

NAVAL POSTGRADUATE SCHOOL
Monterey, California



THESIS

**INFORMATION MANAGEMENT SYSTEM
DEVELOPMENT FOR THE CHARACTERIZATION AND
ANALYSIS OF HUMAN ERROR IN NAVAL AVIATION
MAINTENANCE RELATED MISHAPS**

by

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September 2000

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CHARACTERIZATION AND ANALYSIS OF HUMAN ERROR IN NAVAL
AVIATION MAINTENANCE RELATED MISHAPS**

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ABSTRACT

The purpose of this thesis is to develop a prototype safety information management tool to capture human error in Naval Aviation maintenance mishaps. The Human Factors Analysis and Classification System-Maintenance Extension taxonomy, an effective framework for classifying and analyzing the presence of maintenance errors that lead to mishaps, incidents, and personal injuries, is the foundation of this management tool. The target audience for this information management system tool includes safety personnel, mishap investigators, Aircraft Mishap Board (AMB) members, and analysts. A review of three areas is needed to produce the prototype: (1) the collection, use, and management of accident information, (2) human error theories as related to aviation mishaps, and (3) the design of an effective mishap database tool. A usability study was conducted using potential end-users (Naval Aviation Safety Officers). The participants are given both written procedures to navigate through the prototype and an exit survey. The results of the survey, including objective and subjective responses about the prototype are gathered. The resulting data indicates an improved version of the prototype could directly lead to a decreased mishap rate and overall increased mission readiness due to the training and analysis opportunity it provides.

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LIST OF ACRONYMS

AGM	Aircraft-Ground Mishap
AIMD	Aircraft Intermediate Maintenance Department
AMB	Aircraft Mishap Board
ASO	Aviation Safety Officer
CSA	Command Safety Assessment
DOD	Department of Defense
DON	Department of the Navy
FAA	Federal Aviation Administration
FM	Flight Mishap
FOQA	Flight Operational Quality Assurance
FRM	Flight-Related Mishap
FY	Fiscal Year
GPWS	Ground Proximity Warning System
GUI	Graphical User Interface
HCI	Human-Computer Interface
HFACS	Human Factors Analysis and Classification System
HFACS-ME	Human Factors Analysis and Classification System-Maintenance Extension
HFQMB	Human Factors Quality Management Board
IFSD	In-flight Shutdown
ISA	(Swedish) Information System on Occupational Accidents and Diseases
LAN	Local Area Network
MDA	Maintenance Mishap Data Analysis
ME	Maintenance Extension (see HFACS-ME)
MEDA	Maintenance Error Decision Aid
MEIMS	Maintenance Extension Information Management System
MRM	Maintenance-Related Mishap
NADEP	Naval Aviation Depot
NSC	Naval Safety Center
NPS	Naval Postgraduate School
NTSB	National Transportation Safety Board
OB	Organizational Benchmarking
ORM	Organizational Risk Management
RAM	Random Access Memory
SHEL	Software, Hardware, Environment, and Liveware (Edwards' Model)
SIMS	Safety Information Management System (Naval Safety Center)
TACAIR	Tactical Aircraft
TEAM	Tools for Error Analysis in Maintenance (Galaxy)
USN	United States Navy

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I. INTRODUCTION

A. OVERVIEW

(1) Background

Naval Aviation has had great success in substantially reducing (by half) its Class A Flight Mishap (FM) rate in each successive decade between 1950 and 1999 (see Figure 1). Despite this achievement, the proportion of mishaps attributed to human error has remained at a relative constant rate of about four in five (Nutwell & Sherman, 1997). In 1996, a Navy F-14 Tomcat crashed shortly after taking off from Nashville, Tennessee killing both aircrew and three civilians on the ground (HFQMB, 1997). As a result of this causes of this mishap being solely attributable to human (aircrew) error, senior Naval Leadership established a Human Factors Quality Management Board (HFQMB) with the objective of reducing human error involvement in Naval Aviation Class A flight mishaps by 50 percent at the start of fiscal year (FY) 2000 (HFQMB, 1997). Aircrew *human* error was found to be a contributing factor in 60 percent of Class A FMs and, consequently, was the initial focus of the HFQMB. Although Naval Aviation had its lowest Class A FM rate in FY 1999, the HFQMB's goal of reducing human error related mishaps by 50 percent was not achieved (Naval Safety Center, 1999). Thus, the scope of the HFQMB was expanded to include the reduction of human error in maintenance related aviation mishaps. Maintenance human error contributed to about 20 percent of the Class A FM rate (Naval Safety Center, 1999). This thesis contributes to this endeavor by developing an information management system to facilitate the characterization and analysis of human error in Naval Aviation maintenance related mishaps.

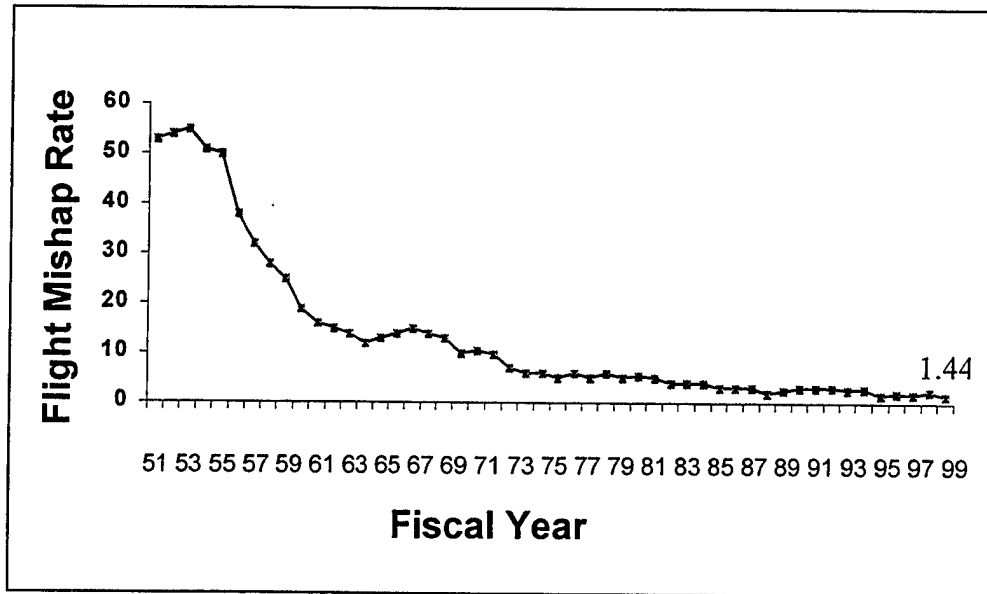


Figure 1: Naval Aviation Class A Flight Mishap Rates for FY 1950-1999 (School of Aviation Safety, 1999)

The HFQMB's (1997) strategy to achieve its objective consists of a three-pronged approach: (1) Mishap Data Analysis (MDA), (2) Organizational Benchmarking (OB), and (3) Command Safety Assessment (CSA). MDA identifies human factors issues in past Class A FMs. Target areas were prioritized for intervention based upon the presence of prevailing human errors. The Human Factors Analysis and Classification System (HFACS) of identifying causal factors through examination of past mishaps was developed to achieve this end. OB is the second approach used to identify the best practices and procedures in other aviation organizations, both military and civilian. For example, the US Army attributed its reduced Class A FM rate to the use of Risk Management by its aircrew. Consequently, Operational Risk Management (ORM) was adopted by Naval Aviation and established as a part of doctrine (Department of the Navy-DON, 1997). CSA was developed to assess a command's safety climate from an aircrew perspective (Ciavarelli & Figlock, 1997). It solicits opinions/attitudes about organizational safety processes and command climate. CSAs may eventually show that

both organizational and supervisory issues impact flight safety (Nutwell & Sherman, 1997).

In January 1999, the Vice Chief of Naval Operations revised the goal to reduce human error in Naval Aviation Class A FMs by 50 percent by the end of FY2000 (Personal communication between T. Meyers and B. Goodrum, 1999). Presently one of every five Class A FMs contain maintenance error. This compelled the HFQMB to expand its focus to include maintenance related mishaps using the same three-prong approach as used for aircrew error analysis.

(2) Maintenance Mishap Data Analysis (MDA)

The analytic framework for examining aircrew and supervisory error in Class A FMs was HFACS. HFACS is a taxonomy which falls in line with the Naval Aviation Safety Program's notion of multiple causal factors, the idea of sequential events leading to an event, and several established human factors theories. HFACS was adjusted and adopted to cover maintenance operations, and the extension was successfully used to examine major mishaps (Schmidt, Schmorow, & Hardee, 1997), minor mishaps (Schmidt, Schmorow, & Figlock, 2000), and incidents/injury (Schmidt, Figlock, & Teeters, 1999) data. The Navy has included an adjusted version of the Maintenance Extension of HFACS (HFACS-ME) for inclusion in the upcoming revision of the Naval Aviation Safety Program Instruction (DON, 2000).

B. PROBLEM STATEMENT

In order to continue to reduce its Class A FM rate, Naval Aviation leadership must understand that all mishaps are not caused solely by *aircrew* error. The analysis of *maintenance* related mishaps offers an increased opportunity to reduce target mishaps and enhance readiness. The HFACS-ME taxonomy has been adapted to classify causal factors that contribute to maintenance mishaps. A modern database tool is essential in more effectively addressing and identifying patterns of human error using HFACS-ME. However, there is no such tool available today. The target audience for such a tool would include safety personnel (e.g., data entry and retrieval by unit safety officers, other safety and training personnel, maintenance officers, maintenance supervisors), mishap investigators-for data retrieval (e.g., Aircraft Mishap Board members, squadron safety officers), and analysts (e.g., from the Naval Safety Center, the command's safety officer or one from its higher headquarters).

This thesis investigates the following questions:

1. How could human errors in maintenance related Naval Aviation mishaps be effectively collected, cataloged, and collated in an information system?
2. How could customers query and use this maintenance error information in order to identify problem areas and trends?
3. How would customers in the fleet effectively and efficiently access maintenance error information in Naval Aviation mishaps?

C. PURPOSE

The intent of this study is to develop and evaluate a safety information management system that will facilitate *data collection, organization, query, analysis, and reporting* of maintenance personnel errors that contribute to Naval Aviation mishaps, equipment damage, and personnel injury using the HFACS-ME taxonomy as its basis.

Drawing upon several theoretical approaches to examine mishaps involving human error, including Heinrich's "Domino" Theory, Edwards' "SHEL" Model, and Reason's "Swiss Cheese" Model, helps to identify not only the unsafe actions causing a mishap, but latent conditions which set the stage for mishaps to occur. HFACS-ME is a composite derivative of these three taxonomies. It classifies and analyzes the presence of human error in maintenance operations leading to major mishaps, accidents of lesser severity, incidents, and maintenance related personal injury cases. However, working with a large database by hand or spreadsheet is very labor intensive. Given the capability of current relevant database tools, an improved information management system will bring HFACS-ME to the next level by improving access and analysis of safety data. Though there is no generally accepted method of accident investigation (Benner, 1975), standardized aircraft accident investigation procedures have been adopted by civilian and military agencies throughout the world (Diehl, 1991).

The result of this study leads to a development of a tool that: (1) captures maintenance error associated with maintenance related incidents; (2) facilitates the identification of common maintenance errors and associated trends; and (3) supports understanding of how to identify human errors in the future.

D. SCOPE AND LIMITATIONS

Fleet personnel, primarily Aviation Safety Officers, will test the prototype Maintenance Extension Information Management System (MEIMS) tool (hereafter referred to as the prototype). The prototype to be developed is to be used by Naval Aviation squadrons, but may have some crossover use by other military branches and civilian airlines. Only maintenance related mishaps caused by human error will be considered. No material failure factors or maintenance related hazard reports or personnel injuries not related to a mishap are to be included.

E. DEFINITIONS

This study uses the following definitions:

Aircraft Mishap Board. Group of officers appointed to investigate and report on an aviation mishap (DON, 1991).

Aviation mishap rate. Number of aviation mishaps per 100,000 flight hours (DON, 1991).

Aviation Safety Officer. Principal advisor to Naval Aviation squadron commanding officers on all aviation safety matters (DON, 1991)

F-14 Tomcat. US Navy aircraft. Two aircrew, two engines, swing-wing, supersonic fighter with air-to-air, air-to-ground, and reconnaissance capability (Rowe & Morrison, 1973).

Fleet Logistics Support Wing. US Navy reserve air wing comprised of transport aircraft (Schmidt, Schmorrow, & Teeters, 1999).

HFACS: Human Factors Analysis and Classification System. System designed to help analyze Naval Aviation mishaps focusing on aircrew error (Shappell & Wiegmann, 1997).

HFACS-ME: Human Factors Analysis and Classification System--Maintenance Extension. HFACS adaptation to classify causal factors that contribute to maintenance mishaps (Schmidt, 1996).

HFQMB: Human Factors Quality Management Board. Established by Naval Aviation senior leadership to reduce human error involvement in Naval Aviation Class A flight mishaps (HFQMB, 1997).

MEIMS: Maintenance Error Information Management System. Prototype tool developed for this thesis.

Mishap. A naval mishap is an unplanned event or series of events directly involving naval aircraft, which result in \$10,000 or greater cumulative damage to naval aircraft, other aircraft, property, or personnel injury (DON, 1991).

Mishap Categories. Naval aircraft mishap categories are defined below (DON, 1991):

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.

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.

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 or death occurred.

Mishap Severity Class. Mishap severity classes are based on personnel injury and property damage (DON, 1991):

Class A. 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.

Class B. 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.

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

Naval Aircraft. Refers to US Navy, US Naval Reserve, US Marine Corps, and US Marine Corps aircraft.

OPNAVINST 3750.6: The Naval Aviation Safety Program. US Navy instruction outlining Naval Aviation's safety program. Revision Q-1991, revision R-in work (DON, 1991 & 2000).

ORM: Operational Risk Management. A decision making tool to increase effectiveness (and hence decrease accidents) by anticipating hazards, reducing the potential for loss due to these hazards, and thus increasing the probability of a successful mission (DON 1997).

F. ORGANIZATION OF STUDY

Chapter II contains a literature review on the development of a prototype to identify human error involvement and patterns in aviation maintenance mishaps. The methods used in this study are discussed in Chapter III. The results of this study are presented in Chapter IV. Finally, Chapter V contains conclusions, findings, and recommendations.

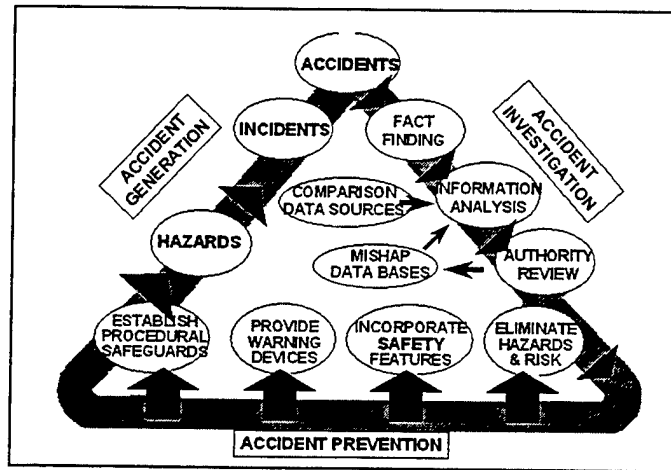
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II. LITERATURE REVIEW

A. OVERVIEW

The literature examined relates to the development of a prototype to identify human error involvement and patterns in aviation maintenance mishaps. It includes textbooks, research articles, and masters theses pertaining to: (1) the collection, use, and management of accident information, (2) human error theories, its involvement in aviation mishaps, and specifically maintenance mishaps, and (3) design and usability of an effective mishap database tool. Collectively, these information sources provide a foundation to develop an effective and user friendly maintenance error analysis and reporting tool.

