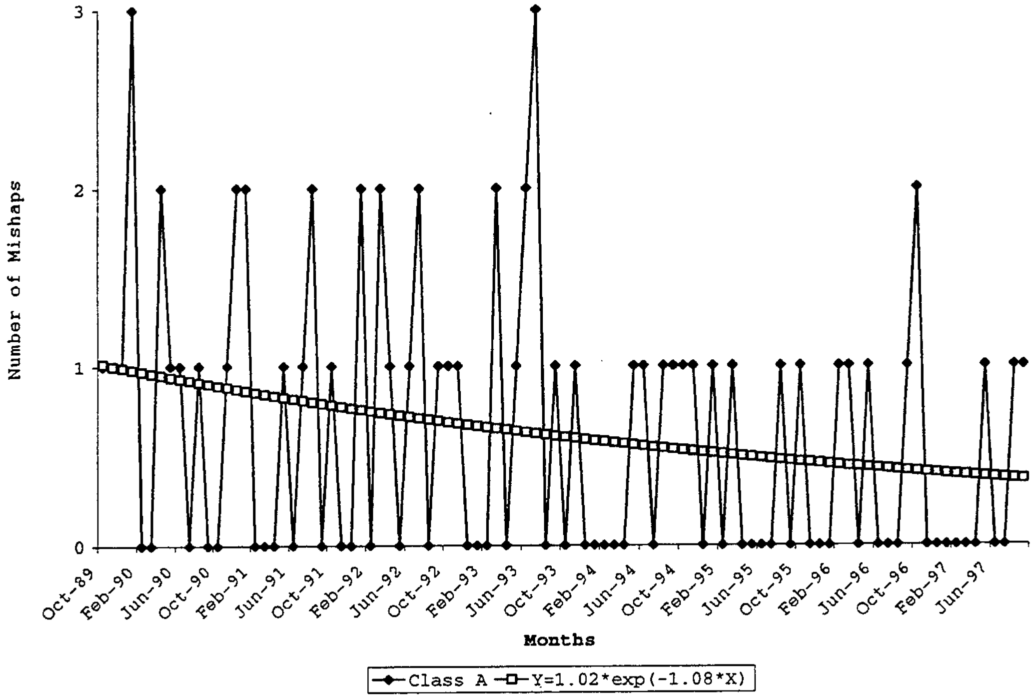

Figure D4: Variable Poisson Process for Class A MRMs

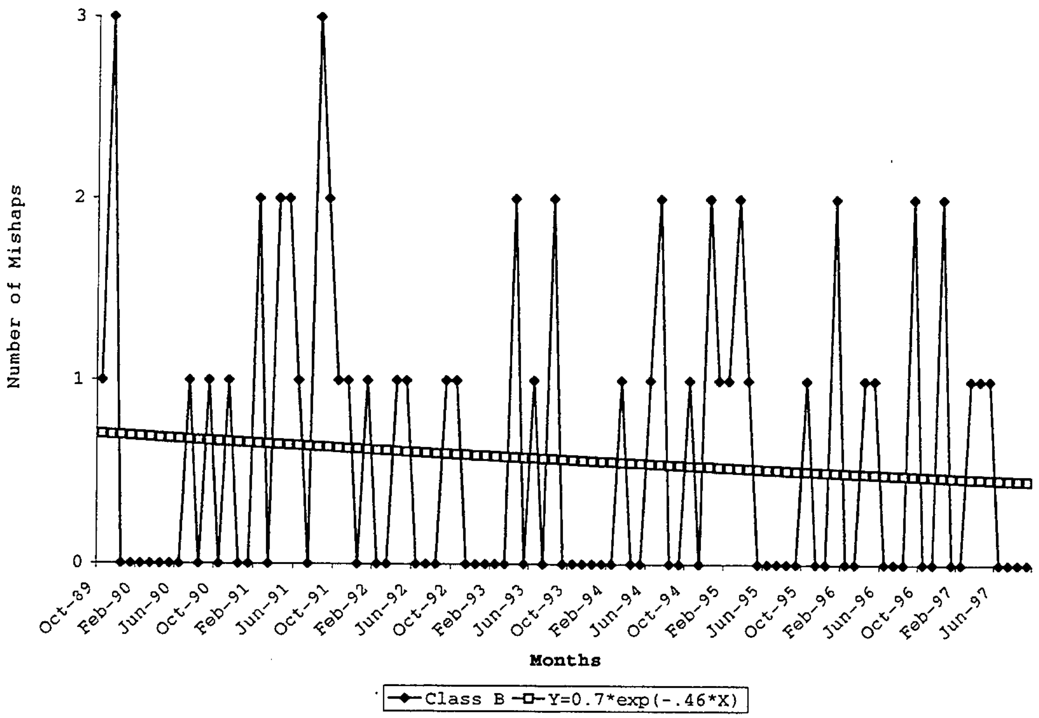

**Figure D5: Variable Poisson Process for Class B MRMs**

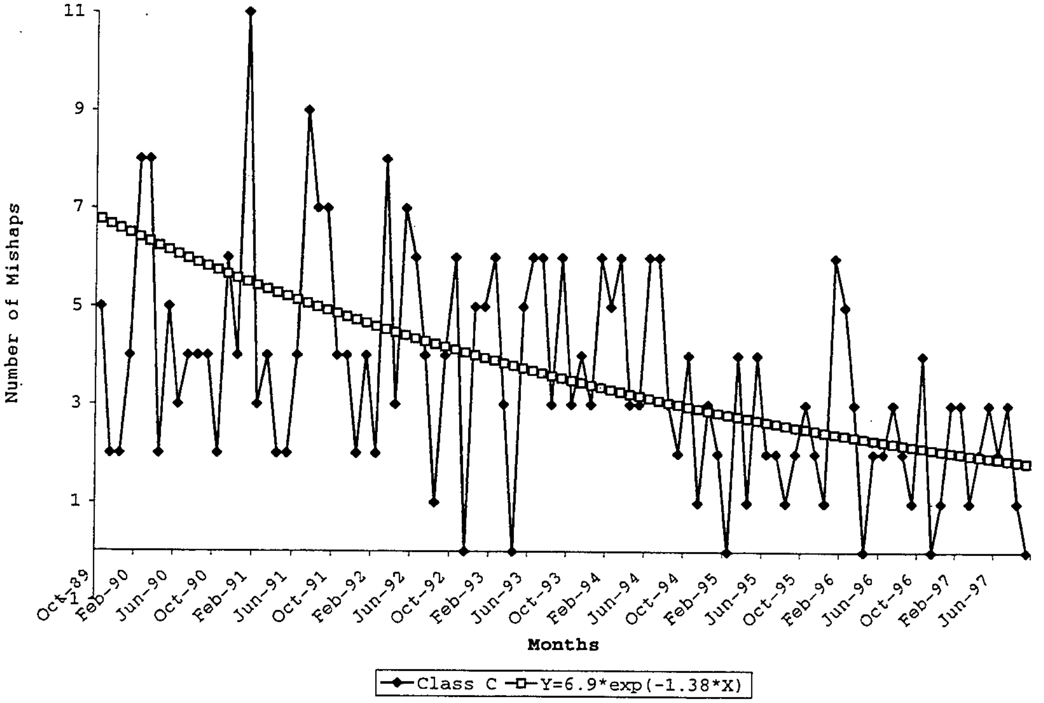

**Figure D6: Variable Poisson Process for Class C MRMs**

# APPENDIX E: PROBABILITY TABLES FOR THE OCCURRENCE OF MAINTENANCE-RELATED MISHAPS

### Table E1: FY98 Flight Mishap Probability Table

| | $\hat{\lambda}_t$ | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Oct97** | 1.01 | 0.36 | 0.37 | 0.19 | 0.06 | 0.02 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Nov97** | 1.00 | 0.37 | 0.37 | 0.18 | 0.06 | 0.02 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Dec97** | 0.99 | 0.37 | 0.37 | 0.18 | 0.06 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Jan98** | 0.98 | 0.37 | 0.37 | 0.18 | 0.06 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Feb98** | 0.98 | 0.38 | 0.37 | 0.18 | 0.06 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Mar98** | 0.97 | 0.38 | 0.37 | 0.18 | 0.06 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Apr98** | 0.96 | 0.38 | 0.37 | 0.18 | 0.06 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **May98** | 0.95 | 0.39 | 0.37 | 0.17 | 0.06 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Jun98** | 0.94 | 0.39 | 0.37 | 0.17 | 0.05 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Jul98** | 0.94 | 0.39 | 0.37 | 0.17 | 0.05 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Aug98** | 0.93 | 0.40 | 0.37 | 0.17 | 0.05 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Sep98** | 0.92 | 0.40 | 0.37 | 0.17 | 0.05 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

### Table E2: FY98 Flight-Related Mishap Probability Table

| | $\hat{\lambda}_t$ | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Oct97** | 0.16 | 0.85 | 0.14 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Nov97** | 0.16 | 0.85 | 0.14 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Dec97** | 0.16 | 0.85 | 0.14 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Jan98** | 0.16 | 0.85 | 0.13 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Feb98** | 0.16 | 0.86 | 0.13 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Mar98** | 0.15 | 0.86 | 0.13 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Apr98** | 0.15 | 0.86 | 0.13 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **May98** | 0.15 | 0.86 | 0.13 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Jun98** | 0.15 | 0.86 | 0.13 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Jul98** | 0.14 | 0.87 | 0.13 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Aug98** | 0.14 | 0.87 | 0.12 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Sep98** | 0.14 | 0.87 | 0.12 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

### Table E3: FY98 Aircraft-Ground Mishap Probability Table

| | $\hat{\lambda}_t$ | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Oct97** | 1.77 | 0.17 | 0.30 | 0.27 | 0.16 | 0.07 | 0.02 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Nov97** | 1.75 | 0.17 | 0.30 | 0.27 | 0.16 | 0.07 | 0.02 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Dec97** | 1.74 | 0.18 | 0.31 | 0.27 | 0.15 | 0.07 | 0.02 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Jan98** | 1.72 | 0.18 | 0.31 | 0.26 | 0.15 | 0.07 | 0.02 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Feb98** | 1.71 | 0.18 | 0.31 | 0.26 | 0.15 | 0.06 | 0.02 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Mar98** | 1.69 | 0.18 | 0.31 | 0.26 | 0.15 | 0.06 | 0.02 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Apr98** | 1.68 | 0.19 | 0.31 | 0.26 | 0.15 | 0.06 | 0.02 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 |
| **May98** | 1.66 | 0.19 | 0.32 | 0.26 | 0.15 | 0.06 | 0.02 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Jun98** | 1.65 | 0.19 | 0.32 | 0.26 | 0.14 | 0.06 | 0.02 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Jul98** | 1.63 | 0.20 | 0.32 | 0.26 | 0.14 | 0.06 | 0.02 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Aug98** | 1.62 | 0.20 | 0.32 | 0.26 | 0.14 | 0.06 | 0.02 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Sep98** | 1.60 | 0.20 | 0.32 | 0.26 | 0.14 | 0.06 | 0.02 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

**Table E4: FY98 Class A Mishap Probability Table**

| | $\hat{\lambda}_t$ | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Oct97** | 0.36 | 0.70 | 0.25 | 0.05 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Nov97** | 0.36 | 0.70 | 0.25 | 0.04 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Dec97** | 0.35 | 0.70 | 0.25 | 0.04 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Jan98** | 0.35 | 0.71 | 0.25 | 0.04 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Feb98** | 0.35 | 0.71 | 0.24 | 0.04 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Mar98** | 0.34 | 0.71 | 0.24 | 0.04 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Apr98** | 0.34 | 0.71 | 0.24 | 0.04 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **May98** | 0.33 | 0.72 | 0.24 | 0.04 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Jun98** | 0.33 | 0.72 | 0.24 | 0.04 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Jul98** | 0.33 | 0.72 | 0.24 | 0.04 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Aug98** | 0.32 | 0.72 | 0.23 | 0.04 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Sep98** | 0.32 | 0.73 | 0.23 | 0.04 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

**Table E5: FY98 Class B Mishap Probability Table**

| | $\hat{\lambda}_t$ | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Oct97** | 0.45 | 0.63 | 0.29 | 0.07 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Nov97** | 0.45 | 0.64 | 0.29 | 0.07 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Dec97** | 0.45 | 0.64 | 0.29 | 0.06 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Jan98** | 0.45 | 0.64 | 0.29 | 0.06 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Feb98** | 0.45 | 0.64 | 0.29 | 0.06 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Mar98** | 0.44 | 0.64 | 0.28 | 0.06 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Apr98** | 0.44 | 0.64 | 0.28 | 0.06 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **May98** | 0.44 | 0.64 | 0.28 | 0.06 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Jun98** | 0.44 | 0.65 | 0.28 | 0.06 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Jul98** | 0.44 | 0.65 | 0.28 | 0.06 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Aug98** | 0.43 | 0.65 | 0.28 | 0.06 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Sep98** | 0.43 | 0.65 | 0.28 | 0.06 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

**Table E6: FY98 Class C Mishap Probability Table**

| | $\hat{\lambda}_t$ | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Oct97** | 1.80 | 0.17 | 0.30 | 0.27 | 0.16 | 0.07 | 0.03 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Nov97** | 1.77 | 0.17 | 0.30 | 0.27 | 0.16 | 0.07 | 0.02 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Dec97** | 1.75 | 0.17 | 0.30 | 0.27 | 0.16 | 0.07 | 0.02 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Jan98** | 1.73 | 0.18 | 0.31 | 0.27 | 0.15 | 0.07 | 0.02 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Feb98** | 1.70 | 0.18 | 0.31 | 0.26 | 0.15 | 0.06 | 0.02 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Mar98** | 1.68 | 0.19 | 0.31 | 0.26 | 0.15 | 0.06 | 0.02 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Apr98** | 1.66 | 0.19 | 0.32 | 0.26 | 0.14 | 0.06 | 0.02 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 |
| **May98** | 1.63 | 0.20 | 0.32 | 0.26 | 0.14 | 0.06 | 0.02 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Jun98** | 1.61 | 0.20 | 0.32 | 0.26 | 0.14 | 0.06 | 0.02 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Jul98** | 1.59 | 0.20 | 0.32 | 0.26 | 0.14 | 0.05 | 0.02 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Aug98** | 1.57 | 0.21 | 0.33 | 0.26 | 0.13 | 0.05 | 0.02 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Sep98** | 1.54 | 0.21 | 0.33 | 0.25 | 0.13 | 0.05 | 0.02 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

# APPENDIX F: PREDICTED COSTS OF MAINTENACE-RELATED MISHAPS

# Table F1: Predicted Maintenance-Related Flight Mishap Costs for FY98-FY02

| FM | $\hat{\lambda}_t$ | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Oct97** | 1.01 | - | 1,897,059 | 1,914,416 | 965,966 | 324,935 | 81,977 | 16,545 | 2,783 | 401 | 51 | 6 | 5,204,139 |
| **Nov97** | 1.00 | - | 1,897,137 | 1,898,383 | 949,815 | 316,813 | 79,255 | 15,861 | 2,645 | 378 | 47 | 5 | 5,160,341 |
| **Dec97** | 0.99 | - | 1,897,080 | 1,882,350 | 933,867 | 308,872 | 76,618 | 15,205 | 2,514 | 356 | 44 | 5 | 5,116,912 |
| **Jan98** | 0.98 | - | 1,896,889 | 1,866,320 | 918,121 | 301,109 | 74,064 | 14,574 | 2,390 | 336 | 41 | 5 | 5,073,848 |
| **Feb98** | 0.98 | - | 1,896,564 | 1,850,296 | 902,578 | 293,520 | 71,590 | 13,969 | 2,271 | 317 | 39 | 4 | 5,031,147 |
| **Mar98** | 0.97 | - | 1,896,107 | 1,834,282 | 887,236 | 286,102 | 69,193 | 13,387 | 2,158 | 298 | 36 | 4 | 4,988,805 |
| **Apr98** | 0.96 | - | 1,895,519 | 1,818,281 | 872,095 | 278,853 | 66,873 | 12,830 | 2,051 | 281 | 34 | 4 | 4,946,819 |
| **May98** | 0.95 | - | 1,894,802 | 1,802,296 | 857,153 | 271,769 | 64,625 | 12,294 | 1,949 | 265 | 31 | 3 | 4,905,187 |
| **Jun98** | 0.94 | - | 1,893,956 | 1,786,330 | 842,410 | 264,846 | 62,449 | 11,780 | 1,852 | 250 | 29 | 3 | 4,863,905 |
| **Jul98** | 0.94 | - | 1,892,983 | 1,770,386 | 827,865 | 258,083 | 60,342 | 11,287 | 1,759 | 235 | 27 | 3 | 4,822,970 |
| **Aug98** | 0.93 | - | 1,891,884 | 1,754,468 | 813,516 | 251,475 | 58,302 | 10,814 | 1,671 | 221 | 26 | 3 | 4,782,380 |
| **Sep98** | 0.92 | - | 1,890,661 | 1,738,577 | 799,363 | 245,021 | 56,328 | 10,359 | 1,588 | 209 | 24 | 2 | 4,742,132 |
| **Oct98** | 0.92 | - | 1,889,314 | 1,722,717 | 785,405 | 238,716 | 54,417 | 9,924 | 1,508 | 196 | 22 | 2 | 4,702,222 |
| **Nov98** | 0.90 | - | 1,887,845 | 1,706,891 | 771,641 | 232,559 | 52,567 | 9,506 | 1,432 | 185 | 21 | 2 | 4,662,649 |
| **Dec98** | 0.90 | - | 1,886,256 | 1,691,101 | 758,068 | 226,546 | 50,777 | 9,105 | 1,360 | 174 | 20 | 2 | 4,623,408 |
| **Jan99** | 0.89 | - | 1,884,547 | 1,675,349 | 744,687 | 220,674 | 49,044 | 8,720 | 1,292 | 164 | 18 | 2 | 4,584,497 |
| **Feb99** | 0.88 | - | 1,882,720 | 1,659,639 | 731,495 | 214,941 | 47,368 | 8,351 | 1,227 | 155 | 17 | 2 | 4,545,914 |
| **Mar99** | 0.87 | - | 1,880,777 | 1,643,973 | 718,492 | 209,343 | 45,746 | 7,997 | 1,165 | 145 | 16 | 2 | 4,507,656 |
| **Apr99** | 0.87 | - | 1,878,718 | 1,628,353 | 705,676 | 203,878 | 44,177 | 7,658 | 1,106 | 137 | 15 | 1 | 4,469,720 |
| **May99** | 0.86 | - | 1,876,545 | 1,612,781 | 693,046 | 198,544 | 42,659 | 7,333 | 1,050 | 129 | 14 | 1 | 4,432,103 |
| **Jun99** | 0.85 | - | 1,874,260 | 1,597,261 | 680,600 | 193,338 | 41,191 | 7,021 | 997 | 121 | 13 | 1 | 4,394,802 |
| **Jul99** | 0.85 | - | 1,871,863 | 1,581,793 | 668,337 | 188,256 | 39,771 | 6,722 | 947 | 114 | 12 | 1 | 4,357,816 |
| **Aug99** | 0.84 | - | 1,869,357 | 1,566,381 | 656,255 | 183,297 | 38,397 | 6,435 | 899 | 108 | 11 | 1 | 4,321,140 |
| **Sep99** | 0.83 | - | 1,866,743 | 1,551,026 | 644,353 | 178,458 | 37,069 | 6,160 | 853 | 101 | 11 | 1 | 4,284,774 |
| **Oct99** | 0.82 | - | 1,864,021 | 1,535,730 | 632,629 | 173,737 | 35,785 | 5,896 | 810 | 95 | 10 | 1 | 4,248,713 |
| **Nov99** | 0.82 | - | 1,861,194 | 1,520,496 | 621,082 | 169,130 | 34,543 | 5,644 | 768 | 90 | 9 | 1 | 4,212,956 |
| **Dec99** | 0.81 | - | 1,858,263 | 1,505,325 | 609,710 | 164,636 | 33,342 | 5,402 | 729 | 84 | 9 | 1 | 4,177,500 |
| **Jan00** | 0.80 | - | 1,855,229 | 1,490,219 | 598,512 | 160,252 | 32,181 | 5,170 | 692 | 79 | 8 | 1 | 4,142,342 |
| **Feb00** | 0.80 | - | 1,852,093 | 1,475,180 | 587,486 | 155,976 | 31,058 | 4,948 | 657 | 75 | 7 | 1 | 4,107,481 |
| **Mar00** | 0.79 | - | 1,848,858 | 1,460,210 | 576,630 | 151,805 | 29,974 | 4,735 | 623 | 70 | 7 | 1 | 4,072,912 |
| **Apr00** | 0.78 | - | 1,845,524 | 1,445,310 | 565,942 | 147,738 | 28,925 | 4,530 | 591 | 66 | 6 | 1 | 4,038,635 |
| **May00** | 0.78 | - | 1,842,094 | 1,430,482 | 555,422 | 143,771 | 27,912 | 4,335 | 561 | 62 | 6 | 1 | 4,004,646 |
| **Jun00** | 0.77 | - | 1,838,567 | 1,415,728 | 545,067 | 139,904 | 26,932 | 4,148 | 532 | 59 | 6 | 0 | 3,970,943 |