Diehl (1991), in a three-stage model of accident investigation and prevention, focuses on human performance and systems safety considerations (see Figure 2). The first stage is Accident Generation: the identification of hazards. Hazards have the potential to lead to an incident (near-accident) or even an accident. Heinrich (1941) study of thousands of accidents determined that for every major accident, there are approximately 30 minor accidents, and 300 hazardous incidents. This pyramidal relationship between hazards, incidents, and accidents also applies to aviation safety (Diehl, 1991).



**Figure 2: Accident Generation, Investigation, and Prevention Elements
(Adapted from Diehl, 1989)**

The second stage is the Accident Investigation Process: the collection, analysis, and review of accident data and the focus of this review. Accidents rarely result from a single sudden event, but are normally associated with a series of events degrading the performance of the equipment, crewmen, or both, until the accident is inevitable (Nance, 1986). Investigating bodies have established similar aircraft accident investigation procedures. The fact-finding phase takes place near the scene of the accident to establish *what happened*. Next, the information analysis emphasizes on describing *what caused* the accident and *why it occurred* (Diehl, 1991). Part of that analysis is based on examining comparative data sources: information about both the normal and emergency performance of the aircraft, as well as human capabilities and limitations. Investigators are now able to theorize as to the causal factors of the accident and its probable sequence of events. Once the analysis is complete a final report is developed by board authorities with the accepted findings, causes, and recommendations. This phase is *judgmental* in nature.

The final stage contains the Prevention Measures (and methods) used to avoid future similar incidents. There are four categories of accident-prevention measures: (1) eliminating hazards and risks, (2) incorporating safety features (3) providing warning devices, and (4) establishing procedural safeguards. As one travels from right to left along the bottom leg of Diehl's triangle, the measures become less expensive, less effective, and less restrictive. (Diehl, 1991).

B. ACCIDENT INFORMATION

(1) Investigation

Accidents occur within an organizational/systems context, and understanding the involved systems and operating environment can provide an enhanced framework for investigating accidents and determining their causes (Wagenaar, Groeneweg, & Hudson, 1994). During the initial phase of an investigation retrospective analysis of past accidents can help to focus on areas of high risk and identify groups of potential causal factors (McElroy, 1974). Effective interventions can then be identified and subsequently implemented to reduce accident occurrence. However, the perceptions of accident investigators can be skewed and thus diminish the effectiveness of an investigation (Benner, 1982). Therefore, a systematic process for investigating and reporting accidents is imperative.

Grimaldi & Simonds (1984) detailed a four-part process for investigations. The first step is to explore the history of the incident as far back as is practical, including activities occurring both during and prior to the event. Second, the investigator must collect as many facts relating to the incident as possible (from reliable witnesses). Next,

the physical environment associated with the accident must be examined. Finally, the use of a defining guide listing common causal factors can be used to determine probable causal factors of the incident itself. This process parallels aspects of that provided by Diehl (1991) in his model of aviation accident investigation.

Though there is no generally accepted method of accident investigation (Benner, 1975), standardized aircraft accident investigation procedures have been adopted by civilian and military agencies throughout the world (Diehl, 1991).

(2) Reporting

Accident reports have generally centered on number of episodes and observations per unit time (Brown, 1990a). Frequencies and rates alone, however, do not provide a sound basis for understanding accidents (Brown, 1990a). The conventional process of reporting accidents by a description followed by supporting documentation varies in scope, depth, quality, objectivity, and contains inconsistencies and varying levels of completeness (Edwards, 1981). In addition, the traditional reporting format does not normally capture human factors information (Adams, Barlow, & Hiddlestone, 1981). To increase the usability of mishap reports, the information they contain must assist in the determination of cause and prevention of future accidents by ensuring collection, classification, and data recording methods are accurate and reliable. The usefulness of the reports is greatly increased when bias is removed and any future potential (based on frequency or severity) of occurrence is easily used (Adams & Hartwell, 1977).

Three elements critical to the success of an accident reporting system are (Chapanis, 1996): (1) properly trained investigators, (2) a good accident reporting form,

and (3) a centralized facility for dealing with reports. If a mishap reporting system is unable to either prevent or reduce the severity of future accidents (Brown, 1990b) subsequent data analysis can be problematic (Pimble & O'Toole, 1982). Analysis of data from typical reporting systems has been accomplished through the following process:

- collecting data on past accidents within a population;
- dividing the sample into groups with and without accidents;
- obtaining measurements of individual characteristics on all participants;
- statistically comparing the two groups; and
- identifying any significant difference between the two groups, associating the differential characteristic with accidents.

Using these methods has resulted in a more complete and thorough analysis effort.

This general style of accident reporting has been used by many studies, but its methods have also been concluded to be suspect (Hale & Hale, 1972; Hansen 1988; Shaw & Sichel, 1971). The symptom may not actually be responsible for the accident, but may be related to another (correlative) variable which may, in fact, bear responsibility.

Recently, accident reporting tools have been advanced and are supporting more rigorous and ordered methods of analysis (Leplat, 1989; Malaterre, 1990; Reason, 1990). The ability of a report to distinguish between causal and correlative variables determines its utility (Hill, Byers, Rothblum, & Booth, 1994).

(3) Data Management

Once data pertaining to an accident is collected, it must be archived for use in accident prevention (National Safety News, 1975). Many methods of recording this information are in use, but some fundamental concepts are recognized including coding the data and the use of computer databases to quickly and efficiently store and retrieve information. In addition, the attributes of the data are critical in ensuring the best information is collected and stored for future use.

The National Safety Council (National Safety News, 1975) established a method of facilitating the sorting and tabulation of accident particulars. Numerical codes are assigned to the different classifications in the mishap. Therefore, the specific case is read once when its facts are assigned code numbers. Concentrating on one phase of the accident problem at a time is a more effective way to reduce incidents than to deliberate on the mishap as a whole. Merely obtaining the information will not prevent recurrence of the accidents. The conditions contributing to the incident must be corrected. Subsequent sorting of these facts by category can then be completed quickly by simply referencing the code numbers.

The Swedish Information System (ISA) on Occupational Accidents and Diseases was developed in 1979 to improve the work environment through increasing knowledge about risks (Andersson & Lagerlof, 1983). The ISA's goal is accomplished through the collection of information in four areas: (1) knowledge about risks, (2) knowledge about preventive actions, (3) cost-benefit analysis, and (4) a "will" to change (see Figure 3). To identify a risk, the experience of one accident of a specific type is viewed as enough, and consequently accident prevention has traditionally been very case-related. However,

experience alone is not satisfactory for identifying and evaluating risks since minor incidents are frequently given less attention and major ones occur less frequently. The ISA system provides reports based on its database: periodic statistics, focused statistics, figures for particular accidents, and frequency of accidents.

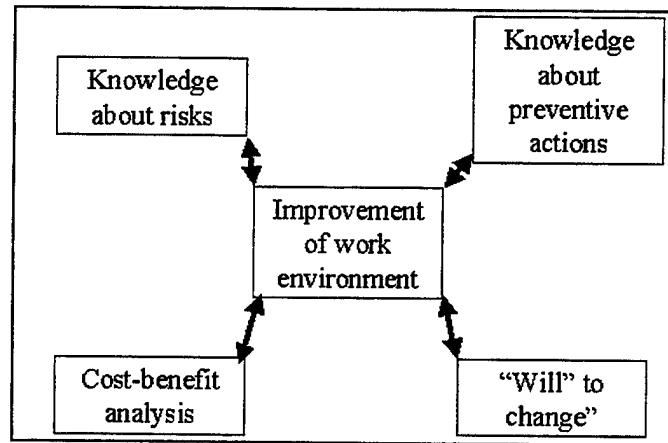


Figure 3: Swedish Information System on Occupational Accidents and Diseases (ISA) (Andersson & Lagerlof, 1983)

It is common to have a system that only reports incidents resulting in an accident (Grimaldi & Simonds, 1984). However, it is important to recognize "near-miss" cases in order to identify potential conditions or practices that are accident producing types and prevent their future occurrence. Essentially the same form could be used in both accident and near-miss incidents.

Setting up a computer analysis can reduce man-hours involved in reviewing mishap histories (Kuhlman, 1977). To set up an effective program, the available information needs to be organized and tabulated into categories. This information then can be presented in a format (report) to the user who can decide how to use it to analyze past occurrences.

(4) Prevention

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), and organizations typically employ both options (Kanis & Weegels, 1990).

Accident prevention was initially based on a widely held notion that people committing unsafe acts, not their working conditions, were to blame for most accidents (Heinrich, 1959). 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.

The most effective accident prevention strategies employ systems engineering (Hawkins, 1993). The systems engineering approach was developed in the 1950s 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, 1980). 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 (Heinrich, Petersen, & Roos, 1980). The literature suggests that 80-90 percent of accidents are attributable to human error (Heinrich, Petersen, & Roos, 1980; Hale & Glendon, 1987; School of Aviation Safety, 2000). Therefore, evaluating human factors associated with accidents can contribute to the understanding of systems and how they fail.

Operational Risk Management (ORM) is another tool used by the armed forces to decrease aviation accident rates. It is a decision making tool used by personnel at all levels to increase effectiveness (and hence decrease accidents) by anticipating hazards, reducing the potential for loss due to these hazards, and thus increasing the probability of a successful mission (DON, 1997). The aviation arm of the United States Army achieved record low accident rates in 1995 and 1996 attributing a large portion of their success to the use of ORM (Department of the Army, 2000). The remaining military services institutionalized ORM in 1997 in attempt to lower their own rates (School of Aviation Safety, 2000). ORM emphasizes identifying hazards and reducing their associated risk to an acceptable level through the use of control measures (DON, 1997). It is especially effective in identifying and analyzing human factor hazards as well.

C. HUMAN ERROR

Knowledge derived from the analysis of human errors can greatly improve safety.

There are numerous theoretical approaches to examine mishaps involving human error (Goetsch, 1996). Some methods have their basis in industrial safety, while others are viewed from a more complex systems perspective, with an emphasis on human factors and operator error. Table 1 outlines some of the more well-known approaches.

Table 1: Theoretical Approaches to Defining Accident Processes (Schmidt, 1998)

Source	Model	Approach
Industrial Safety	Heinrich's Domino Theory	Linear
Systems Safety	Edwards' SHEL Model	Interface
Human Factors	Reason's Swiss Cheese Model	Vertical

(1) Heinrich's "Domino" Theory

The original accident causation theory is considered to be Heinrich's "Domino" Theory (Goetsch, 1996). Heinrich believed accidents could be viewed as a linear five step sequence of related factors (chain of events) that lead to an actual mishap (Bird, 1980). The two central principles of the Domino Theory are (Goetsch, 1996): (1) accidents are caused by the actions of the preceding factors, and (2) removal of the middle factor (unsafe act or condition) will negate the actions of the preceding factors and thus prevent accidents and injuries (see Figure 4).

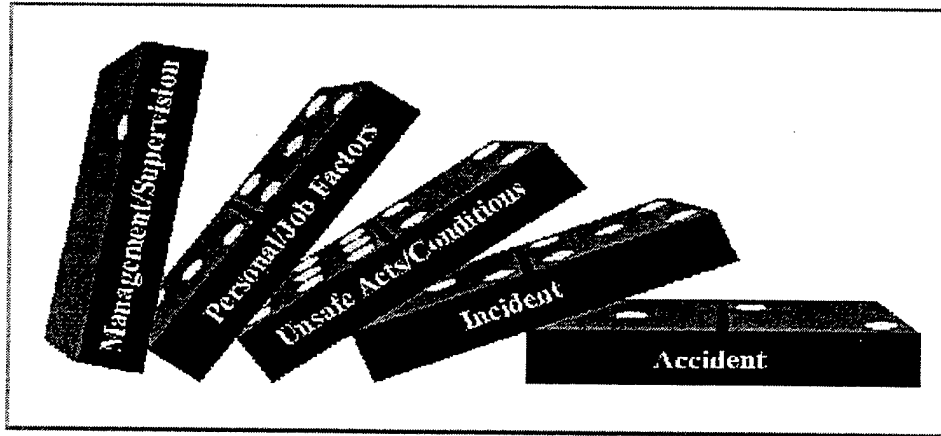


Figure 4: Domino Theory (School of Aviation Safety, 1998)

The following is a characterization of each domino (Bird, 1980):

- Lack of Control by Management (lack of supervision). The professional manager has four control functions: planning, organizing, leading, and controlling. Managers at all levels and all activities must perform these functions to ensure proper completion of work.
- Basic Cause(s) of incident--Origin(s). A lack of management control (domino one) allows certain basic causes of incidents to exist. These causes are classified into two separate categories:
 - Personal Factors: denoted by a lack of knowledge or skill, improper motivation, physical or mental problems. Personal factors explain why people engage in substandard practices.
 - Job Factors: denoted by inadequate work standards, inadequate design or maintenance, inadequate purchasing standards, normal wear and tear, abnormal usage. Job factors explain why substandard conditions exist.

- Immediate Cause(s)--Symptoms (unsafe act/condition). If basic causes of incidents exist, the opportunity for actual substandard practices and conditions (errors) also exists. A substandard practice or condition is a deviation from an accepted standard or practice.
- Incident--Contact. If substandard practices and conditions exist, an incident may occur that may or may not result in a loss. Of note, every incident that occurs provides an opportunity to collect data that could prevent a future occurrence.
- Accident: Loss of People or Property. Once an incident has occurred it can result in a loss of personnel or property.

Each step causes the next to occur, as would a series of falling dominos. If factors from any of the first three dominos are removed, the accident will effectively be prevented.

(2) Edwards' "SHEL" Model

The "SHEL" Model (Edwards, 1988) was developed in the early 1970s to provide a more effective means to evaluate human-machine systems failures. The model identifies and classifies four dimensions in evaluating human-machine systems failures: Software, Hardware, Environment, and Liveware.

- Software (S): 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; typically, a collection of documents.

- Hardware (H): buildings, vehicles, equipment, and materials of which the system is comprised.
- Environmental conditions (E): operating setting (physical, economic, political and social factors) of the software, hardware, and liveware operate.
- Liveware (L): people involved with the system.

Thus the SHEL Model is comprised of these system dimensions and the relationships between them (see Figure 5).

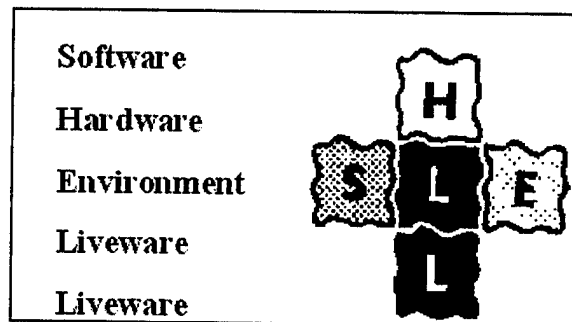


Figure 5: SHEL Model of System Design (Hawkins, 1993)

The SHEL Model assumes that a failure in the system will occur when one of the dimensions or the connection between them fails (Edwards, 1988). People are rarely the only cause of a mishap. They are, in fact, caused by the interaction of many factors (Shappell & Wiegmann, 1997). The SHEL Model is a significant change from the previously held idea that mishaps have single cause factors (Edwards, 1981). The SHEL Model describes systems, identifies areas for concern in a system, and provides a framework for accident investigation.