| FM | $\hat{\lambda}_t$ | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Jul00** | 0.76 | - | 1,834,947 | 1,401,049 | 534,876 | 136,132 | 25,986 | 3,968 | 505 | 55 | 5 | 0 | 3,937,523 |
| **Aug00** | 0.76 | - | 1,831,233 | 1,386,446 | 524,847 | 132,456 | 25,071 | 3,796 | 479 | 52 | 5 | 0 | 3,904,385 |
| **Sep00** | 0.75 | - | 1,827,429 | 1,371,922 | 514,977 | 128,871 | 24,187 | 3,632 | 454 | 49 | 5 | 0 | 3,871,526 |
| **Oct00** | 0.74 | - | 1,823,534 | 1,357,476 | 505,267 | 125,377 | 23,333 | 3,474 | 431 | 46 | 4 | 0 | 3,838,943 |
| **Nov00** | 0.74 | - | 1,819,551 | 1,343,112 | 495,713 | 121,971 | 22,508 | 3,323 | 409 | 43 | 4 | 0 | 3,806,635 |
| **Dec00** | 0.73 | - | 1,815,482 | 1,328,829 | 486,314 | 118,651 | 21,712 | 3,178 | 388 | 41 | 4 | 0 | 3,774,598 |
| **Jan01** | 0.73 | - | 1,811,326 | 1,314,630 | 477,068 | 115,416 | 20,942 | 3,040 | 368 | 38 | 3 | 0 | 3,742,831 |
| **Feb01** | 0.72 | - | 1,807,086 | 1,300,515 | 467,974 | 112,263 | 20,198 | 2,907 | 349 | 36 | 3 | 0 | 3,711,332 |
| **Mar01** | 0.71 | - | 1,802,764 | 1,286,485 | 459,030 | 109,191 | 19,480 | 2,780 | 331 | 34 | 3 | 0 | 3,680,097 |
| **Apr01** | 0.71 | - | 1,798,360 | 1,272,542 | 450,233 | 106,197 | 18,787 | 2,659 | 314 | 32 | 3 | 0 | 3,649,126 |
| **May01** | 0.70 | - | 1,793,876 | 1,258,686 | 441,583 | 103,280 | 18,117 | 2,542 | 297 | 30 | 3 | 0 | 3,618,415 |
| **Jun01** | 0.70 | - | 1,789,314 | 1,244,919 | 433,078 | 100,438 | 17,470 | 2,431 | 282 | 28 | 2 | 0 | 3,587,962 |
| **Jul01** | 0.69 | - | 1,784,675 | 1,231,241 | 424,715 | 97,670 | 16,846 | 2,324 | 267 | 26 | 2 | 0 | 3,557,766 |
| **Aug01** | 0.68 | - | 1,779,960 | 1,217,654 | 416,493 | 94,973 | 16,243 | 2,222 | 253 | 25 | 2 | 0 | 3,527,824 |
| **Sep01** | 0.68 | - | 1,775,170 | 1,204,157 | 408,410 | 92,346 | 15,660 | 2,125 | 240 | 23 | 2 | 0 | 3,498,134 |
| **Oct01** | 0.67 | - | 1,770,308 | 1,190,753 | 400,465 | 89,787 | 15,098 | 2,031 | 228 | 22 | 2 | 0 | 3,468,694 |
| **Nov01** | 0.67 | - | 1,765,375 | 1,177,441 | 392,655 | 87,296 | 14,556 | 1,942 | 216 | 21 | 2 | 0 | 3,439,501 |
| **Dec01** | 0.66 | - | 1,760,371 | 1,164,222 | 384,979 | 84,869 | 14,032 | 1,856 | 205 | 19 | 2 | 0 | 3,410,555 |
| **Jan02** | 0.66 | - | 1,755,298 | 1,151,097 | 377,436 | 82,506 | 13,526 | 1,774 | 194 | 18 | 1 | 0 | 3,381,851 |
| **Feb02** | 0.65 | - | 1,750,158 | 1,138,068 | 370,023 | 80,204 | 13,039 | 1,696 | 184 | 17 | 1 | 0 | 3,353,390 |
| **Mar02** | 0.64 | - | 1,744,952 | 1,125,133 | 362,739 | 77,964 | 12,568 | 1,621 | 174 | 16 | 1 | 0 | 3,325,168 |
| **Apr02** | 0.64 | - | 1,739,682 | 1,112,294 | 355,582 | 75,782 | 12,113 | 1,549 | 165 | 15 | 1 | 0 | 3,297,183 |
| **May02** | 0.64 | - | 1,734,348 | 1,099,551 | 348,550 | 73,658 | 11,675 | 1,480 | 156 | 14 | 1 | 0 | 3,269,434 |
| **Jun02** | 0.63 | - | 1,728,952 | 1,086,905 | 341,641 | 71,591 | 11,251 | 1,415 | 148 | 13 | 1 | 0 | 3,241,919 |
| **Jul02** | 0.62 | - | 1,723,496 | 1,074,357 | 334,855 | 69,578 | 10,843 | 1,352 | 140 | 13 | 1 | 0 | 3,214,635 |
| **Aug02** | 0.62 | - | 1,717,980 | 1,061,906 | 328,189 | 67,619 | 10,449 | 1,292 | 133 | 12 | 1 | 0 | 3,187,581 |
| **Sep02** | 0.61 | - | 1,712,406 | 1,049,553 | 321,641 | 65,712 | 10,069 | 1,234 | 126 | 11 | 1 | 0 | 3,160,754 |
| | | | | | | | | | | | | | 245,959,174 |

# Table F2: Predicted Maintenance-Related Flight-Related Mishap Costs for FY98-FY02

| **FRM** | $\hat{\lambda}_t$ | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Oct97** | 0.16 | - | 15,658 | 2,573 | 211 | 12 | 0 | 0 | 0 | 0 | 0 | 0 | 18,455 |
| **Nov97** | 0.16 | - | 15,473 | 2,506 | 203 | 11 | 0 | 0 | 0 | 0 | 0 | 0 | 18,193 |
| **Dec97** | 0.16 | - | 15,289 | 2,441 | 195 | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 17,936 |
| **Jan98** | 0.16 | - | 15,107 | 2,378 | 187 | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 17,682 |
| **Feb98** | 0.16 | - | 14,926 | 2,317 | 180 | 9 | 0 | 0 | 0 | 0 | 0 | 0 | 17,432 |
| **Mar98** | 0.15 | - | 14,747 | 2,256 | 173 | 9 | 0 | 0 | 0 | 0 | 0 | 0 | 17,185 |
| **Apr98** | 0.15 | - | 14,570 | 2,198 | 166 | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 16,942 |
| **May98** | 0.15 | - | 14,395 | 2,141 | 159 | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 16,702 |
| **Jun98** | 0.15 | - | 14,221 | 2,085 | 153 | 7 | 0 | 0 | 0 | 0 | 0 | 0 | 16,466 |
| **Jul98** | 0.14 | - | 14,049 | 2,030 | 147 | 7 | 0 | 0 | 0 | 0 | 0 | 0 | 16,233 |
| **Aug98** | 0.14 | - | 13,878 | 1,977 | 141 | 7 | 0 | 0 | 0 | 0 | 0 | 0 | 16,003 |
| **Sep98** | 0.14 | - | 13,709 | 1,926 | 135 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 15,777 |
| **Oct98** | 0.14 | - | 13,542 | 1,875 | 130 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 15,554 |
| **Nov98** | 0.14 | - | 13,377 | 1,826 | 125 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 15,333 |
| **Dec98** | 0.13 | - | 13,213 | 1,778 | 120 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 15,116 |
| **Jan99** | 0.13 | - | 13,051 | 1,732 | 115 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 14,903 |
| **Feb99** | 0.13 | - | 12,890 | 1,686 | 110 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 14,692 |
| **Mar99** | 0.13 | - | 12,731 | 1,642 | 106 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 14,484 |
| **Apr99** | 0.13 | - | 12,574 | 1,599 | 102 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 14,279 |
| **May99** | 0.13 | - | 12,419 | 1,556 | 98 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 14,077 |
| **Jun99** | 0.12 | - | 12,265 | 1,515 | 94 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 13,878 |
| **Jul99** | 0.12 | - | 12,112 | 1,475 | 90 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 13,681 |
| **Aug99** | 0.12 | - | 11,961 | 1,436 | 86 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 13,488 |
| **Sep99** | 0.12 | - | 11,812 | 1,398 | 83 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 13,297 |
| **Oct99** | 0.12 | - | 11,665 | 1,361 | 79 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 13,108 |
| **Nov99** | 0.12 | - | 11,518 | 1,325 | 76 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 12,923 |
| **Dec99** | 0.11 | - | 11,374 | 1,290 | 73 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 12,740 |
| **Jan00** | 0.11 | - | 11,231 | 1,256 | 70 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 12,560 |
| **Feb00** | 0.11 | - | 11,090 | 1,223 | 67 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 12,382 |
| **Mar00** | 0.11 | - | 10,950 | 1,190 | 65 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 12,207 |
| **Apr00** | 0.11 | - | 10,811 | 1,158 | 62 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 12,034 |
| **May00** | 0.11 | - | 10,675 | 1,128 | 60 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 11,864 |
| **Jun00** | 0.10 | - | 10,539 | 1,097 | 57 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 11,696 |