(3) Reason's "Swiss Cheese" Model

The Swiss Cheese model (Reason, 1990) of accident causation is another widely accepted perspective. Reason took a human factors approach to view the vertical association of a group of factors that lead to an eventual accident. His model differentiates between two error types: (1) active failures--the actions (or inactions) of operators that are believed to have caused the accident, and (2) latent conditions--situations primarily caused by management decisions or actions whose repercussions may only become apparent when they are triggered by other mitigating factors. The conjunction between context and acts, when taken together, are latent conditions. Latent conditions set the groundwork for an accident while active failures are the final catalyst for the mishap to occur. Safeguards in a system can prevent latent conditions from taking effect by reducing the probability for the commission of an active failure. Thus Reason's model seen as Swiss cheese slices' lined in a row, with each vertical slice representing a defense layer and each hole representing an active failure or latent condition in the defense. An accident will occur when the holes are aligned (see Figure 6).

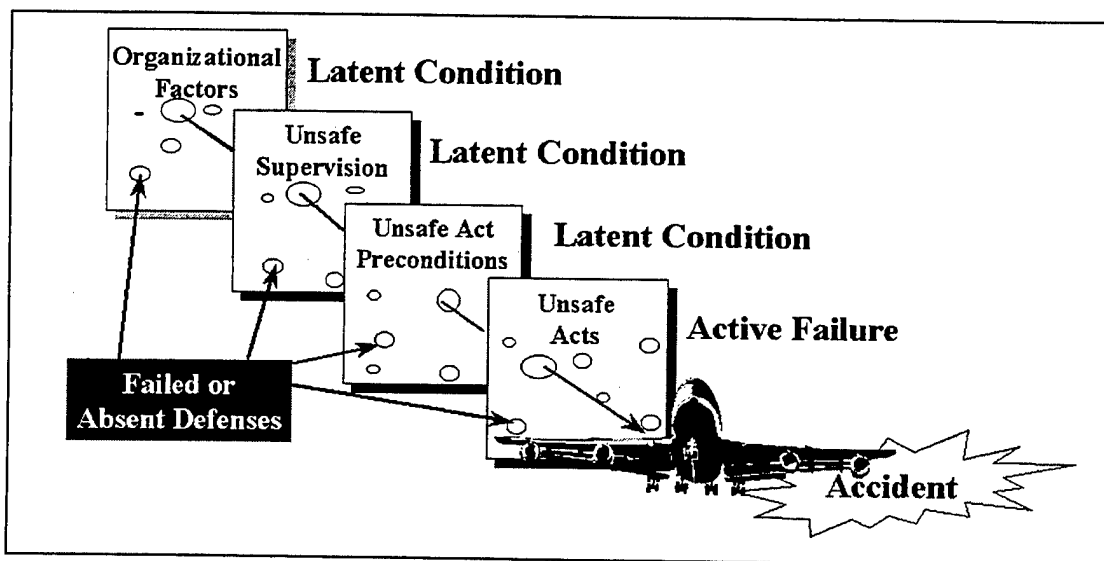


Figure 6: Reason's Swiss Cheese Model (Schmidt & Lawson, 2000)

Reason's (1997) model is not static, but dynamic, with each defensive layer moving according to the characteristics of the situation (Reason, 1997). An event may occur in one of three levels: (1) person-unsafe acts, (2) workplace-error provoking conditions, and (3) organization-error establishing conditions. The starting point for an accident occurs with organizational factors; strategic decisions and associated processes (resource allocation, budgeting, forecasting, planning) are initiated. These organizationally established processes are shaped and influenced by a corporate culture being distributed throughout the organization to individual workplaces. Corporate processes evidence themselves as inadequate staffing, time pressures, equipment, training, and working conditions. These factors, combined with the natural proclivity to commit errors and/or violations results in unsafe acts. Very few of these acts actually create holes in the defense layers en route to becoming an accident (Reason, 1997).

(4) Human Factors Analysis & Classification System (HFACS)

A restructuring and expansion of the Swiss Cheese Model evolved into HFACS which was specifically designed to help analyze Naval Aviation mishaps (Shappell & Wiegmann, 1997). HFACS focuses on aircrew error and also incorporates features of Heinrich's Domino Theory and Edwards' SHELL Model. The resulting taxonomy of unsafe operations identifies both active failures and latent conditions within four categories (DON, 2000): (1) unsafe acts; (2) pre-conditions for unsafe acts; (3) unsafe supervision, and (4) organizational influences. This classification can then be, and, in fact, has been, used to target the most appropriate intervention (see Figure 7). The Naval

Safety Center has adopted the use of the HFACS model for analysis of aircrew error in Naval Aviation mishaps.

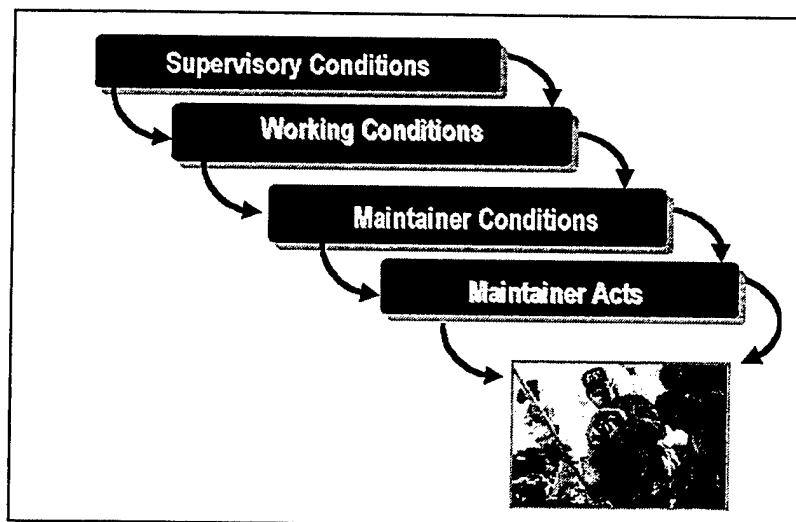


Figure 7: Levels of Human-Component Failure (Schmidt, 1998)

The following is a brief description of the HFACS taxonomy (DON, 2000).

Unsafe acts take two forms: (1) errors and (2) violations. Errors are found in most mishaps due to the facts that human beings by their nature make mistakes and are often the last flaw before the mishap occurs. There are three basic error types: (1) decision, (2) perceptual, and (3) skill-based. Violations, on the other hand, are the willful disregard for the rules and are not seen in as many mishaps. They are also further categorized into routine and exceptional violation categories. *Pre-conditions for unsafe acts* set the table for the unsafe act to occur. Its two major subdivisions are (1) substandard conditions of operators and (2) substandard practices of operators. Substandard conditions included adverse mental and physiological states and physical/mental limitations. Substandard practices include crew resource management and personal readiness. Failures associated with *unsafe supervision* are divided into four areas: (1) inadequate supervision, (2) planned inappropriate operations, (3) failure to correct a known problem, and (4)

supervisory violations. Upper-level management failures, or *organizational influences*, directly effect not only supervisory practices, but operator conditions and actions. These latent failures can be traced to issues dealing with resource management, organizational climate, and operational processes.

(5) Human Error in Maintenance Mishaps

Maintenance level human factors in aircraft mishaps can be categorized similarly to aircrew level human factors (DON, 2000). The Maintenance Extension (ME) of the HFACS taxonomy was adapted to classify causal factors that contribute to maintenance mishaps (Schmidt, 1996). It contains four human error categories: (1) Supervisory Conditions; (2) Working Conditions; (3) Maintainer Conditions; and (4) Maintainer Acts (see Figure 8). These categories provide for multiple causations, a chain of inter-related events, and observation between the link between components providing for a combined approach to study human error and its causes.

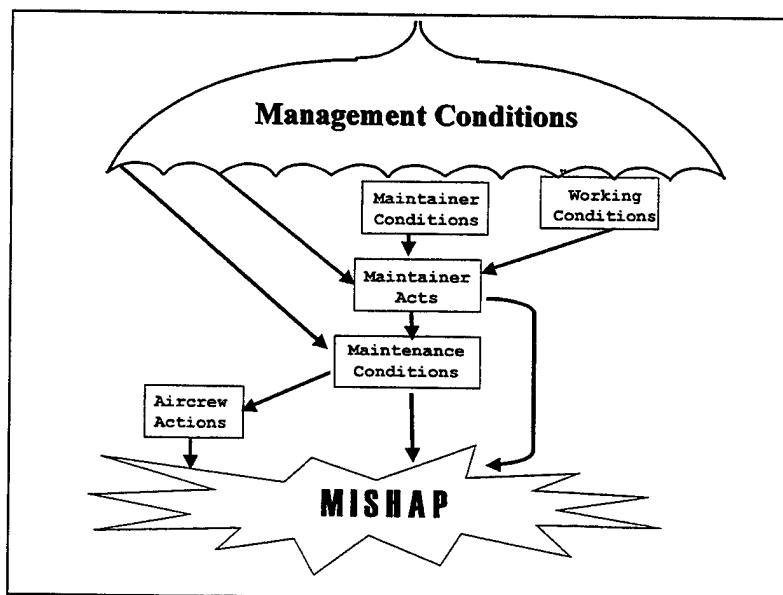


Figure 8: HFACS Maintenance Extension (HFACS-ME)
(DON, 2000)

Supervisory, Working, and Maintainer Conditions are latent conditions that can impact the performance of a maintainer (Schmidt, Schmorrow, & Hardee, 1997). This may contribute to maintainer act, an active failure, leading directly to a maintenance related mishap (MRM), maintenance condition, or personal injury. Thus, the HFACS-ME categories enable a safety analyst to identify failures at each of the four levels historically related to accidents (Schmidt, Schmorrow, & Hardee, 1997). The working conditions of a maintainer, as compared to those of the aircrew, will often play a more significant role in errors observed during maintenance evolutions (DON, 2000). Maintenance conditions have the potential to become a latent condition with which the aircrew would have to accommodate in flight and can also directly lead to mishap or injury through no fault of the aircrew. The three orders of maintenance error: first, second, and third order, reflect a decomposition of the error type from a macro to a micro perspective (see Table 2).

The following describe the categories of the original HFACS-ME taxonomy. Supervisory Conditions may contribute to an active failure due to either unforeseen or squadron errors. Maintainer Conditions that can contribute to an active failure include medical, crew resource management, and personal readiness. (Schmidt, 1998)

Working Conditions include the physical environment in which the maintainer works and the tools they use in the course of their work. Circumstances that can contribute to an active failure include poor environmental factors (lighting, weather, environmental hazards), inadequate equipment (damaged, unavailable, uncertified), and uncomfortable workspaces (confining, obstructed, inaccessible). (Schmidt, 1998)

Table 2: HFACS Maintenance Extension Categories (DON, 2000)

First Order	Second Order	Third Order
Supervisory Conditions	Organizational	Hazardous Operations Inadequate Documentation Inadequate Design Inadequate Processes Inadequate Resources
	Squadron	Inadequate Supervision Inappropriate Operations Uncorrected Problem Supervisory Misconduct
Maintainer Conditions	Medical	Unsafe Mental State Unsafe Physical State Unsafe Limitation
	Crew Coordination	Inadequate Communication Inadequate Assertiveness Inadequate Adaptability/Flexibility
	Readiness	Inadequate Training/Preparation Inadequate Certification/Qualification Personnel Readiness Infringement
Working Conditions	Environment	Inadequate Lighting/Light Unsafe Weather/Exposure Unsafe Environmental Hazards
	Equipment	Damaged Unavailable Dated/Uncertified
	Workspace	Confining Obstructed Inaccessible
Maintainer Acts	Error	Attention Memory Knowledge/Rule Based Skill Based Judgment/Decision Making
	Violation	Routine Infraction Flagrant Sabotage

Errors and violations are active failures in the form of Maintainer Acts. Active Failures can either directly cause damage and injury, or lead to a latent Maintenance Condition. Errors is substandard performance due to inattention, poor workmanship, and complacency. Violations are intended actions including both the routine or exceptional variety. Routine violations are consistent departures from rules and regulations condoned by management. Thus routine violations are considered to be acceptable departures from rules and regulations. Exceptional violations are substandard practices and actions not condoned by management. (Schmidt, 1998).

HFACS-ME was effective in capturing the nature of and relationships among active failures and latent conditions present in 63 Class A (hull loss or fatality) Naval Aviation maintenance mishaps (Schmidt, Schmorow, & Hardee, 1997), 470 reportable (over \$10,000 damage or permanent/partial disability) Naval Aviation maintenance mishaps (Schmidt, Schmorow, & Figlock, 2000), 124 incidents (Mishap Reports, Hazard Reports, and Injury Reports) for Fleet Logistics Support Wing maintenance operations (Schmidt, Figlock, & Teeters, 1999), and 15 select National Transportation Safety Board (NTSB) major (hull loss or fatality) maintenance accidents. The insight into latent conditions and active failures provides a solid perspective for trend analysis, investigation prioritization, and control development.

(6) Maintenance Error Issues

Marx (1998) stated that human error has not been served well by conventional accident investigation methods. These processes normally end once human error is identified without trying to understand why it occurred. This problem has been attributed

to several factors (Schmidt, 1998): (1) reporting criteria, (2) investigator biases, (3) report scope, depth, and quality, (4) reporting system design, and (5) database construction. By focusing on a human factors oriented investigation and reporting process, we can understand why people make certain mistakes.

The prevention of accidents is critically linked to a sufficient investigation of human factors (Harle, 1994). Such investigation methods must be properly designed, implemented and supported. Past attempts at this have generated more superficial information than substance (Zotov, 1996) and have failed to properly consider the human element in the system (Bruggink, 1996). Human factors based investigation methods are considered by aviation industry personnel to be a better form of inquiry; however, they are not being widely used (Schmidt, 1998). Reason's model established a conceptual framework of human error that has been widely accepted throughout government, military, and commercial sectors. Despite this acceptance, his model does not completely define the forerunners to accidents (Marx, 1998).

(7) Maintenance Error Decision Aid (MEDA)

Boeing Aircraft Corporation developed an event-driven tool to reduce maintenance related accidents by assisting investigators in the identification of accident contributing factors and recommendations for correction--Maintenance Error Decision Aid or "MEDA" (Hibit & Marx, 1994). MEDA supports human-centered error investigation in an attempt to encourage users to change their paradigm about investigations of maintenance error. MEDA is based on a maintenance system model where contributing factors are identified at each of four encompassing stages: (1) the

individual mechanic, (2) the mechanics immediate work environment, (3) the supervision provided to the mechanic, and (4) the organizational climate set for the mechanic (Boeing, 1997).

Boeing collected in-flight shutdown (IFSD) due to maintenance error data from 15 airlines with 500,000 to 1 million engine hours of Boeing aircraft between 1983 and 1993 (Boeing, 1997). Each of these errors was assigned a causal factor before being added to the database. Success would be achieved by incorporating this system into an organization's everyday operations with internal management of maintenance error providing the best return (Goglia, J., National Transportation Safety Board, personal communication with Schmidt, J., 1998). MEDA is based on process improvement and discourages the practice of simply punishing the person who commits the error. Investigators establish contributing factors to the event and recommendations for process improvement, all of which are added to the MEDA database. Once improvements have been made, this information is provided to all affected employees (Boeing, 1997).

Success has been cited by organizations using MEDA, e.g., reduction in maintenance related incidents, improved maintenance practices (Sargent & Smith, 1999). However, Marx (1998) notes that MEDA (and human factors based investigation methods in general) is not being widely used. Of 92 carriers using MEDA, only 6 are in the United States. Placing blame on workers, not transcending proximate causes, emphasizing the static who, what, when variables, not searching for underlying causes, and being only a philosophy vice an integrated solution were all cited as reasons for not using MEDA and other similar tools (Goglia, J., National Transportation Safety Board, personal communication with Schmidt, J., 1998).

Both Galaxy and BF Goodrich have created software applications for MEDA to transform it from a pencil and paper collection method to the information age. Galaxy developed "TEAM"--Tools for Error Analysis in Maintenance (www.galaxyscientific.com, 2000) and BF Goodrich (BF Goodrich, 1997) followed with a hybrid system that incorporates MEDA and another system called Aurora (www.hfskyway.gov, 1999). These applications allow the user to collect, organize, analyze, and report data through an interactive graphical user interface system. Users are able to enter new or update existing error data, create reports (e.g., MEDA forms, contributing factors/error summaries, and audit information/checklists), and update information on corrective actions being taken.

(8) Sharing Maintenance Error Data

The Flight Operational Quality Assurance (FOQA) program is a voluntary, but Federal Aviation Administration (FAA) sanctioned effort, to share aggregated safety data, continuous from flight data recorders, across commercial airline carriers (www.faa.gov, 2000). The intent is to provide a means to examine industry wide trends and use the derived information to enhance training of personnel, operational procedures, maintenance and engineering, air traffic control, and airport surface safety. FAA Administrator Jane Garvey stated, "FOQA programs are already producing the hard data we need to identify safety records, target potential problems, and make corrections before accidents happen (Reuters, 2000)." Data to be collected includes Ground Proximity Warning System (GPWS) warnings, excessive rotation rates on take off, un-stabilized approaches, hard landings, and compliance with standard operating procedures.

Additional information includes fuel efficiency, out-of trim airframe configuration identification, engine condition, compliance with noise abatement, rough runway surfaces, and aircraft structural fatigue (Garvey, 1998).

Presently, 230 total aircraft consisting of 13 aircraft types are electronically collecting/sharing FOQA data (Reuters, 2000). An impetus for sharing under the banner of safety is that shared FOQA data is not used for enforcement purposes except under egregious circumstances. This cooperation has not been as successful in extending to the hangar bay and flight line in terms of maintenance and sharing error and incident data. The FAA and NTSB both concur that this is an essential part of the overall safety equation for increasing commercial aviation safety. One major problem standing in the way is having a common process/taxonomy for capturing, recording, and archiving accident/incident/error data for aggregate and trend analysis (Goglia, J., National Transportation Safety Board, personal communication with Schmidt, J., 1998).

Boeing's MEDA, Galaxy's TEAM (Tools for Error Analysis in Maintenance) tool and BF Goodrich's MEDA software tool all attempt to achieve a vehicle for not only capturing mishap information, but also to share data across the industry (Goglia, J., National Transportation Safety Board, personal communication with Schmidt, J., 1998). Unfortunately, though used by some of Boeing's customers (e.g., BF Goodrich in its re-work facility), MEDA has not been adopted as an industry standard (Marx, 1998). This is due, in part, to the in house requirement to staff such an initiative, the training requirements involved, and issues related to unions, culpability, etc. The latter is tied to the emphasis on the immediate act of the person and not the organizational and work

settings that have contributed to it. Consequently, a need exists to develop a tool encompassing accident data collection, organization, analysis, and reporting.

D. TOOL DESIGN CONSIDERATIONS

(1) System Design

The usability of a product is directly linked to the user interface. A user interface that is easy to learn and use will have favorable usability evaluations. To maximize the usability of an interface, Shneiderman (1997) proposed eight golden rules of graphical user interface design: (1) consistency, (2) shortcuts for frequent users, (3) informative feedback, (4) dialogs designed to yield closure, (5) error prevention and simple error handling, (6) simple reversal of actions, (7) internal locus of control, and (8) reduced short-term memory load. A sense of comprehension and competence among the users will be the end result of following these rules. If users feel familiar and competent with systems, they will more likely them highly. (Shneiderman, 1997).

Consistency can relate to many aspects of the system: terminology, color, layout, input, display formats, etc. Though consistency cannot always be maintained across all dimensions of a system, symbology and methods of interaction should be consistent. Frequent users can reduce the number interactions required for a specific result through *shortcuts*. These will also increase the pace of interaction. *Information feedback* can vary in degree depending on the frequency and severity of action involved and allow users to more fully understand their current status by immersing them in the graphical environment. *Designing dialogs to yield closure* can be achieved by grouping actions to set up a natural flow through the user's tasks. This gives the user a better sense of the

actions as they are being performed and a better awareness of a sequence's closure. (Shneiderman, 1997).

Error prevention/handling allows the user to maintain confidence in the system's fidelity and ability to recover from minor fluctuations. *Reversing an action* allows users to recover from their mistakes easily, reducing stress or anxiety of operating within the system. Designing an *internal locus of control* allows the users to be in command of the environment and not vice versa. Users would not experience autonomous movement within the environment or a drastic change of the visual orientation. Finally, the *reduction of short-term memory load* includes access to integrated assistance information (e.g., cues, mnemonics, standardized sequence of actions). (Shneiderman, 1997).

(2) Usability Study

Usability testing is a systematic means of observing the ease of use of a product and collecting related data. Dumas & Redish (1994) identified three tenets of usability studies: (1) It should be used to diagnose problems vice determining that the product is flawless; (2) Usability testing should be employed early and often during the development cycle; and (3) It is part of a process that focuses on usability throughout design and development.

A thorough testing plan needs to be developed in order to best incorporate usability into the development process. Several factors must be addressed in an evaluation plan (Shneiderman, 1997; Nielsen, 1993; Hix & Hartson, 1993; Preece, et. al., 1994; Newman & Lamming, 1995). First, the current stage of the design will determine the requirements for testing, with different conditions for different stages. Second, the

criticality of the environment helps to decide the objectives of the test. Finally, other factors, such as the novelty of the project, number of expected users, time available, cost of the project, available resources (e.g., time, money, people), and experience of the testers all play a role in defining the usability study.

A usability study not only maximizes the usability of the system, but ensures contractual requirements have been completed and to provide evidence of testing in cases of lawsuits or if legal issues arise. Errors in a system will be tolerated to varying degrees dependent upon the need to bring the system to full operational use and the impact the errors may have during that time. However, a system is more difficult to test as increasing amounts of input are required, yet these tests are increasingly needed. (Shneiderman, 1997).

Some (Nielsen & Mack, 1994) argue for an expert evaluation of a system to increase a product's usability. Formal reviews can provide more useful information when compared to informal demonstrations of a product. Thus, system design and testing should employ expert reviewers who typically produce a report detailing problems and recommendations for improvement. These reviews may take the form of heuristic evaluation, guideline review, consistency inspection, cognitive-walkthrough, and formal usability inspection (see Table 3). Even if the experts are reviewing unfamiliar systems and technologies, they still provide a fresh look at a system and are useful in evaluating system development.

Table 3: Expert Review Methods (Shneiderman, 1997)

Expert-Review Method	Description
Heuristic evaluation	Expert reviewers critique an interface to determine conformance with a short list of design heuristics such as the eight golden rules.
Guideline review	The interface is checked for conformance with the organizational or other guidelines document.
Consistency inspection	Experts verify consistency across a family of interfaces, checking for consistency of terminology, color, layout, input and output formats, within the interfaces as well as in the training materials and online help.
Cognitive-walkthrough	Experts simulate users walking through the interface to carry out typical tasks. Simulating the day in the life of the user should be part of the evaluation.
Formal usability inspection	Experts hold courtroom-style meeting, with a moderator to judge, to present the interface and to discuss its merits and weaknesses.

Shneiderman, 1997

Usability studies take additional forms, such as discount usability engineering; “short and sweet” approaches to task analysis, prototyping, and testing. Another style of study is a field study conducted in actual work environments in order to achieve realistic, user evaluation. Alternatively, beta testing challenges actual users break the system. This method can expedite the development process and correct errors missed through conventional testing. Usability testing can lack comprehensive system evaluation due to time constraints and also tends to emphasize first-time usage (Shneiderman, 1997). Thus usability studies must be supplemented with other methods of evaluation, such as expert review. (Shneiderman, 1997).

An important decision to be made when planning a usability study is how long the test should take (Dumas & Redish, 1994). If the study is conducted as an integrated part of the design process and is not simply being conducted on a completed system, then the test length should be reduced to a level to both obtain necessary information and not be a burden. Dumas & Redish (1994) place traditional testing into four categories.

(1) Formal testing with comprehensive test reports requires eight to twelve weeks. (2) If a strong collaboration is exhibited among team members and a shortened report format is used, then four to six weeks are required. (3) If a particular part of the system is to be studied with well established procedures, then one week may be appropriate. (4) Finally, just-in-time testing can provide useful information in a few days, if necessary, but is discouraged.

Dumas & Redish (1994) contend proper planning includes defining goals, identifying concerns, recruiting individuals and their participation, creating and organizing tasks/task scenarios, deciding on usability measures, preparing test materials and test environment, and conducting a pilot test. Defining goals and identifying concerns is a three-stage process: (1) making choices among goals and concerns; (2) moving from general to specific concerns helping to mold concerns into quantitative objectives; and (3) understanding the source of the goals and concerns allowing the usability engineer to better develop the testing scenarios and tasks. Developed user profiles, preferably prior to system design and usability testing, can provide the basis for deciding upon participants in a study. The realities of time and budget constraints often result in usability studies having less participants than usability engineers (10-12) or statisticians (at least 36-48) may desire. (Dumas & Redish, 1994).

(3) Human-Computer Interface (HCI) Design Issues

Brown (1989) posits that information database management system should be considered a simple tool, simplifying rather than complicating the tasks of the user. Thus the design of the system should reduce mental processing operations (learning complex

commands/syntax, memorizing codes/abbreviations, translating data into other units/formats) required to operate the tool. He feels the allocation of functions, one of the most important categories of design decisions, should be performed based on the capabilities of both the user and the system. Brown (1989) suggests five “user” rules for allocating functions in routine interface design: (1) Minimize the amount of procedural memorization. (2) Reduce mental manipulation. Data should be presented clearly and in a useable form. (3) Minimize manual entries. Allow the user to select from a displayed list vice forcing manually entries. (4) Offer computer aids (e.g., checklists, summary displays, and help functions) to reduce both required mental processing and the need for executing complex, multi-step procedures. (5) Use computer algorithms to process and present complex data.

Mental models, or a cognitive representation of the internal parts and operations of a system, are another important part of successful HCI. The user’s mental model allows him/her to predict the appropriate procedure for a desired outcome, even if the procedure has been forgotten. Thus, a user’s mental model can give the user an understanding of how a system works and develop and refine his/her knowledge when learning about or using the system. Several principles for mental models should be incorporated into a system: consistency (both actions and classes of actions), physical analogies, user expectations, and stimulus-response compatibility. (Brown, 1989).

The designer should provide for a balance of ease of learning, ease of use, and functionality in a system. Brown (1989) identifies four techniques to ensure this balance is maintained: (1) incorporate needs of novices, experts, and intermittent users into the design, (2) avoid excess functionality, (3) provide multiple paths, and (4) progressive

disclosure and graceful evolution design. These procedures will ensure equilibrium is established in a system.

E. SUMMARY

A well-defined, systematic accident investigation, analysis, and reporting process is critical in the effort to reduce the Naval Aviation mishap rate. Yet, no one good universal system currently exists (Marx, 1998). Such a tool must have a reporting system relying on a solid data collection process with the ability to readily access the stored data. Many times, mishap data is lost or not used, often leading to yet another incident. The goal for such a tool is to use the data for prevention of future accidents.

Effectively addressing human error issues can greatly increase safety levels. Several robust approaches to examining mishaps involving human error achieve this goal: Heinrich's "Domino" Theory, Edwards' "SHEL" Model, and Reason's "Swiss Cheese" Model. Once an approach is examined, a means of bridging the gap between theory and user must be made. The Navy's Human Factors Analysis & Classification System (HFACS) and its Maintenance Extension offshoot (HFACS-ME) appear to be potential approaches for investigating, reporting and analyzing maintenance error.

However, the designer must maximize the usability of the interface. This can be accomplished by following Shneiderman's (1997) eight golden rules of graphical user interface design. Once the system is designed, a usability study with a prototype tool ensures the product is ready for general use by testing it with a selected group of users. Finally, Human-Computer Interface issues must be addressed to simplify rather than

complicate the life of the user. Once the above goals are met, the system is ready to meet its challenge.

III. METHODS

A. RESEARCH APPROACH

A software desktop analysis and reporting tool for maintenance error in aviation would greatly facilitate Naval Aviation's effort to capture human factors in mishaps and develop interventions. The Maintenance Error Information Management System (MEIMS) is a computer-based prototype tool designed using Microsoft Access 97 and Visual Basic 6.0. The prototype utilizes a database derived from the Naval Safety Center's Safety Information Management System (SIMS) database, which contains information on over 600 maintenance error related mishaps that occurred between 1989 and 1999. The system has a graphical user interface (GUI) that allows the end-user to operate the system with basic computer skills.

The prototype was distributed to a representative sample of potential end-users. The participants were provided a prepared task list that required them to navigate through and utilize features of the tool. At the completion of the task list, the participants had viewed and used all portions of the prototype tool, and completed an exit survey composed of questions pertaining to demographic background information and both objective and open-ended items to elicit the participants' views of the usability of the system and value of both the system and the data. The objective data was transcribed into a Microsoft Excel spreadsheet for analysis while a content analysis was conducted on the open-ended survey questions. Note, the exit survey used only five Likert style questions because the major focus of the effort was the creation of the prototype tool vice the usability study. The questions were shaped intuitively and are considered to be simply the first stage of developing a formalized post-prototype tool.

B. DESCRIPTION OF MAINTENANCE EXTENSION INFORMATION MANAGEMENT SYSTEM (MEIMS)

(1) Overview

The Maintenance Extension Information System (MEIMS) prototype tool was designed to allow the user to have access to the data base via three functional tools: (a) sorting the data by *queries*, (b) obtaining output from the data base via *written reports* and *graphical displays*, and (c) providing input to the data base through the *addition of new data*. Each function was displayed on separate pages with interactive controls providing user-prototype interaction. The following paragraphs provide a description of the prototype. A completion description of all of the displays is found in Appendix A.

(2) Main Menu

The Main Menu of the prototype allows the user to select (left click) one of five different options: (a) Query Menu, (b) Report Menu, (c) Expert Graph Menu, (d) Adding New Data, and (e) Exiting the system (see Figure A1). Help is provided to the user on this and all pages in the form of "control tips" (i.e., brief descriptions) when the mouse arrow is placed over a control (i.e., text box, command button, etc.) (see Figure A5). Additional help is found in the "status bar" at the bottom of the screen when a control is highlighted.