| **FRM** | $\hat{\lambda}_t$ | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Jul00** | 0.10 | - | 10,405 | 1,068 | 55 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 11,530 |
| **Aug00** | 0.10 | - | 10,273 | 1,040 | 53 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 11,367 |
| **Sep00** | 0.10 | - | 10,142 | 1,012 | 50 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 11,206 |
| **Oct00** | 0.10 | - | 10,013 | 985 | 48 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 11,048 |
| **Nov00** | 0.10 | - | 9,885 | 959 | 46 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 10,891 |
| **Dec00** | 0.10 | - | 9,758 | 933 | 45 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 10,737 |
| **Jan01** | 0.09 | - | 9,633 | 908 | 43 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 10,585 |
| **Feb01** | 0.09 | - | 9,510 | 884 | 41 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 10,436 |
| **Mar01** | 0.09 | - | 9,387 | 860 | 39 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 10,288 |
| **Apr01** | 0.09 | - | 9,267 | 837 | 38 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 10,142 |
| **May01** | 0.09 | - | 9,147 | 814 | 36 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 9,999 |
| **Jun01** | 0.09 | - | 9,029 | 792 | 35 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 9,857 |
| **Jul01** | 0.09 | - | 8,912 | 771 | 33 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 9,718 |
| **Aug01** | 0.09 | - | 8,797 | 750 | 32 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 9,580 |
| **Sep01** | 0.08 | - | 8,683 | 730 | 31 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 9,445 |
| **Oct01** | 0.08 | - | 8,570 | 710 | 29 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 9,311 |
| **Nov01** | 0.08 | - | 8,459 | 691 | 28 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 9,179 |
| **Dec01** | 0.08 | - | 8,349 | 673 | 27 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 9,049 |
| **Jan02** | 0.08 | - | 8,240 | 654 | 26 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 8,921 |
| **Feb02** | 0.08 | - | 8,133 | 637 | 25 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 8,795 |
| **Mar02** | 0.08 | - | 8,026 | 620 | 24 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 8,671 |
| **Apr02** | 0.08 | - | 7,922 | 603 | 23 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 8,548 |
| **May02** | 0.08 | - | 7,818 | 587 | 22 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 8,427 |
| **Jun02** | 0.07 | - | 7,715 | 571 | 21 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 8,308 |
| **Jul02** | 0.07 | - | 7,614 | 555 | 20 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8,190 |
| **Aug02** | 0.07 | - | 7,514 | 540 | 19 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8,074 |
| **Sep02** | 0.07 | - | 7,415 | 526 | 19 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7,960 |
|  |  |  |  |  |  |  |  |  |  |  |  |  | 749,565 |

# Table F3: Predicted Maintenance-Related Aircraft-Ground Mishap Costs for FY98-FY02

| AGM | $\hat{\lambda}_t$ | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Oct97** | 1.77 | - | 25,092 | 44,422 | 39,322 | 23,205 | 10,270 | 3,636 | 1,073 | 271 | 60 | 12 | 147,365 |
| **Nov97** | 1.75 | - | 25,267 | 44,326 | 38,881 | 22,736 | 9,972 | 3,499 | 1,023 | 256 | 56 | 11 | 146,027 |
| **Dec97** | 1.74 | - | 25,440 | 44,224 | 38,439 | 22,274 | 9,680 | 3,366 | 975 | 242 | 53 | 10 | 144,702 |
| **Jan98** | 1.72 | - | 25,610 | 44,115 | 37,997 | 21,818 | 9,396 | 3,237 | 929 | 229 | 49 | 9 | 143,389 |
| **Feb98** | 1.71 | - | 25,777 | 44,001 | 37,554 | 21,368 | 9,119 | 3,113 | 886 | 216 | 46 | 9 | 142,088 |
| **Mar98** | 1.69 | - | 25,942 | 43,880 | 37,111 | 20,924 | 8,848 | 2,993 | 844 | 204 | 43 | 8 | 140,798 |
| **Apr98** | 1.68 | - | 26,104 | 43,754 | 36,668 | 20,487 | 8,585 | 2,878 | 804 | 192 | 40 | 8 | 139,520 |
| **May98** | 1.66 | - | 26,264 | 43,622 | 36,226 | 20,056 | 8,328 | 2,766 | 766 | 182 | 38 | 7 | 138,254 |
| **Jun98** | 1.65 | - | 26,421 | 43,484 | 35,784 | 19,631 | 8,078 | 2,659 | 729 | 171 | 35 | 6 | 136,999 |
| **Jul98** | 1.63 | - | 26,575 | 43,341 | 35,342 | 19,213 | 7,834 | 2,555 | 695 | 162 | 33 | 6 | 135,756 |
| **Aug98** | 1.62 | - | 26,727 | 43,193 | 34,902 | 18,801 | 7,596 | 2,455 | 661 | 153 | 31 | 6 | 134,524 |
| **Sep98** | 1.60 | - | 26,875 | 43,039 | 34,462 | 18,396 | 7,365 | 2,359 | 630 | 144 | 29 | 5 | 133,303 |
| **Oct98** | 1.59 | - | 27,021 | 42,880 | 34,023 | 17,997 | 7,140 | 2,266 | 599 | 136 | 27 | 5 | 132,093 |
| **Nov98** | 1.57 | - | 27,164 | 42,716 | 33,585 | 17,604 | 6,920 | 2,176 | 570 | 128 | 25 | 4 | 130,894 |
| **Dec98** | 1.56 | - | 27,305 | 42,547 | 33,148 | 17,217 | 6,707 | 2,090 | 543 | 121 | 24 | 4 | 129,706 |
| **Jan99** | 1.54 | - | 27,442 | 42,373 | 32,713 | 16,837 | 6,499 | 2,007 | 517 | 114 | 22 | 4 | 128,529 |
| **Feb99** | 1.53 | - | 27,577 | 42,195 | 32,280 | 16,463 | 6,297 | 1,927 | 491 | 107 | 21 | 3 | 127,363 |
| **Mar99** | 1.52 | - | 27,709 | 42,011 | 31,848 | 16,096 | 6,101 | 1,850 | 467 | 101 | 19 | 3 | 126,207 |
| **Apr99** | 1.50 | - | 27,838 | 41,824 | 31,418 | 15,734 | 5,910 | 1,776 | 445 | 95 | 18 | 3 | 125,061 |
| **May99** | 1.49 | - | 27,964 | 41,632 | 30,990 | 15,379 | 5,724 | 1,704 | 423 | 90 | 17 | 3 | 123,926 |
| **Jun99** | 1.48 | - | 28,087 | 41,436 | 30,564 | 15,030 | 5,543 | 1,636 | 402 | 85 | 16 | 3 | 122,801 |
| **Jul99** | 1.46 | - | 28,207 | 41,236 | 30,140 | 14,687 | 5,368 | 1,569 | 382 | 80 | 15 | 2 | 121,687 |
| **Aug99** | 1.45 | - | 28,325 | 41,031 | 29,719 | 14,350 | 5,197 | 1,506 | 364 | 75 | 14 | 2 | 120,582 |
| **Sep99** | 1.44 | - | 28,439 | 40,823 | 29,300 | 14,019 | 5,031 | 1,444 | 346 | 71 | 13 | 2 | 119,488 |
| **Oct99** | 1.42 | - | 28,551 | 40,611 | 28,883 | 13,695 | 4,870 | 1,385 | 328 | 67 | 12 | 2 | 118,403 |
| **Nov99** | 1.41 | - | 28,659 | 40,395 | 28,469 | 13,376 | 4,713 | 1,329 | 312 | 63 | 11 | 2 | 117,329 |
| **Dec99** | 1.40 | - | 28,765 | 40,176 | 28,057 | 13,063 | 4,561 | 1,274 | 297 | 59 | 10 | 2 | 116,264 |
| **Jan00** | 1.38 | - | 28,867 | 39,953 | 27,649 | 12,756 | 4,414 | 1,222 | 282 | 56 | 10 | 1 | 115,209 |
| **Feb00** | 1.37 | - | 28,967 | 39,727 | 27,243 | 12,454 | 4,270 | 1,171 | 268 | 52 | 9 | 1 | 114,163 |
| **Mar00** | 1.36 | - | 29,063 | 39,498 | 26,840 | 12,159 | 4,131 | 1,123 | 254 | 49 | 8 | 1 | 113,127 |
| **Apr00** | 1.35 | - | 29,157 | 39,266 | 26,439 | 11,869 | 3,996 | 1,076 | 242 | 46 | 8 | 1 | 112,100 |
| **May00** | 1.33 | - | 29,248 | 39,030 | 26,042 | 11,584 | 3,865 | 1,031 | 229 | 44 | 7 | 1 | 111,083 |
| **Jun00** | 1.32 | - | 29,335 | 38,792 | 25,649 | 11,306 | 3,738 | 988 | 218 | 41 | 7 | 1 | 110,074 |

| **AGM** | $\hat{\lambda}_t$ | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Jul00** | 1.31 | - | 29,420 | 38,551 | 25,258 | 11,032 | 3,614 | 947 | 207 | 39 | 6 | 1 | 109,075 |
| **Aug00** | 1.30 | - | 29,502 | 38,307 | 24,870 | 10,764 | 3,494 | 907 | 196 | 36 | 6 | 1 | 108,085 |
| **Sep00** | 1.29 | - | 29,581 | 38,061 | 24,486 | 10,502 | 3,378 | 869 | 186 | 34 | 6 | 1 | 107,104 |
| **Oct00** | 1.28 | - | 29,657 | 37,812 | 24,105 | 10,245 | 3,266 | 833 | 177 | 32 | 5 | 1 | 106,132 |
| **Nov00** | 1.26 | - | 29,729 | 37,561 | 23,728 | 9,993 | 3,156 | 798 | 168 | 30 | 5 | 1 | 105,169 |
| **Dec00** | 1.25 | - | 29,799 | 37,308 | 23,354 | 9,746 | 3,050 | 764 | 159 | 29 | 4 | 1 | 104,214 |
| **Jan01** | 1.24 | - | 29,866 | 37,052 | 22,983 | 9,504 | 2,948 | 731 | 151 | 27 | 4 | 1 | 103,268 |
| **Feb01** | 1.23 | - | 29,930 | 36,795 | 22,617 | 9,268 | 2,848 | 700 | 143 | 25 | 4 | 1 | 102,331 |
| **Mar01** | 1.22 | - | 29,992 | 36,535 | 22,253 | 9,036 | 2,752 | 670 | 136 | 24 | 4 | 0 | 101,402 |
| **Apr01** | 1.21 | - | 30,050 | 36,274 | 21,893 | 8,809 | 2,659 | 642 | 129 | 22 | 3 | 0 | 100,482 |
| **May01** | 1.20 | - | 30,105 | 36,011 | 21,537 | 8,587 | 2,568 | 614 | 122 | 21 | 3 | 0 | 99,570 |
| **Jun01** | 1.19 | - | 30,157 | 35,746 | 21,185 | 8,370 | 2,480 | 588 | 116 | 20 | 3 | 0 | 98,666 |
| **Jul01** | 1.17 | - | 30,207 | 35,480 | 20,836 | 8,158 | 2,395 | 563 | 110 | 18 | 3 | 0 | 97,771 |
| **Aug01** | 1.16 | - | 30,254 | 35,212 | 20,491 | 7,950 | 2,313 | 538 | 104 | 17 | 3 | 0 | 96,883 |
| **Sep01** | 1.15 | - | 30,297 | 34,943 | 20,150 | 7,747 | 2,234 | 515 | 99 | 16 | 2 | 0 | 96,004 |
| **Oct01** | 1.14 | - | 30,338 | 34,672 | 19,813 | 7,548 | 2,157 | 493 | 94 | 15 | 2 | 0 | 95,133 |
| **Nov01** | 1.13 | - | 30,376 | 34,401 | 19,479 | 7,353 | 2,082 | 472 | 89 | 14 | 2 | 0 | 94,269 |
| **Dec01** | 1.12 | - | 30,412 | 34,128 | 19,150 | 7,163 | 2,010 | 451 | 84 | 14 | 2 | 0 | 93,413 |
| **Jan02** | 1.11 | - | 30,444 | 33,855 | 18,824 | 6,977 | 1,940 | 431 | 80 | 13 | 2 | 0 | 92,566 |
| **Feb02** | 1.10 | - | 30,474 | 33,580 | 18,501 | 6,796 | 1,872 | 413 | 76 | 12 | 2 | 0 | 91,725 |
| **Mar02** | 1.09 | - | 30,501 | 33,305 | 18,183 | 6,618 | 1,807 | 395 | 72 | 11 | 2 | 0 | 90,893 |
| **Apr02** | 1.08 | - | 30,525 | 33,029 | 17,869 | 6,445 | 1,743 | 377 | 68 | 11 | 1 | 0 | 90,068 |
| **May02** | 1.07 | - | 30,547 | 32,752 | 17,558 | 6,275 | 1,682 | 361 | 64 | 10 | 1 | 0 | 89,250 |
| **Jun02** | 1.06 | - | 30,565 | 32,475 | 17,252 | 6,110 | 1,623 | 345 | 61 | 9 | 1 | 0 | 88,440 |
| **Jul02** | 1.05 | - | 30,581 | 32,197 | 16,949 | 5,948 | 1,566 | 330 | 58 | 9 | 1 | 0 | 87,638 |
| **Aug02** | 1.04 | - | 30,595 | 31,918 | 16,650 | 5,790 | 1,510 | 315 | 55 | 8 | 1 | 0 | 86,842 |
| **Sep02** | 1.03 | - | 30,605 | 31,640 | 16,355 | 5,636 | 1,457 | 301 | 52 | 8 | 1 | 0 | 86,054 |
|  |  |  |  |  |  |  |  |  |  |  |  |  | 6,841,264 |

# Table F4: Predicted Maintenance-Related Class A Mishap Costs for FY98-FY02

| Class A | $\hat{\lambda}_t$ | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Oct97** | 0.36 | - | 3,188,126 | 1,150,001 | 207,411 | 24,939 | 2,249 | 162 | 10 | 1 | 0 | 0 | 4,572,898 |
| **Nov97** | 0.36 | - | 3,166,195 | 1,129,862 | 201,596 | 23,980 | 2,139 | 153 | 9 | 0 | 0 | 0 | 4,523,935 |
| **Dec97** | 0.35 | - | 3,144,286 | 1,110,030 | 195,937 | 23,057 | 2,035 | 144 | 8 | 0 | 0 | 0 | 4,475,497 |
| **Jan98** | 0.35 | - | 3,122,400 | 1,090,501 | 190,429 | 22,169 | 1,936 | 135 | 8 | 0 | 0 | 0 | 4,427,578 |
| **Feb98** | 0.35 | - | 3,100,541 | 1,071,272 | 185,068 | 21,314 | 1,841 | 127 | 7 | 0 | 0 | 0 | 4,380,172 |
| **Mar98** | 0.34 | - | 3,078,711 | 1,052,340 | 179,851 | 20,492 | 1,751 | 120 | 7 | 0 | 0 | 0 | 4,333,273 |
| **Apr98** | 0.34 | - | 3,056,915 | 1,033,702 | 174,774 | 19,700 | 1,665 | 113 | 6 | 0 | 0 | 0 | 4,286,876 |
| **May98** | 0.33 | - | 3,035,153 | 1,015,355 | 169,834 | 18,938 | 1,584 | 106 | 6 | 0 | 0 | 0 | 4,240,976 |
| **Jun98** | 0.33 | - | 3,013,430 | 997,294 | 165,027 | 18,205 | 1,506 | 100 | 5 | 0 | 0 | 0 | 4,195,568 |
| **Jul98** | 0.33 | - | 2,991,748 | 979,517 | 160,350 | 17,500 | 1,432 | 94 | 5 | 0 | 0 | 0 | 4,150,646 |
| **Aug98** | 0.32 | - | 2,970,109 | 962,020 | 155,799 | 16,821 | 1,362 | 88 | 5 | 0 | 0 | 0 | 4,106,205 |
| **Sep98** | 0.32 | - | 2,948,515 | 944,800 | 151,372 | 16,168 | 1,295 | 83 | 4 | 0 | 0 | 0 | 4,062,239 |
| **Oct98** | 0.32 | - | 2,926,970 | 927,855 | 147,066 | 15,540 | 1,232 | 78 | 4 | 0 | 0 | 0 | 4,018,745 |
| **Nov98** | 0.31 | - | 2,905,476 | 911,179 | 142,876 | 14,936 | 1,171 | 73 | 4 | 0 | 0 | 0 | 3,975,716 |
| **Dec98** | 0.31 | - | 2,884,035 | 894,771 | 138,801 | 14,354 | 1,113 | 69 | 4 | 0 | 0 | 0 | 3,933,148 |
| **Jan99** | 0.31 | - | 2,862,649 | 878,627 | 134,838 | 13,795 | 1,059 | 65 | 3 | 0 | 0 | 0 | 3,891,035 |
| **Feb99** | 0.30 | - | 2,841,320 | 862,743 | 130,982 | 13,257 | 1,006 | 61 | 3 | 0 | 0 | 0 | 3,849,374 |
| **Mar99** | 0.30 | - | 2,820,051 | 847,117 | 127,233 | 12,740 | 957 | 57 | 3 | 0 | 0 | 0 | 3,808,158 |
| **Apr99** | 0.30 | - | 2,798,844 | 831,744 | 123,586 | 12,242 | 910 | 54 | 3 | 0 | 0 | 0 | 3,767,384 |
| **May99** | 0.29 | - | 2,777,701 | 816,623 | 120,040 | 11,764 | 865 | 51 | 2 | 0 | 0 | 0 | 3,727,046 |
| **Jun99** | 0.29 | - | 2,756,624 | 801,749 | 116,592 | 11,303 | 822 | 48 | 2 | 0 | 0 | 0 | 3,687,141 |
| **Jul99** | 0.29 | - | 2,735,614 | 787,120 | 113,239 | 10,861 | 781 | 45 | 2 | 0 | 0 | 0 | 3,647,662 |
| **Aug99** | 0.28 | - | 2,714,674 | 772,731 | 109,979 | 10,435 | 743 | 42 | 2 | 0 | 0 | 0 | 3,608,606 |
| **Sep99** | 0.28 | - | 2,693,806 | 758,581 | 106,809 | 10,026 | 706 | 40 | 2 | 0 | 0 | 0 | 3,569,969 |
| **Oct99** | 0.28 | - | 2,673,010 | 744,665 | 103,727 | 9,632 | 671 | 37 | 2 | 0 | 0 | 0 | 3,531,745 |
| **Nov99** | 0.28 | - | 2,652,290 | 730,982 | 100,731 | 9,254 | 638 | 35 | 2 | 0 | 0 | 0 | 3,493,930 |
| **Dec99** | 0.27 | - | 2,631,646 | 717,526 | 97,818 | 8,890 | 606 | 33 | 2 | 0 | 0 | 0 | 3,456,521 |
| **Jan00** | 0.27 | - | 2,611,080 | 704,296 | 94,986 | 8,540 | 576 | 31 | 1 | 0 | 0 | 0 | 3,419,512 |
| **Feb00** | 0.27 | - | 2,590,594 | 691,289 | 92,234 | 8,204 | 547 | 29 | 1 | 0 | 0 | 0 | 3,382,899 |
| **Mar00** | 0.26 | - | 2,570,189 | 678,501 | 89,558 | 7,881 | 520 | 27 | 1 | 0 | 0 | 0 | 3,346,678 |
| **Apr00** | 0.26 | - | 2,549,867 | 665,929 | 86,958 | 7,570 | 494 | 26 | 1 | 0 | 0 | 0 | 3,310,845 |
| **May00** | 0.26 | - | 2,529,629 | 653,570 | 84,430 | 7,271 | 470 | 24 | 1 | 0 | 0 | 0 | 3,275,395 |
| **Jun00** | 0.26 | - | 2,509,477 | 641,421 | 81,973 | 6,984 | 446 | 23 | 1 | 0 | 0 | 0 | 3,240,325 |