(3) Query Menu

The Query Menu provides the user two manners of output (see Figure A2). The first is through the selection of one of eight command buttons to sort the data base by one or more of its fields: aircraft model (F-14, H-46, etc.), aircraft type (tactical aircraft

(TACAIR), helicopters, heavy aircraft, trainers, and others), branch of service of the aircraft (USN, USMC), location of the mishap (ashore, embarked, and detached), mishap classification (A, B, or C), mishap type (Flight Mishap (FM), Flight-Related Mishap (FRM), or Aircraft-Ground Mishap (AGM)), calendar year of the mishap (1989-1999), and any combination of the above (Multiple Criteria selection).

When a single category control is selected a sub-menu appears where the user can define the exact description of the category via a combo box (see Figures A3 and A6). Upon selecting the “View Selection” control a Maintenance Mishap Query window is displayed revealing each instance (mishap) of the selected description (see Figure A4). In addition, the user may page through all mishaps of the selection by selecting the right arrow on the bottom of the window (see Figures A4 and A5). The data for each mishap is displayed in text boxes, with the selected category denoted with blue background (see Figure A4). Additionally, maintenance related contributing factors to the mishap with their HFACS-ME codes are displayed at the bottom of the window. Selecting the “Multiple Criteria” control on the Query Menu will allow the user to further define the data base by selecting any or all of the seven solo categories (see Figures A7 and A8). A Multiple Criteria sub-menu appears and allows the user to “check” the desired categories and further define them by selecting criteria provided in combo boxes on the sub-menu. In these cases, all of the selected categories will have a blue background on the resulting Maintenance Mishap Query window (see Figure A9).

Throughout the prototype, “Define HFACS Codes” controls are displayed. When selected they will provide a summary sheet of the level one, two, and three HFACS-ME codes, with each acronym defined (see Figures A9 and A10). In addition, at any time the

user may close a window and return to the previous sub-menu by selecting the “Close Form” or “<Back” control (see Figure A5). Each of the four primary menus has a “Return to Main Menu” control which returns the user to the Main Menu when selected.

The second output provided by the Query Menu is the HFACS-ME Summary Form (see Figure A11). This form allows the user to view a summary of data categorized by HFACS-ME levels one, two, and three. The user may also further define the output by selecting any or all of the previously mentioned seven categories via combo boxes (see Figure A12).

(4) Report Menu

Report Menu is the second option a user may select from the Main Menu (see Figure A13). The Report Menu offers eight reports which provide data listing the total number of mishaps and the number and percentages of mishaps by HFACS-ME levels one, two, and three (see Figure A15). The user may select from the following distribution presentations: all mishaps, aircraft model, mishap class, mishap type, mishap class by mishap type, branch of service, mishap location, and chronological listing by aircraft model (see Figures A14 - A16). All reports are closed by selecting the “Close” control at the top of the window.

(5) Expert Graph Menu

The third option from the Main Menu is the Expert Graph Menu (see Figure A17). The user may create a two-axis, three-dimensional graph presentation. The x- and y-axes are populated with one of the following categories: aircraft model, aircraft type,

mishap location, branch of service, mishap class, mishap type, HFACS-ME level one, HFACS-ME level two, and HFACS-ME level three (see Figure A18). The user may then select one or more of the fields from each axis category sub-menu via a combo box (see Figures A18 and A19). The resultant graph is presented in a three-dimensional, multi-colored view (see Figure A20).

(6) Add New Data Menu

The user may populate the data base by selecting the “Add New Data” control on the Main Menu (see Figure A21). The user must then fill in an “Enter New Maintenance Mishap Data” form with the following fields: mishap class, mishap type, date of mishap, aircraft type/model (F-14, H-46, etc.), aircraft category (TACAIR, helo, etc.), branch of service, location of mishap, and a brief description of the mishap. The prototype automatically assigns a Mishap Identification Number. A sub-menu on the form asks the user to input mishap “factor” data. This information includes: a brief description of the factors and the HFACS-ME level three code. Upon selection of the level three code, the levels one and two codes and descriptions and level three descriptions are automatically entered by the prototype, as is the Factor Identification Number (see Figure A23). The user can enter an additional factor by selecting the “Add New Factor” control (see Figure A23). After all mishap data is entered, the “Close Form” control is selected (see Figure A23). The “Final Data Entry” form appears and asks the user to select “Enter” and wait for the “Done” box to be checked to show successful data entry.

C. DATA COLLECTION

(1) Subjects/Participants

Students (n=42) attending the Aviation Safety Officer (ASO) course at the School of Aviation Safety, at the Naval Postgraduate School in Monterey, CA participated in the study. Individual activities are allocated class spaces to determine enrollment in the ASO course and, consequently, attendee demographics represent a wide cross section of Naval Aviators and Naval Flight Officers, Coast Guard and other DOD officers, Flight Surgeons and Aeromedical Safety Officers, and foreign nationals from all aircraft communities. ASO course graduates are responsible for the management and implementation of squadron safety programs to include mishaps and include investigations and reporting. They are likely to be one of the primary end-users of the tool. Participant demographics were characterized by aviation background, computer experience, and availability of software and hardware systems used in the Navy and Marine Corps.

(2) Apparatus

The ASO students had access to three computer labs (Pentium level) at the School of Aviation Safety via login identification and password to a group account. The computer in each lab had a full prototype functioning desktop analysis and reporting tool loaded onto it. After a participant gained access to the computer, the "MEIMS" icon was found on the computer desktop and selected to open the application.

The prototype was developed using Microsoft Access 2000 and Visual Basic 6.0 and consisted of four sections: database queries, reports, graphic presentations, and data

entry. Each section was divided into further subsections allowing the participant to more specifically design his access to the database. This allowed the participant to achieve the four functional requirements for the software tool: data collection, organization, analysis, and reporting (see Appendix A for a more complete description of the prototype).

(3) Instrument

A participant usability survey was constructed by the author consisting of three parts: (1) Participant demographics, (2) Likert type assessment questions, and (3) Open-ended items. Collection of demographic information was accomplished through the participant selecting from a list of descriptors (rank, branch of service, experience level/years of service). Survey questions were designed to determine if the prototype software tool met participant investigation, reporting, and analysis requirements. The Likert questions used a five point rating scale with verbal anchors: Strongly Agree, Agree, Neutral, Disagree, and Strongly Disagree. Open-ended questions were included to gain subjective responses on the overall impression of the prototype software tool, recommendations for improvement, and comments on areas not adequately covered by parts one and two of the survey (see Appendix B).

(4) Procedure

The prototype software desktop analysis and reporting tool containing a database derived from Naval Safety Center maintenance mishaps was loaded on seven computers in three computer labs with 24-hour accessibility. A MEIMS icon was placed on each computer desktop page to allow access into the program.

Prototype testing occurred over a span of one week. Participants were given a group orientation briefing by the author on the purpose, goals, and procedures of the prototype including a projected computer demonstration. In addition, they were given a 10-page guide to walk them through prototype testing (see Appendices B and C). The guide consisted of:

- Instructions for Accessing the Prototype Software Tool --information to log on and open the prototype (see Appendix B).
- Prototype Software Tool Task List--a series of planned navigation routes within the prototype whereby the participant would be able to view the entire system (see Appendix B).
- Participant's Impression of the Prototype Software Tool/Exit Survey (see Appendix C).

The author, with full knowledge of both prototype MEIMS tool and Microsoft Access procedures took six minutes to complete the testing. It was expected that each participant would need 15-20 minutes to complete the process. Though information on time to navigate for each individual was not taken, informal feedback to the author indicated a range of 15-30 minutes with the longer times being needed for those with less computer and Microsoft Access experience. One computer was a lower-end model (i.e., Pentium I, 133 MHz, 4mb RAM) which caused some functions not to work properly, most notably the expert graphing option. At the completion of the task list, participants viewed all portions of the prototype system, and formed an opinion on its effectiveness. Participants then completed an exit survey composed of demographic background

questions and perusal of the prototype system. Surveys were all submitted through a drop box provided in a common area.

D. DATA TABULATION

The data was transcribed from the survey onto a Microsoft Excel 2000 spreadsheet. The Likert questions, based on a five-point scale, were coded into Excel, using numbers 1 through 5 corresponding to the respective anchors (Strongly Disagree, Disagree, Neutral, Agree, and Strongly Agree). Descriptive statistics were generated using Excel functions including the mean, standard deviation, range, and frequency distribution of the collected data. Content analysis was conducted on the responses provided from the open-ended survey questions. The categorization of participants by participant aircraft maintenance organization type and computer/software application experience level were noted. However, due to no noticeable differences between categories, all subsequent analysis was performed on all participants as a single group.

E. DATA ANALYSIS

Basic and general information about the demographic and question results were depicted using descriptive non-parametric analysis is conducted on the survey data in order to. Basic summary statistics are developed with results including demographic information and satisfaction levels with the prototype. Analysis of the data is performed using the functions of Microsoft Excel.

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IV. RESULTS

A. SAMPLE

The 13 item exit survey was administered to 45 participants from a School of Aviation Safety "Aviation Safety Officer" course with a response rate of 95.6% (n=43). Each Naval Aviation command is required to have an officer trained by the Safety School. Thus the participants were designated Naval Aviators and Naval Flight Officers and represented a cross section of the aviation commands that make up the squadrons in the Navy and Marine Corps.

B. DEMOGRAPHIC INFORMATION

The material collected in Part I of the exit survey consisted of demographic information and established the aviation and computer experience levels of each participant had both with computers and in aviation. The information is later used to determine if experience level in either category affected a participant's level of satisfaction and/or impacted the usability of the prototype MEIMS tool. The following paragraphs characterize the survey results for part I.

Question one revealed that 39 of the participants were members of aviations units that performed maintenance at the squadron level (n = 39, 90.7%). The remaining four participants were either members of higher-headquarter staffs (n = 2; 4.7%) or units that used civilian contract personnel to perform the maintenance (n = 2; 4.7%). *Question two* indicated that all but one participant (n = 42, 97.7%) stated they had at least two years of experience using a computer. The remaining participant had less than one year of computer experience. *Question three* determined that all participants (n = 43; 100%)

were users of Microsoft Office, while minimal numbers had used either Lotus Notes (n = 4; 9.3%) or Corel/Word Perfect (n = 3; 7.0%). *Question four* established a participant's familiarity with different software applications, greater than 80 percent stated they were familiar with at least one of the following: word processing, spreadsheet, presentation, and e-mail (n >= 35; 81.4%). The average participant was familiar with approximately four (4.3) of the categories (see Table 4).

Table 4. Number of Participants Familiar with Specific Software Applications (n=43)

	Word Processing	Spread Sheet	Presentations	Graphic Software	E-mail	Database
# Familiar	42	37	35	11	40	19
%	97.7	86	81.4	25.6	93	44.2

Question five revealed the normal operating system (OS) for participants, 42 (n = 42; 97.7%) responded with either Windows 97/2000, Windows NT, or both (see Table 5). Two participants did not answer the question. The prototype was loaded on computers running the Windows NT operating systems. Participants could indicate more than one OS.

Table 5. Normal Operating System of the Participant (n=41)

	Windows	Windows NT	Mac	Unix	Linux
Normal OS, #	35	29	3	4	2
%	85.4	70.7	7.3	9.9	4.9

C. PARTICIPANT SATISFACTION WITH THE PROTOTYPE MEIMS TOOL

(1) Responses to Impressions and Usability Questions

Part II of the exit survey examined a participant's impressions of the usability of the prototype MEIMS tool and its value to Naval Aviation. Participants responded to five statements using Likert type responses selecting from one of five responses: strongly agree, agree, neutral, disagree, and strongly disagree. Values of five through one respectively were assigned to the statements. One participant did not respond to any of the statements. The participants were also given the chance to make subjective comments on any of the five statements.

(a) *Statement one* asked whether or not a participant found the prototype to be presented in a logical form. The histogram of the frequency distribution for statement one is presented in Figure 9. The mean was 4.26, standard deviation = 0.665, range = 4. Most participants (n = 39; 92.7%) agreed that the prototype was designed and presented in a logical fashion. One participant did not select a response.

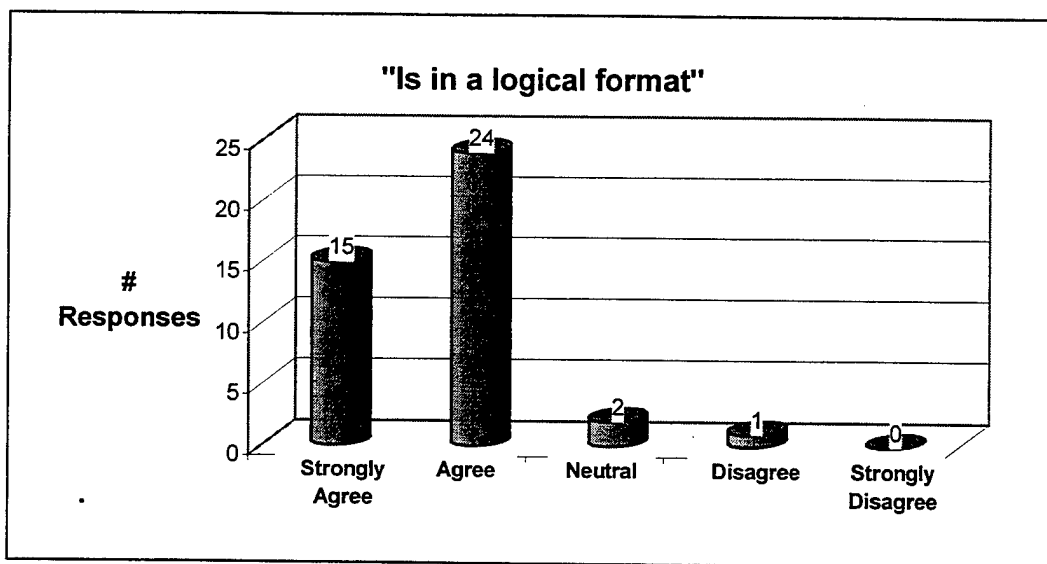


Figure 9: Exit Survey, Part II, Statement One, Response Distribution

(b) *Statement two* asked about the ease of navigation of the prototype. The histogram of the frequency distribution for statement two is presented in Figure 10. The mean was 3.95, standard deviation = 0.947, range = 5. A large majority of the participants (n = 33; 80.5%) agreed that the prototype was easy to navigate. Two participants did not make a response to this statement.