| **Class A** | $\hat{\lambda}_t$ | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Jul00** | 0.25 | - | 2,489,411 | 629,479 | 79,586 | 6,708 | 424 | 21 | 1 | 0 | 0 | 0 | 3,205,631 |
| **Aug00** | 0.25 | - | 2,469,434 | 617,742 | 77,266 | 6,443 | 403 | 20 | 1 | 0 | 0 | 0 | 3,171,308 |
| **Sep00** | 0.25 | - | 2,449,546 | 606,206 | 75,011 | 6,188 | 383 | 19 | 1 | 0 | 0 | 0 | 3,137,353 |
| **Oct00** | 0.24 | - | 2,429,748 | 594,868 | 72,820 | 5,943 | 364 | 18 | 1 | 0 | 0 | 0 | 3,103,761 |
| **Nov00** | 0.24 | - | 2,410,042 | 583,726 | 70,691 | 5,707 | 346 | 17 | 1 | 0 | 0 | 0 | 3,070,529 |
| **Dec00** | 0.24 | - | 2,390,428 | 572,776 | 68,622 | 5,481 | 328 | 16 | 1 | 0 | 0 | 0 | 3,037,653 |
| **Jan01** | 0.24 | - | 2,370,909 | 562,017 | 66,612 | 5,263 | 312 | 15 | 1 | 0 | 0 | 0 | 3,005,128 |
| **Feb01** | 0.23 | - | 2,351,484 | 551,444 | 64,659 | 5,054 | 296 | 14 | 1 | 0 | 0 | 0 | 2,972,952 |
| **Mar01** | 0.23 | - | 2,332,155 | 541,055 | 62,762 | 4,854 | 282 | 13 | 1 | 0 | 0 | 0 | 2,941,121 |
| **Apr01** | 0.23 | - | 2,312,923 | 530,848 | 60,918 | 4,661 | 267 | 12 | 0 | 0 | 0 | 0 | 2,909,630 |
| **May01** | 0.23 | - | 2,293,788 | 520,819 | 59,128 | 4,475 | 254 | 12 | 0 | 0 | 0 | 0 | 2,878,476 |
| **Jun01** | 0.22 | - | 2,274,752 | 510,967 | 57,388 | 4,297 | 241 | 11 | 0 | 0 | 0 | 0 | 2,847,656 |
| **Jul01** | 0.22 | - | 2,255,815 | 501,288 | 55,698 | 4,126 | 229 | 10 | 0 | 0 | 0 | 0 | 2,817,166 |
| **Aug01** | 0.22 | - | 2,236,978 | 491,779 | 54,057 | 3,961 | 218 | 10 | 0 | 0 | 0 | 0 | 2,787,003 |
| **Sep01** | 0.22 | - | 2,218,242 | 482,439 | 52,462 | 3,803 | 207 | 9 | 0 | 0 | 0 | 0 | 2,757,162 |
| **Oct01** | 0.22 | - | 2,199,607 | 473,264 | 50,913 | 3,651 | 196 | 8 | 0 | 0 | 0 | 0 | 2,727,641 |
| **Nov01** | 0.21 | - | 2,181,074 | 464,252 | 49,409 | 3,506 | 187 | 8 | 0 | 0 | 0 | 0 | 2,698,436 |
| **Dec01** | 0.21 | - | 2,162,645 | 455,400 | 47,948 | 3,366 | 177 | 7 | 0 | 0 | 0 | 0 | 2,669,544 |
| **Jan02** | 0.21 | - | 2,144,318 | 446,707 | 46,529 | 3,231 | 168 | 7 | 0 | 0 | 0 | 0 | 2,640,961 |
| **Feb02** | 0.21 | - | 2,126,096 | 438,168 | 45,151 | 3,102 | 160 | 7 | 0 | 0 | 0 | 0 | 2,612,684 |
| **Mar02** | 0.20 | - | 2,107,978 | 429,783 | 43,813 | 2,978 | 152 | 6 | 0 | 0 | 0 | 0 | 2,584,710 |
| **Apr02** | 0.20 | - | 2,089,965 | 421,548 | 42,513 | 2,858 | 144 | 6 | 0 | 0 | 0 | 0 | 2,557,035 |
| **May02** | 0.20 | - | 2,072,058 | 413,461 | 41,251 | 2,744 | 137 | 5 | 0 | 0 | 0 | 0 | 2,529,657 |
| **Jun02** | 0.20 | - | 2,054,257 | 405,520 | 40,026 | 2,634 | 130 | 5 | 0 | 0 | 0 | 0 | 2,502,572 |
| **Jul02** | 0.20 | - | 2,036,562 | 397,723 | 38,836 | 2,528 | 123 | 5 | 0 | 0 | 0 | 0 | 2,475,776 |
| **Aug02** | 0.19 | - | 2,018,973 | 390,066 | 37,680 | 2,427 | 117 | 5 | 0 | 0 | 0 | 0 | 2,449,268 |
| **Sep02** | 0.19 | - | 2,001,492 | 382,548 | 36,559 | 2,329 | 111 | 4 | 0 | 0 | 0 | 0 | 2,423,044 |
| | | | | | | | | | | | | | 203,211,552 |

## Table F5: Predicted Maintenance-Related Class B Mishap Costs for FY98-FY02

| Class B | $\hat{\lambda}_t$ | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Oct97** | 0.45 | - | 110,439 | 50,221 | 11,419 | 1,731 | 197 | 18 | 1 | 0 | 0 | 0 | 174,026 |
| **Nov97** | 0.45 | - | 110,162 | 49,865 | 11,286 | 1,703 | 193 | 17 | 1 | 0 | 0 | 0 | 173,228 |
| **Dec97** | 0.45 | - | 109,885 | 49,512 | 11,154 | 1,675 | 189 | 17 | 1 | 0 | 0 | 0 | 172,434 |
| **Jan98** | 0.45 | - | 109,607 | 49,160 | 11,024 | 1,648 | 185 | 17 | 1 | 0 | 0 | 0 | 171,643 |
| **Feb98** | 0.45 | - | 109,329 | 48,811 | 10,896 | 1,621 | 181 | 16 | 1 | 0 | 0 | 0 | 170,856 |
| **Mar98** | 0.44 | - | 109,051 | 48,463 | 10,769 | 1,595 | 177 | 16 | 1 | 0 | 0 | 0 | 170,072 |
| **Apr98** | 0.44 | - | 108,772 | 48,118 | 10,643 | 1,569 | 174 | 15 | 1 | 0 | 0 | 0 | 169,292 |
| **May98** | 0.44 | - | 108,494 | 47,774 | 10,518 | 1,544 | 170 | 15 | 1 | 0 | 0 | 0 | 168,516 |
| **Jun98** | 0.44 | - | 108,214 | 47,433 | 10,395 | 1,519 | 166 | 15 | 1 | 0 | 0 | 0 | 167,743 |
| **Jul98** | 0.44 | - | 107,935 | 47,093 | 10,274 | 1,494 | 163 | 14 | 1 | 0 | 0 | 0 | 166,974 |
| **Aug98** | 0.43 | - | 107,655 | 46,756 | 10,153 | 1,470 | 160 | 14 | 1 | 0 | 0 | 0 | 166,208 |
| **Sep98** | 0.43 | - | 107,375 | 46,420 | 10,034 | 1,446 | 156 | 14 | 1 | 0 | 0 | 0 | 165,446 |
| **Oct98** | 0.43 | - | 107,095 | 46,087 | 9,916 | 1,422 | 153 | 13 | 1 | 0 | 0 | 0 | 164,687 |
| **Nov98** | 0.43 | - | 106,814 | 45,755 | 9,800 | 1,399 | 150 | 13 | 1 | 0 | 0 | 0 | 163,932 |
| **Dec98** | 0.43 | - | 106,533 | 45,426 | 9,685 | 1,377 | 147 | 13 | 1 | 0 | 0 | 0 | 163,180 |
| **Jan99** | 0.42 | - | 106,252 | 45,098 | 9,571 | 1,354 | 144 | 12 | 1 | 0 | 0 | 0 | 162,432 |
| **Feb99** | 0.42 | - | 105,971 | 44,772 | 9,458 | 1,332 | 141 | 12 | 1 | 0 | 0 | 0 | 161,687 |
| **Mar99** | 0.42 | - | 105,690 | 44,449 | 9,347 | 1,310 | 138 | 12 | 1 | 0 | 0 | 0 | 160,946 |
| **Apr99** | 0.42 | - | 105,408 | 44,127 | 9,236 | 1,289 | 135 | 11 | 1 | 0 | 0 | 0 | 160,208 |
| **May99** | 0.42 | - | 105,127 | 43,807 | 9,127 | 1,268 | 132 | 11 | 1 | 0 | 0 | 0 | 159,473 |
| **Jun99** | 0.41 | - | 104,845 | 43,489 | 9,020 | 1,247 | 129 | 11 | 1 | 0 | 0 | 0 | 158,742 |
| **Jul99** | 0.41 | - | 104,563 | 43,174 | 8,913 | 1,227 | 127 | 10 | 1 | 0 | 0 | 0 | 158,014 |
| **Aug99** | 0.41 | - | 104,280 | 42,860 | 8,808 | 1,207 | 124 | 10 | 1 | 0 | 0 | 0 | 157,289 |
| **Sep99** | 0.41 | - | 103,998 | 42,547 | 8,703 | 1,187 | 121 | 10 | 1 | 0 | 0 | 0 | 156,568 |
| **Oct99** | 0.41 | - | 103,715 | 42,237 | 8,600 | 1,167 | 119 | 10 | 1 | 0 | 0 | 0 | 155,850 |
| **Nov99** | 0.41 | - | 103,433 | 41,929 | 8,499 | 1,148 | 116 | 9 | 1 | 0 | 0 | 0 | 155,135 |
| **Dec99** | 0.40 | - | 103,150 | 41,623 | 8,398 | 1,130 | 114 | 9 | 1 | 0 | 0 | 0 | 154,424 |
| **Jan00** | 0.40 | - | 102,867 | 41,318 | 8,298 | 1,111 | 112 | 9 | 1 | 0 | 0 | 0 | 153,716 |
| **Feb00** | 0.40 | - | 102,584 | 41,016 | 8,200 | 1,093 | 109 | 9 | 1 | 0 | 0 | 0 | 153,011 |
| **Mar00** | 0.40 | - | 102,301 | 40,715 | 8,102 | 1,075 | 107 | 9 | 1 | 0 | 0 | 0 | 152,309 |
| **Apr00** | 0.40 | - | 102,018 | 40,416 | 8,006 | 1,057 | 105 | 8 | 1 | 0 | 0 | 0 | 151,611 |
| **May00** | 0.39 | - | 101,735 | 40,119 | 7,910 | 1,040 | 103 | 8 | 1 | 0 | 0 | 0 | 150,915 |
| **Jun00** | 0.39 | - | 101,452 | 39,824 | 7,816 | 1,023 | 100 | 8 | 1 | 0 | 0 | 0 | 150,223 |

| Class B | $\hat{\lambda}_t$ | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Jul00** | 0.39 | - | 101,168 | 39,531 | 7,723 | 1,006 | 98 | 8 | 1 | 0 | 0 | 0 | 149,534 |
| **Aug00** | 0.39 | - | 100,885 | 39,239 | 7,631 | 989 | 96 | 7 | 0 | 0 | 0 | 0 | 148,849 |
| **Sep00** | 0.39 | - | 100,602 | 38,949 | 7,540 | 973 | 94 | 7 | 0 | 0 | 0 | 0 | 148,166 |
| **Oct00** | 0.39 | - | 100,318 | 38,662 | 7,450 | 957 | 92 | 7 | 0 | 0 | 0 | 0 | 147,487 |
| **Nov00** | 0.38 | - | 100,035 | 38,376 | 7,361 | 941 | 90 | 7 | 0 | 0 | 0 | 0 | 146,810 |
| **Dec00** | 0.38 | - | 99,752 | 38,091 | 7,273 | 926 | 88 | 7 | 0 | 0 | 0 | 0 | 146,137 |
| **Jan01** | 0.38 | - | 99,468 | 37,809 | 7,186 | 910 | 87 | 7 | 0 | 0 | 0 | 0 | 145,467 |
| **Feb01** | 0.38 | - | 99,185 | 37,528 | 7,100 | 895 | 85 | 6 | 0 | 0 | 0 | 0 | 144,800 |
| **Mar01** | 0.38 | - | 98,901 | 37,250 | 7,015 | 881 | 83 | 6 | 0 | 0 | 0 | 0 | 144,136 |
| **Apr01** | 0.37 | - | 98,618 | 36,972 | 6,931 | 866 | 81 | 6 | 0 | 0 | 0 | 0 | 143,475 |
| **May01** | 0.37 | - | 98,335 | 36,697 | 6,847 | 852 | 79 | 6 | 0 | 0 | 0 | 0 | 142,817 |
| **Jun01** | 0.37 | - | 98,051 | 36,424 | 6,765 | 838 | 78 | 6 | 0 | 0 | 0 | 0 | 142,162 |
| **Jul01** | 0.37 | - | 97,768 | 36,152 | 6,684 | 824 | 76 | 6 | 0 | 0 | 0 | 0 | 141,510 |
| **Aug01** | 0.37 | - | 97,485 | 35,882 | 6,604 | 810 | 75 | 5 | 0 | 0 | 0 | 0 | 140,861 |
| **Sep01** | 0.37 | - | 97,202 | 35,614 | 6,524 | 797 | 73 | 5 | 0 | 0 | 0 | 0 | 140,215 |
| **Oct01** | 0.36 | - | 96,919 | 35,347 | 6,446 | 784 | 71 | 5 | 0 | 0 | 0 | 0 | 139,572 |
| **Nov01** | 0.36 | - | 96,636 | 35,082 | 6,368 | 771 | 70 | 5 | 0 | 0 | 0 | 0 | 138,932 |
| **Dec01** | 0.36 | - | 96,353 | 34,819 | 6,291 | 758 | 68 | 5 | 0 | 0 | 0 | 0 | 138,295 |
| **Jan02** | 0.36 | - | 96,070 | 34,558 | 6,215 | 745 | 67 | 5 | 0 | 0 | 0 | 0 | 137,661 |
| **Feb02** | 0.36 | - | 95,787 | 34,298 | 6,140 | 733 | 66 | 5 | 0 | 0 | 0 | 0 | 137,030 |
| **Mar02** | 0.36 | - | 95,505 | 34,040 | 6,066 | 721 | 64 | 5 | 0 | 0 | 0 | 0 | 136,401 |
| **Apr02** | 0.35 | - | 95,222 | 33,784 | 5,993 | 709 | 63 | 4 | 0 | 0 | 0 | 0 | 135,776 |
| **May02** | 0.35 | - | 94,940 | 33,529 | 5,921 | 697 | 62 | 4 | 0 | 0 | 0 | 0 | 135,153 |
| **Jun02** | 0.35 | - | 94,658 | 33,276 | 5,849 | 685 | 60 | 4 | 0 | 0 | 0 | 0 | 134,533 |
| **Jul02** | 0.35 | - | 94,376 | 33,025 | 5,778 | 674 | 59 | 4 | 0 | 0 | 0 | 0 | 133,916 |
| **Aug02** | 0.35 | - | 94,094 | 32,775 | 5,708 | 663 | 58 | 4 | 0 | 0 | 0 | 0 | 133,302 |
| **Sep02** | 0.35 | - | 93,812 | 32,527 | 5,639 | 652 | 56 | 4 | 0 | 0 | 0 | 0 | 132,691 |
|  |  |  |  |  |  |  |  |  |  |  |  |  | 9,146,477 |