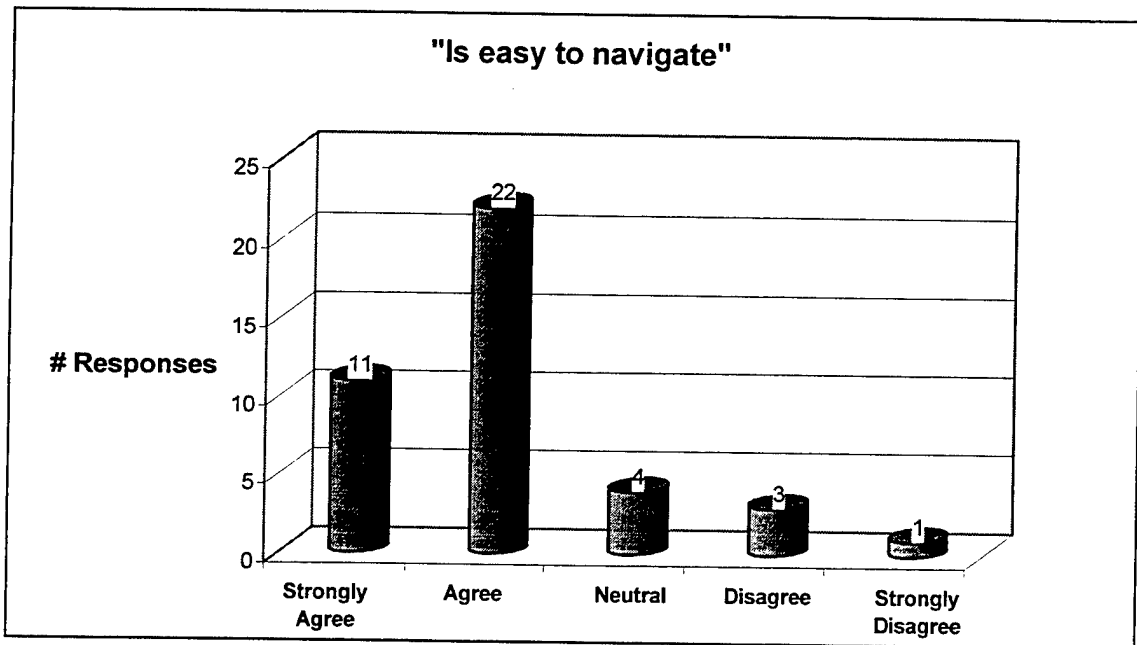


Figure 10: Exit Survey, Part II, Statement Two, Response Distribution

(c) *Statement three.* The participants were asked whether they felt MEIMS was “interesting.” The histogram of the frequency distribution for statement three is presented in Figure 11. The mean was 4.07, standard deviation = 0.818, range = 4. A large majority of the participants (n = 33; 80.5%) indicated the prototype was of interest to them. Two participants did not select a response.

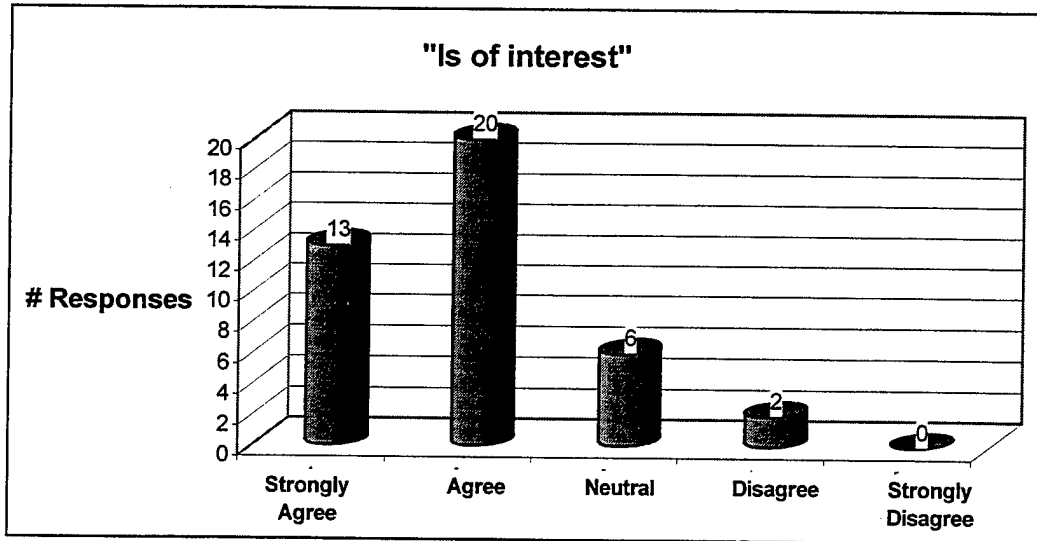


Figure 11: Exit Survey, Part II, Statement Three, Response Distribution

(d) *Statement four* asked about the relevance of the prototype to aviation maintenance operations. The histogram of the frequency distribution for statement four is presented in Figure 12. The mean was 4.40, standard deviation = 0.627, range = 3. Most participants (n = 39; 92.9%) indicated the prototype was of extreme relevance to maintenance operations. One participant did not respond to statement four.

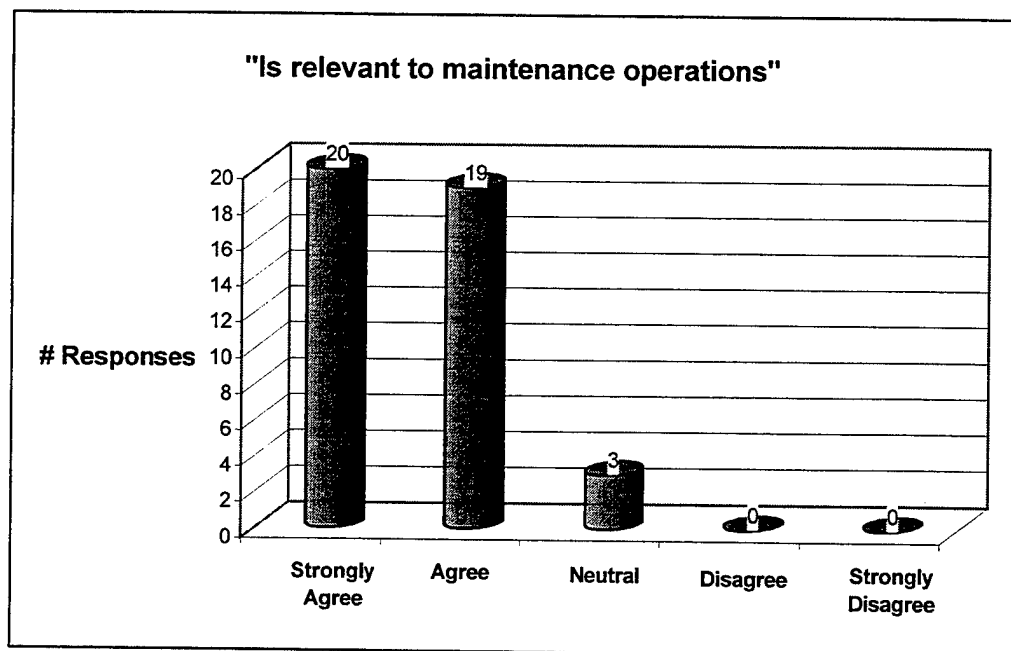


Figure 12: Exit Survey, Part II, Statement Four, Response Distribution

(e) *Statement five* asked whether prototype concept was a good one. The histogram of the frequency distribution for statement five is presented in Figure 13. The mean was 4.71, standard deviation = 0.427, range = 2. All participants (n = 42; 100%) indicated the concept of the prototype was a good one. One participant did not respond to this statement.

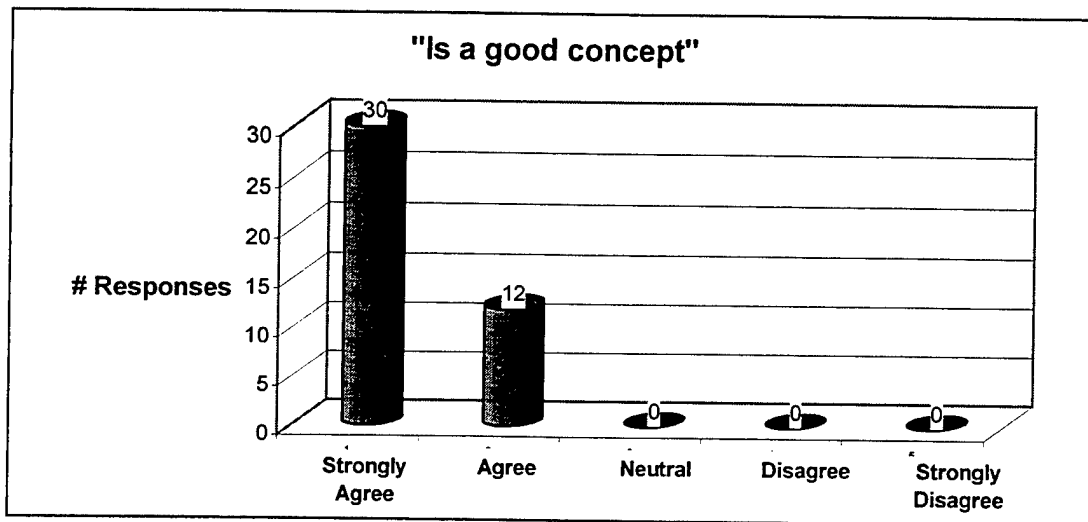


Figure 13: Exit Survey, Part II, Statement Five, Response Distribution

(2) Responses to Open-ended Questions

Part III of the exit survey contained three open-ended questions for the participants to respond to their overall satisfaction with the prototype. Every participant availed himself of this opportunity to provide constructive criticism. The responses from all 43 participants were overwhelmingly positive. Every participant indicated there was great merit in a tool such as the prototype and all of the “criticisms” were presented in a professional/positive manner. The desire of the participants was to take this prototype, in its current form, and improve it for their use in the fleet.

(a) *Question one* asked the participant to list the most positive aspects of the prototype. Nine participants indicated the prototype was an excellent source of data

that could be used for training, trend analysis, and decision making. Others thought the prototype was useful to provide comparisons between variables (aircraft, mishap type, location, etc.). Some sample inputs include:

- *“Recurring maintenance issues stick out like a sore thumb.”*
- *“MEIMS provides the ability to determine common mishap causal factors and prevent future ones of the same type.”*
- *“MEIMS can help us look at our highest risk maintenance working conditions and identify those areas where we should be especially cognizant of potential disaster.”*

(b) *Question two* asked for the most negative aspects of the prototype.

Overall comments indicated that participants with lower than normal computer “savvy” found it initially more difficult to navigate and understand the operation of the prototype. However, as interaction time with the prototype increased, so did the ease of operation. Problem areas of the prototype application were focused in one of three areas: HFACS-ME terminology, interface, and data entry.

(1) *HFACS-ME*. Ten participants noted the HFACS-ME taxonomy is not an ingrained part of everyday terminology and thus found it difficult to understand. The ability to access the HFACS-ME Code definitions from various parts of the prototype helped, but additional explanation of the each vice a mere translation of the three-letter acronym would have added more value to the participant. The participants felt that any eventual end-user of the prototype would need a good working knowledge of HFACS-ME in order to be able to get the most use out of the prototype; and that even the training received as part of the study may not be sufficient.

(2) *Interface*. Seven participants declared the prototype to not intuitively obvious in its operation. The fear was potential end-users with a lack of general computer skills would be discouraged from using the prototype. However two participants commented that the prototype became more user friendly with each use. Six participants said there was not enough on-line help available for usage training.

(3) *Data Entry*. Though there were only four negative comments about data entry, they were all astute observations made by participants who obviously had advanced computer skills (though they were indistinguishable from others based on their demographic inputs). Comments on data entry included not having positive closure when data is entered and being able to enter the same data twice with no penalty/feedback. The remaining two comments were focused on unclear procedures for data entry.

(4) Other “negatives”.

- *Navigation* issues were minor, limited to suggestions for improved access between pages (being able to go directly from one page to another without having to back out of previously selected pages-four participant inputs).
- If the participant selected parameters for a desired function (graphing or report) that were so specific that no data matched them, the function appeared not to work. The “error” message displayed to the participant did not satisfactorily explain the problem.
- In some instances the three-dimensional *graphs* in the front hide data in the back. Also, the graphs did not fully define the “colored” categories.

- Computer quality. There were several instances of one or more of the functions, especially in the graphing option, not working due to lack of memory in the computer.

(c) *Question three* asked for suggested changes to the prototype. The participants brought out several key points critical for inclusion in future variations of MEIMS. Most of the suggestions related directly to one or more of the previously mentioned “negatives.” Nine comments were made about improving the ability for the end-user to understand *HFACS-ME* through either improved HFACS definitions within the prototype, additional help/tutorial on-line, and formal training for all end-users. Eight participants also made suggestions to improve the interface and navigation of the prototype to increase usability (e.g., adding additional methods to view HFACS-ME definitions and better descriptions of Levels 1, 2, and 3) . Though no specific comments were made about data entry improvement, the “negatives” mentioned above imply fixes to be made: providing positive feedback upon entering data, not being able to enter the same data more than once, and making the data entry procedures simpler and more clear.

A noteworthy input made by four individual participants was in the area of “target end-user.” The original intent of MEIMS was for it to be distributed to squadrons for use in both data retrieval and data entry. Four participants made strong statements to the effect that the squadron level end-user should not be able to input data into the system, but that it should be done at a higher level, such as at the Naval Safety Center where the understanding of HFACS and HFACS-ME is greater and thus so is the ability to correctly input data into MEIMS.

Other inputs:

- Four participants indicated their desire to have more information about each mishap available for viewing (e.g., long summary vice short summary, adding the narrative of the mishap, etc.).
- Increasing the size of the data base by using mishaps prior to 1989 and using hazard reports was felt to be a means of improving the quality of the data (three participants).
- Eight specific changes to the actual interface were also suggested (e.g., increasing text box size in order to view all of the data field, a better method to show aircraft model to prevent confusion by adding the nickname to the model number: EA-6 Prowler, E-6 Mercury; being able to scroll through the chronological report vice viewing it page by page; separating H-1 into AH-1 and UH-1 categories, etc.).
- Using a higher speed, larger memory, improved processor computer was also suggested to improve efficiency of MEIMS.

V. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

A. SUMMARY

Naval Aviation has determined to reduce its mishap rate. The reduction of human error involved in maintenance related mishaps will be one step in achieving that goal; now it has to find appropriate tools to accomplish this. The Human Factors Analysis and Classification System-Maintenance Extension (HFACS-ME) is a taxonomy which covers maintenance operations and falls in line with the Naval Aviation Safety Program's notion of multiple causal factors, the idea of sequential events leading to an event, and several established human factors theories. HFACS-ME has been successfully used to examine human error in mishaps and incidents. The prototype MEIMS (Maintenance Extension Information Management System) tool is a safety information management system based on the HFACS-ME taxonomy used to facilitate the characterization and analysis of human error in Naval Aviation maintenance mishaps. Tools such as a final version of MEIMS will provide assistance in identifying human error patterns and facilitate intervention development.

B. CONCLUSIONS

The participants' overall satisfaction of the prototype MEIMS tool indicated there is a need to provide access to mishap data information for use in training, analysis, and investigations. Participant feedback demonstrated the concept of MEIMS to be sound and its tie-in with Maintenance Operations readily apparent. However, the prototype requires some adjustment before successful implementation by end-users can be achieved.

The prototype, itself, received slightly lower, though still very positive, ratings than the concept of a maintenance human error related information management system. Even though a tool can be of good intent, if it is not considered usable by the end-user, it will sit on the shelf. For MEIMS to be “the tool” it must have its shortcoming resolved:

- Lack of general maintenance organization HFACS-ME training including familiarity with HFACS-ME terminology..
- Less than desirable human-computer interface for end-users with below average computer skills.
- Poor data entry confirmation indications. The inability for the end-user to enter data into the prototype in a simple and consistent format may lead to inconsistent inputs and hence poor data (i.e., garbage in, garbage out).
- Also several minor shortfalls need to be refined:
- Lack of standardized and convenient navigation.
- Poor “error” messages in the cases of null data selections.
- Some three-dimensional graphs hiding data depending on the view selected.
- The inability to run the prototype successfully on some older personal computers.