## Table F6: Predicted Maintenance-Related Class C Mishap Costs for FY98-FY02

| Class C | $\hat{\lambda}_t$ | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Oct97** | 1.80 | - | 13,805 | 24,825 | 22,321 | 13,380 | 6,015 | 2,163 | 648 | 167 | 37 | 7 | 83,370 |
| **Nov97** | 1.77 | - | 13,956 | 24,752 | 21,950 | 12,977 | 5,754 | 2,041 | 603 | 153 | 34 | 7 | 82,227 |
| **Dec97** | 1.75 | - | 14,104 | 24,671 | 21,578 | 12,582 | 5,502 | 1,925 | 561 | 140 | 31 | 6 | 81,099 |
| **Jan98** | 1.73 | - | 14,248 | 24,581 | 21,205 | 12,195 | 5,260 | 1,815 | 522 | 129 | 28 | 5 | 79,986 |
| **Feb98** | 1.70 | - | 14,389 | 24,484 | 20,831 | 11,815 | 5,026 | 1,711 | 485 | 118 | 25 | 5 | 78,889 |
| **Mar98** | 1.68 | - | 14,527 | 24,380 | 20,458 | 11,444 | 4,802 | 1,612 | 451 | 108 | 23 | 4 | 77,807 |
| **Apr98** | 1.66 | - | 14,661 | 24,268 | 20,084 | 11,081 | 4,586 | 1,518 | 419 | 99 | 20 | 4 | 76,740 |
| **May98** | 1.63 | - | 14,792 | 24,148 | 19,711 | 10,726 | 4,378 | 1,429 | 389 | 91 | 19 | 3 | 75,687 |
| **Jun98** | 1.61 | - | 14,920 | 24,022 | 19,340 | 10,380 | 4,178 | 1,345 | 361 | 83 | 17 | 3 | 74,649 |
| **Jul98** | 1.59 | - | 15,044 | 23,890 | 18,969 | 10,041 | 3,986 | 1,266 | 335 | 76 | 15 | 3 | 73,625 |
| **Aug98** | 1.57 | - | 15,164 | 23,751 | 18,600 | 9,711 | 3,802 | 1,191 | 311 | 70 | 14 | 2 | 72,615 |
| **Sep98** | 1.54 | - | 15,281 | 23,605 | 18,232 | 9,388 | 3,626 | 1,120 | 288 | 64 | 12 | 2 | 71,619 |
| **Oct98** | 1.52 | - | 15,394 | 23,454 | 17,867 | 9,074 | 3,456 | 1,053 | 267 | 58 | 11 | 2 | 70,636 |
| **Nov98** | 1.50 | - | 15,503 | 23,297 | 17,504 | 8,767 | 3,294 | 990 | 248 | 53 | 10 | 2 | 69,667 |
| **Dec98** | 1.48 | - | 15,609 | 23,134 | 17,143 | 8,469 | 3,138 | 930 | 230 | 49 | 9 | 1 | 68,712 |
| **Jan99** | 1.46 | - | 15,711 | 22,966 | 16,785 | 8,178 | 2,989 | 874 | 213 | 44 | 8 | 1 | 67,769 |
| **Feb99** | 1.44 | - | 15,810 | 22,792 | 16,430 | 7,895 | 2,846 | 821 | 197 | 41 | 7 | 1 | 66,840 |
| **Mar99** | 1.42 | - | 15,904 | 22,614 | 16,078 | 7,620 | 2,709 | 770 | 183 | 37 | 7 | 1 | 65,923 |
| **Apr99** | 1.40 | - | 15,995 | 22,431 | 15,729 | 7,353 | 2,578 | 723 | 169 | 34 | 6 | 1 | 65,018 |
| **May99** | 1.38 | - | 16,082 | 22,244 | 15,383 | 7,093 | 2,453 | 678 | 156 | 31 | 5 | 1 | 64,126 |
| **Jun99** | 1.36 | - | 16,165 | 22,052 | 15,042 | 6,840 | 2,333 | 636 | 145 | 28 | 5 | 1 | 63,247 |
| **Jul99** | 1.35 | - | 16,245 | 21,857 | 14,704 | 6,594 | 2,218 | 597 | 134 | 26 | 4 | 1 | 62,379 |
| **Aug99** | 1.33 | - | 16,320 | 21,657 | 14,370 | 6,356 | 2,109 | 560 | 124 | 23 | 4 | 1 | 61,523 |
| **Sep99** | 1.31 | - | 16,392 | 21,454 | 14,040 | 6,125 | 2,004 | 525 | 114 | 21 | 4 | 1 | 60,679 |
| **Oct99** | 1.29 | - | 16,460 | 21,248 | 13,714 | 5,901 | 1,904 | 492 | 106 | 20 | 3 | 0 | 59,847 |
| **Nov99** | 1.27 | - | 16,524 | 21,038 | 13,392 | 5,683 | 1,809 | 461 | 98 | 18 | 3 | 0 | 59,026 |
| **Dec99** | 1.26 | - | 16,585 | 20,825 | 13,075 | 5,473 | 1,718 | 431 | 90 | 16 | 3 | 0 | 58,216 |
| **Jan00** | 1.24 | - | 16,642 | 20,610 | 12,762 | 5,268 | 1,631 | 404 | 83 | 15 | 2 | 0 | 57,418 |
| **Feb00** | 1.22 | - | 16,694 | 20,392 | 12,454 | 5,071 | 1,548 | 378 | 77 | 13 | 2 | 0 | 56,630 |
| **Mar00** | 1.20 | - | 16,744 | 20,171 | 12,150 | 4,879 | 1,469 | 354 | 71 | 12 | 2 | 0 | 55,853 |
| **Apr00** | 1.19 | - | 16,789 | 19,949 | 11,851 | 4,694 | 1,394 | 331 | 66 | 11 | 2 | 0 | 55,087 |
| **May00** | 1.17 | - | 16,831 | 19,724 | 11,557 | 4,514 | 1,323 | 310 | 61 | 10 | 1 | 0 | 54,331 |
| **Jun00** | 1.16 | - | 16,869 | 19,497 | 11,268 | 4,341 | 1,254 | 290 | 56 | 9 | 1 | 0 | 53,586 |

| **Class C** | $\hat{\lambda}_t$ | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Jul00** | 1.14 | - | 16,904 | 19,269 | 10,983 | 4,173 | 1,189 | 271 | 52 | 8 | 1 | 0 | 52,851 |
| **Aug00** | 1.12 | - | 16,934 | 19,040 | 10,703 | 4,011 | 1,127 | 254 | 48 | 8 | 1 | 0 | 52,126 |
| **Sep00** | 1.11 | - | 16,962 | 18,809 | 10,428 | 3,855 | 1,069 | 237 | 44 | 7 | 1 | 0 | 51,411 |
| **Oct00** | 1.09 | - | 16,985 | 18,577 | 10,158 | 3,703 | 1,013 | 221 | 40 | 6 | 1 | 0 | 50,705 |
| **Nov00** | 1.08 | - | 17,006 | 18,344 | 9,893 | 3,557 | 959 | 207 | 37 | 6 | 1 | 0 | 50,010 |
| **Dec00** | 1.06 | - | 17,022 | 18,110 | 9,633 | 3,416 | 909 | 193 | 34 | 5 | 1 | 0 | 49,324 |
| **Jan01** | 1.05 | - | 17,036 | 17,875 | 9,378 | 3,280 | 860 | 181 | 32 | 5 | 1 | 0 | 48,647 |
| **Feb01** | 1.03 | - | 17,046 | 17,640 | 9,128 | 3,149 | 815 | 169 | 29 | 4 | 1 | 0 | 47,980 |
| **Mar01** | 1.02 | - | 17,052 | 17,405 | 8,883 | 3,022 | 771 | 157 | 27 | 4 | 0 | 0 | 47,322 |
| **Apr01** | 1.01 | - | 17,055 | 17,169 | 8,642 | 2,900 | 730 | 147 | 25 | 4 | 0 | 0 | 46,672 |
| **May01** | 0.99 | - | 17,055 | 16,934 | 8,407 | 2,782 | 691 | 137 | 23 | 3 | 0 | 0 | 46,032 |
| **Jun01** | 0.98 | - | 17,052 | 16,698 | 8,176 | 2,669 | 653 | 128 | 21 | 3 | 0 | 0 | 45,401 |
| **Jul01** | 0.97 | - | 17,046 | 16,463 | 7,950 | 2,559 | 618 | 119 | 19 | 3 | 0 | 0 | 44,778 |
| **Aug01** | 0.95 | - | 17,036 | 16,228 | 7,729 | 2,454 | 584 | 111 | 18 | 2 | 0 | 0 | 44,164 |
| **Sep01** | 0.94 | - | 17,023 | 15,993 | 7,513 | 2,353 | 553 | 104 | 16 | 2 | 0 | 0 | 43,558 |
| **Oct01** | 0.93 | - | 17,008 | 15,759 | 7,301 | 2,255 | 522 | 97 | 15 | 2 | 0 | 0 | 42,960 |
| **Nov01** | 0.91 | - | 16,989 | 15,526 | 7,095 | 2,161 | 494 | 90 | 14 | 2 | 0 | 0 | 42,371 |
| **Dec01** | 0.90 | - | 16,967 | 15,294 | 6,893 | 2,071 | 467 | 84 | 13 | 2 | 0 | 0 | 41,790 |
| **Jan02** | 0.89 | - | 16,943 | 15,062 | 6,695 | 1,984 | 441 | 78 | 12 | 1 | 0 | 0 | 41,216 |
| **Feb02** | 0.88 | - | 16,915 | 14,831 | 6,502 | 1,900 | 417 | 73 | 11 | 1 | 0 | 0 | 40,651 |
| **Mar02** | 0.86 | - | 16,885 | 14,602 | 6,314 | 1,820 | 393 | 68 | 10 | 1 | 0 | 0 | 40,093 |
| **Apr02** | 0.85 | - | 16,852 | 14,373 | 6,130 | 1,743 | 372 | 63 | 9 | 1 | 0 | 0 | 39,543 |
| **May02** | 0.84 | - | 16,817 | 14,146 | 5,950 | 1,668 | 351 | 59 | 8 | 1 | 0 | 0 | 39,001 |
| **Jun02** | 0.83 | - | 16,778 | 13,921 | 5,775 | 1,597 | 331 | 55 | 8 | 1 | 0 | 0 | 38,466 |
| **Jul02** | 0.82 | - | 16,738 | 13,696 | 5,604 | 1,529 | 313 | 51 | 7 | 1 | 0 | 0 | 37,938 |
| **Aug02** | 0.81 | - | 16,694 | 13,474 | 5,437 | 1,463 | 295 | 48 | 6 | 1 | 0 | 0 | 37,418 |
| **Sep02** | 0.80 | - | 16,649 | 13,252 | 5,274 | 1,399 | 278 | 44 | 6 | 1 | 0 | 0 | 36,904 |
| | | | | | | | | | | | | | 3,424,157 |

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