Providing solutions to these identified failings will improve the usability of future versions of MEIMS; and subsequently the opportunity for it to be a factor in reducing the aviation mishap rate is enhanced.

C. RECOMMENDATIONS

(1) Recommended Prototype MEIMS Tool Improvements

- *HFACS-ME*. Incorporate improved HFACS-ME definitions within MEIMS by ensuring access to the definition page is available on every form. Better descriptions of the HFACS-ME acronyms would also improve usability and understanding. Incorporating additional on-line help/tutorials will improve the end-users knowledge of HFACS-ME and make MEIMS a more productive tool for their use.
- *Interface*. A computer science expert should participate in the fine tuning of MEIMS interface options to ensure navigation is consistent and easily done for those with sub-par computer skills.
- *Data Entry*. Ensure data entry procedures are made as simple and clear as possible including providing positive feedback to the end-user once the entry has been taken. MEIMS must not allow repeat entries of the same data.
- *Target End-user*. Unless data entry procedures can be significantly simplified MEIMS should be used as at the maintenance organization level in the read/analysis mode only. Entry of data should be conducted by higher levels (i.e., the Naval Safety Center for Naval Aviation) where the understanding of HFACS-ME is greater and thus so is the ability to correctly input data into MEIMS.
- Include a longer *summary/narrative* for each mishap.

- *Additional data.* Include mishaps prior to 1989 and all hazard reports to improve the quality of the data base.
- Increase *text box sizes* to view all data field.
- Change *aircraft identifier* to include aircraft nickname in addition to type/model to avoid similar names.
- Separate *AH-1 and UH-1* into two categories, vice only H-1 due to the aircraft's inherent differences.
- Change the *chronological report* to a scrolling view, vice page by page to improve readability.
- If a selection is made for data that has a *null value*, ensure the error message indicates the lack of response from MEIMS is due to "no data available for selected entry" vice simply an error with the system.
- Arrange data on *three-dimensional graphs* so that the fields with the largest numbers are put in the rear rows and scaled down to the front so that no data is hidden to the end-user.
- *Suggested Computer Capability.* Ensure end-users understand that computers with higher speed processors and larger memories will improve the efficiency of MEIMS.
- Add an option to include *percentages* on the three-dimensional graphing function, vice only quantity. This will show relative weight, vice always being more heavily weighted for aircraft types with a larger inventory (FA-18, H-46, etc.).

(2) The Future of MEIMS. The research for this paper involved data derived from the Naval Safety Center's data base of Naval Aviation mishaps. A variation of the prototype MEIMS tool could be revised to include data from commercial mishaps (both passenger carriers and general aviation). Civilian aviation also has a record of human error, including maintenance related human error, contributing to mishaps.

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APPENDIX A

PROTOTYPE MAINTENANCE ERROR INFORMATION MANAGEMENT SYSTEM (MEIMS) TOOL REVIEW

1. MAIN MENU

The Main Menu appears after MEIMS ICON is selected (see Figure A1).

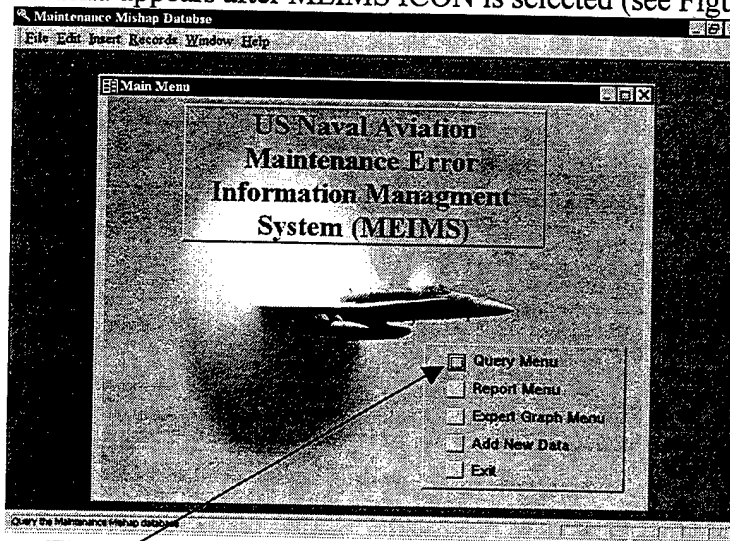


Figure A1: Prototype MEIMS Tool Main Menu

Select "Query Menu" command button to view Query Menu (see Figure A2).

2. QUERY MENU

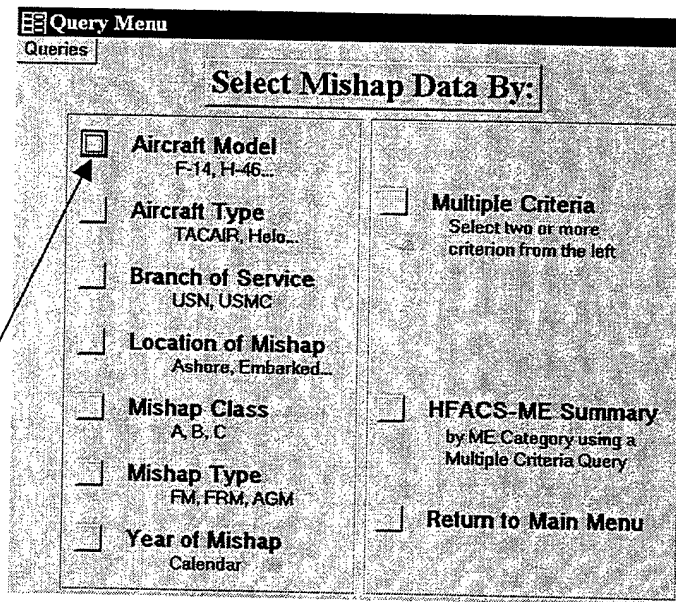


Figure A2: Query Menu

Select "Aircraft Model" command button.

The Query by Aircraft Model menu appears (see Figure A3).

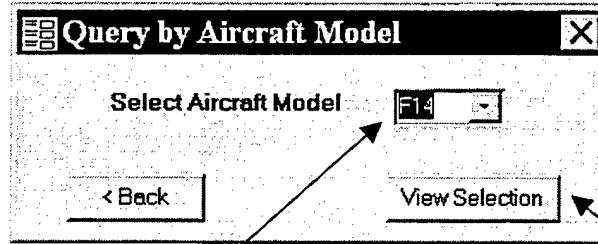


Figure A3: Query by Aircraft Model Sub-Menu
 Select aircraft model in combo box and select "View Selection" command button.

The "Summary of Mishap" form appears (see Figure A4).

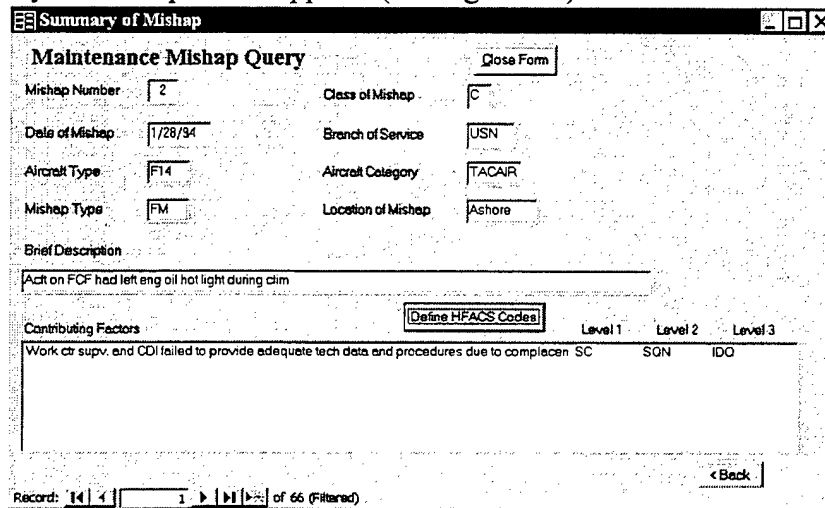


Figure A4: Summary of Mishap Form with F14 Selected as Aircraft Type
 Select the right arrow after "Record:" on the bottom line to view additional records.

F14 record number two appears (see Figure A5). Note that if the mouse arrow is placed over a text box or other control, a control tip text appears. Select "<Back" to return.

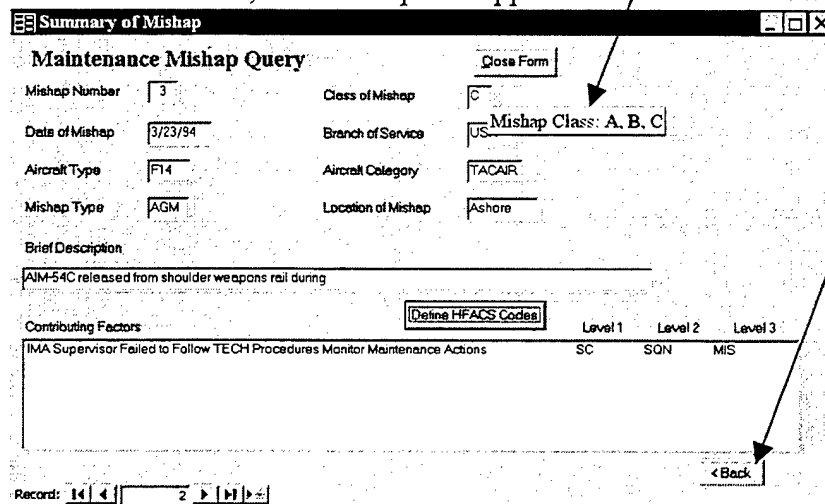
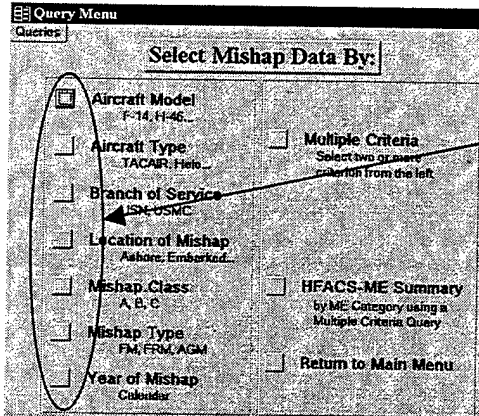


Figure A5: Summary of Mishap Form with F14 Selected as Aircraft Type, Record Two



Additional queries may be executed by selecting any of the control buttons on the left of the Query Form (see Figure A6).

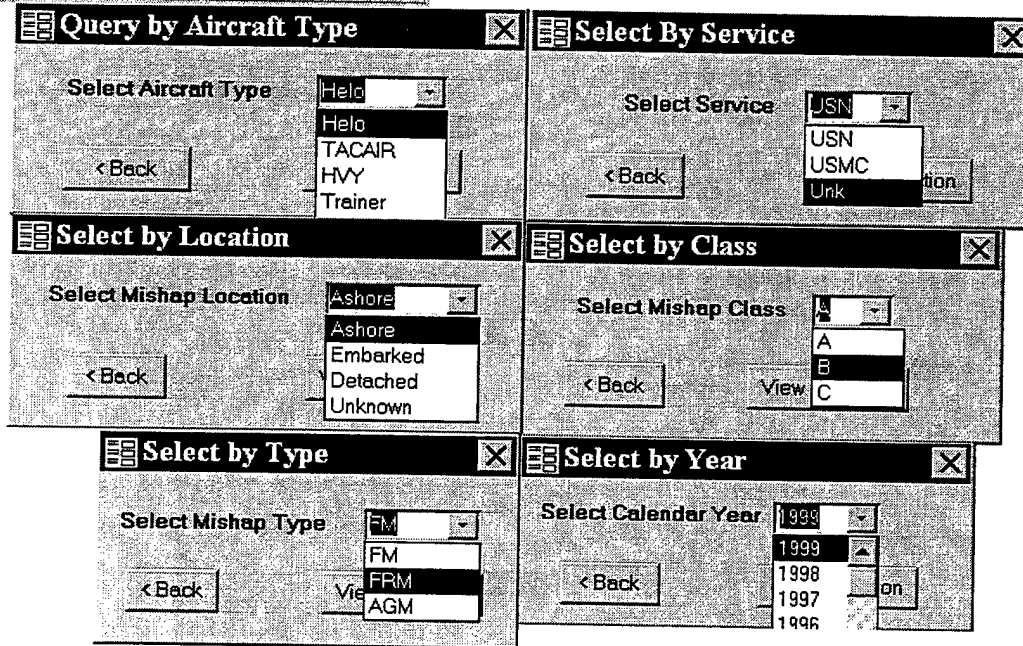


Figure A6: Query Menu with Sub-Menus for Additional Queries

Select "Multiple Criteria" command button on Query Menu to more precisely define query (see Figure A7).

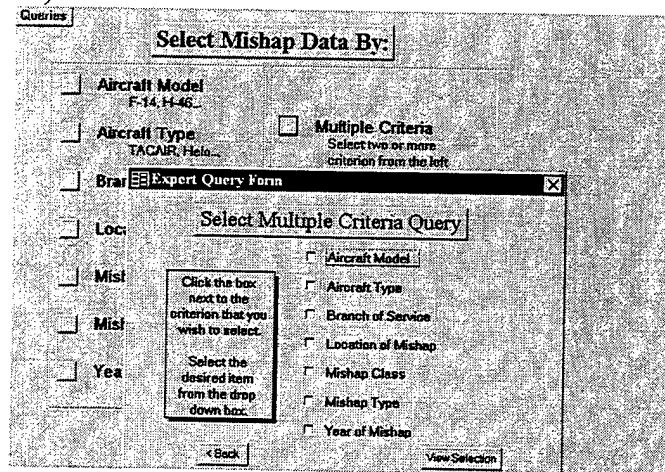


Figure A7: Query Menu with Multiple Criteria Sub-Menu

Define query by selecting desired check boxes and detailing information in combo boxes (see Figure A8).

Expert Query Form

Select Multiple Criteria Query

Click the box next to the criterion that you wish to select.
Select the desired item from the drop down box.

- Aircraft Model
- Aircraft Type
- Branch of Service
- Location of Mishap
- Mishap Class
- Mishap Type
- Year of Mishap

< Back View Selection

Figure A8: Multiple Criteria Sub-Menu with Desired Selections
Select "View Selection" to view Summary of Mishap form (see Figure A9).

Summary of Mishap

Maintenance Mishap Query

Mishap Number: 557

Date of Mishap: 7/8/51

Aircraft Type: F14

Mishap Type: FM

Brief Description: A/C DEP CTRL FLT During CV Break

Contributing Factors: NASC MAINT INST Does not REQ Safety EQUIP
MAINT Men Lost SA While Performing MAINT

Level 1 Level 2 Level 3

SC	ORG	DOC
MC	MED	MNT

Record: 1 of 4 (Filtered)

Figure A9: Summary of Mishap Form from Multiple Criteria Selection.

Note that the desired selection appears in a blue text box. Select "Define HFACS Codes" command button to define Level 1, 2, and 3 codes (see Figure A10).

	Organizational (ORG)	Hazardous Operations (HAZ)	Inadequate Documentation (DOC)	Inadequate Design (DES)	Inadequate Resources (RES)	Inadequate Processes (PRO)
Supervisory Conditions (SQ)	Squadron (SQN)	Inadequate Supervision (IDG)	Inappropriate Operations (OPS)	Uncorrected Problem (PRB)	Supervisory Misconduct (MIS)	
	Medical (MED)	Mental State (MNT)	Physical State (PHY)	Limitation (LM)		
Maintainer Conditions (MC)	Crew Coordination (CRW)	Communication (COM)	Assertiveness (ASS)	Adaptability/Flexibility (ADA)		
	Readiness (RDY)	Training/Preparation (TRG)	Certification/Qualification (CRT)	Infringement (INF)	Close Form	
	Environment (ENV)	Lighting/Light (LGT)	Weather/Exposure (WXE)	Environmental Hazards (EHZ)		
Working Conditions (WC)	Equipment (EQP)	Damaged (DMG)	Unavailable (UNA)	Dated/Uncertified (DUC)		
	Workspace (WRK)	Confining (CON)	Obstructed (OBS)	Inaccessible (INA)		
	Error (ERR)	Attention (ATT)	Memory (MEM)	Knowledge/Rule-Based (KNW)	Skill Based (SKL)	Judgement/Decision-Making (JDG)
Maintainer Acts (MA)	Violation (VID)	Routine (ROU)	Infraction (IFC)	Flagrant (FLG)	Sabotage (SAB)	

Figure A10: "Define HFACS Codes" Form

This form may be selected at various points throughout the prototype in order to receive HFACS code definition. Return to Query Menu (see Figure A11).

The screenshot shows a 'Query Menu' window with a title bar and a 'Queries' section. The main area is titled 'Select Mishap Data By:' and contains several search criteria with checkboxes:

- Aircraft Model (F-14, H-46...)
- Aircraft Type (TACAR, Helo...)
- Branch of Service (USN, USMC)
- Location of Mishap (Ashore, Embarked...)
- Mishap Class (A, B, C)
- Mishap Type (FM, FPM, AGM)
- Year of Mishap (Calendar)

On the right side, there are two additional options:

- Multiple Criteria (Select two or more criteria from the left)
- HFACS-ME Summary (by ME Category using a Multiple Criteria Query)

At the bottom right, there is a button labeled 'Return to Main Menu'. An arrow points from the 'HFACS-ME Summary' option to the text below the figure.

Figure A11: Query Menu

Select HFACS-ME Summary command button.

The HFACS-ME Summary form appears and displays HFACS level 1, 2, and 3 summary for all aircraft. Refine query by selecting desired information in combo boxes (see Figure A12).

Category	Sub-category	Count	Percentage
Supervisory Conditions (SQ)	Organizational (ORG)	11	50%
	Squadron (SQN)	13	59%
Maintainer Conditions (MC)	Medical (MED)	0	0%
	Crew Coordination (CRW)	0	0%
	Readiness (RDY)	1	5%
	Environment (ENV)	1	5%
Working Conditions (WC)	Equipment (EQP)	0	0%
	Working Conditions (WC)	1	5%

Figure A12: HFACS-ME Summary Form

Return to Main Menu (see Figure A13).

3. REPORT MENU

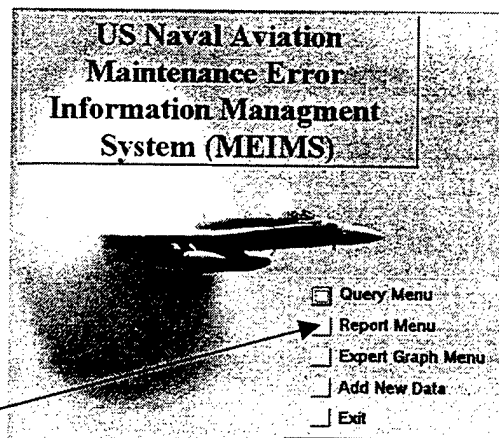


Figure A13: Main Menu

Select "Report Menu". Report Menu appears (see Figure A14).

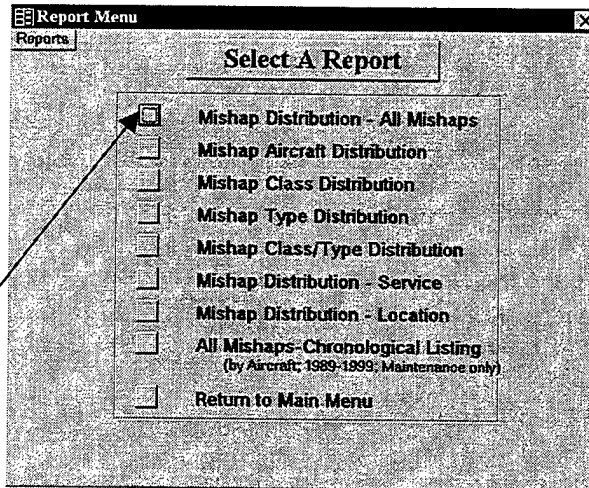


Figure A14: Report Menu

Select "Mishap Distribution-All Mishaps" command button to view corresponding report (see Figure A15).

All Maintenance Related Mishaps (1989-1999)			
Total Mishaps		595	
Unsafe Supervisory Conditions (USC)		452	76%
221	37%	Organizational	
13	6%	Hazardous Unsafe Operations	
51	4%	Inadequate Documentation	
78	25%	Inadequate Design	
53	40%	Inadequate Processes	
4	2%	Inadequate Resources	
338	58%	Squadron	
260	71%	Inadequate Supervision	
78	23%	Inappropriate Operations	
33	10%	Uncorrected Problems	
91	27%	Supervisory Misconduct	
Unsafe Maintainer Conditions (UMC)		112	18%
41	7%	Medical	
18	4%	Physical State	
24	4%	Mental State	
0	0%	Limitation	
68	11%	Crew Coordination	
0	0%	Assertiveness	
68	100%	Communication	
0	0%	Adaptability/Flexibility	
14	2%	Readiness	
7	5%	Training/Preparation	
3	2%	Certification/Qualification	
4	3%	Integrity	
Unsafe Working Conditions (UWC)		25	4%
8	3%	Environmental	
16	64%	Equipment	
2	8%	Workspace	
Unsafe Maintainer Acts (UMA)		436	73%
290	49%	Error	
111	38%	Attention	
39	13%	Memory	
100	34%	Knowledge/Rule Based	
62	21%	Skill Based	
44	15%	Judgment/Decision-Making	
248	42%	Violation	
1	0%	Routine	
234	94%	Infraction	
24	10%	Flagrant	
0	0%	Sabotage	

Figure A15: Mishap Distribution-All Mishaps Report

Additional reports may be selected from the Report Menu including “All Mishaps-Chronological Listing” (see Figure A16).

Chronological listing of all Maintenance Related Mishaps by Aircraft Type (1989-1999)				
Date	ID	Class	Type	Description
A4				
10/26/89	466	C	FRM	TACTS pod departed LAU-7 guided missile launcher
11/30/89	468	A	FM	AC on PMCF, ENO Flashed Out
1/24/90	472	C	AOM	During ground taxi, left crossed over drainage gra
5/5/92	505	C	FM	Canopy lost inflt over water.
1/20/93	512	C	FM	Acft landed nose gear up, both main down and locks
11/1/93	526	C	AOM	EOD Team Member injured when bang flare ignited af
1/7/94	264	C	FM	AC DEP Controlled FLT During FCF SLAT Checking Wing DMG
AV8				
3/12/90	48	C	AOM	UNCOMMANDED ENGINE ACCELERATION CAUSED ACFT TO STRIKE ANOTHER ACFT
3/6/90	82	A	FM	AC DEP RWY on LDO & Rolled Over
6/19/90	84	A	FM	AC Caught Fire on T/O Roll; Pilot Successfully Aborted T/O
8/9/90	23	C	FM	ENO Fire Due to Fuel Leak
8/8/90	24	A	FM	AC Crashed into Desert After Loss of ENO
1/6/91	25	C	FM	CANOPY DEPARTED AIRCRAFT DURING FLIGHT
5/8/91	26	B	AOM	AC Brake Loose During High-Power Striking BLDG
6/10/91	27	C	FM	AIRCRAFT DEPARTED RUNWAY AFTER SLOW LANDING

Figure A16: All Mishaps-Chronological Listing Report

Return to Main Menu (see Figure A17).

4. EXPERT GRAPH MENU

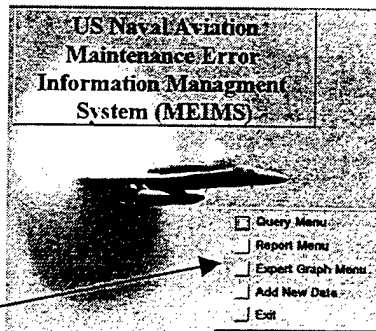


Figure A17: Main Menu

Select “Expert Graph Menu” (see Figure A18).

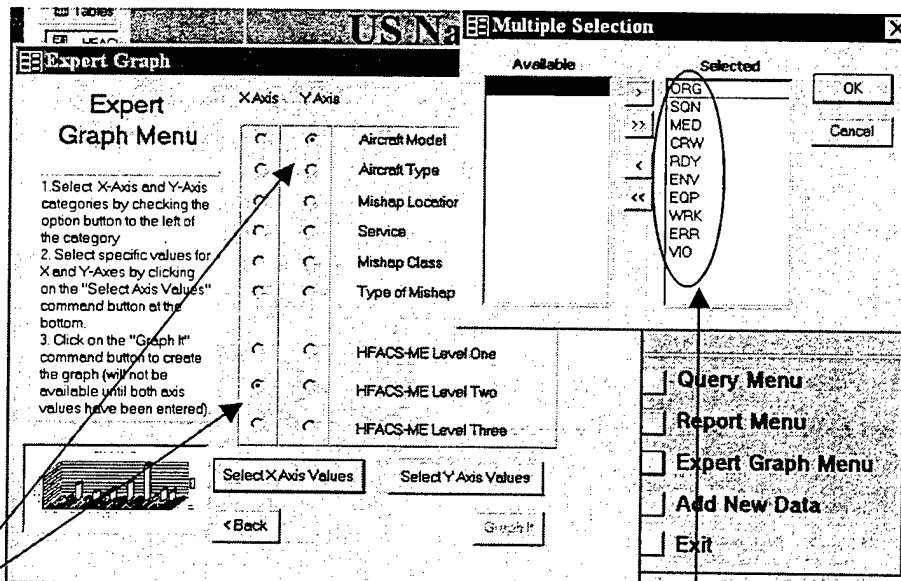


Figure A18: Expert Graph Menu and X-Axis Category Sub-Menu

Select categories for X and Y axes. Make selections for X axis..

and for Y axis (see Figure A19).

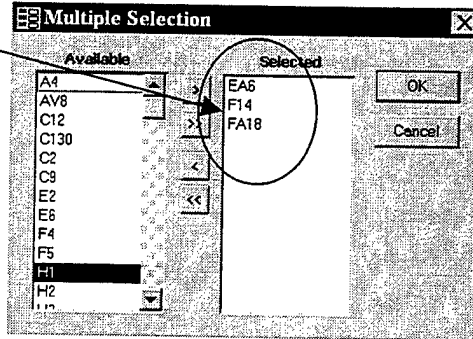


Figure A19: Y-Axis Category Sub-Menu

Select "Graph It" on Expert Graph Menu (see Figure A18). Three-dimensional graph appears (see Figure A20).

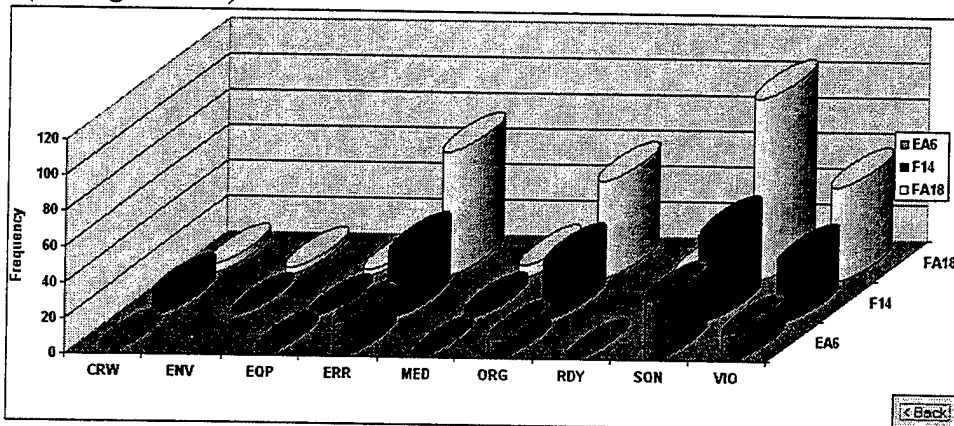


Figure A20: Expert Graph (Level 2 Codes vs Aircraft Type: EA6, F14, FA18)

Return to Main Menu (see Figure A21).

5. ADD NEW DATA MENU

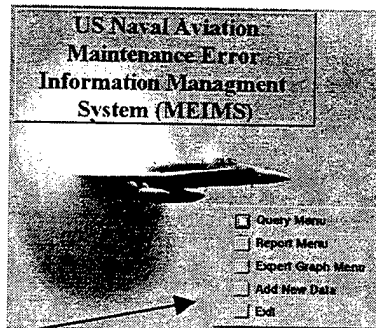


Figure A21: Main Menu

Select "Add New Data".

Data Entry Form appears (see Figure A22).

Figure A22: Data Entry Form

Enter data for new mishap (see Figure A23). Select "Add New Factor" for each factor to enter. When 3rd Level Code entered, 2nd and 1st Level Codes are automatically entered by the prototype.

Figure A23: Data Entry Form with Sample Data Applied

Once complete, select "Close Form". Final Data Entry Form appears (see Figure A24).

Figure A24: Final Data Entry Form.

Select "Enter" to complete data entry. After check appears in "Done" box, select "Close Form".

APPENDIX B

PROTOTYPE MAINTENANCE ERROR INFORMATION MANAGEMENT SYSTEM (MEIMS) TOOL EVALUATION

Background. Thank you for participating in a usability study (evaluation) of a prototype tool for the Maintenance Error Information Management System (MEIMS). This tool was developed by CDR Brian Wood, USN as part of a thesis project for his Master of Science program in Information Technology Management. The information management system was developed to effectively address and identify patterns of human error in Naval Aviation maintenance-related aircraft mishaps. The Human Factors Analysis and Classification System Maintenance Extension (HFACS-ME) taxonomy is the foundation of MEIMS and is an effective method for classifying and analyzing the presence of human error in maintenance operations leading to major mishaps, accidents of lesser severity, incidents and maintenance related personal injury cases. However, working with a large database (approximately 600 Naval Aviation maintenance-related mishaps in Fiscal Years 90-99) is very labor intensive. Given the capability of current relevant database tools, an improved information management system will bring HFACS-ME to the next level.

MEIMS captures maintenance error data, facilitates the identification of common maintenance errors and associated trends, and supports understanding of how to identify human errors in the future. The target audience for this information management system tool includes safety personnel (data entry & retrieval by unit safety officers, other safety & training personnel, maintenance officers, maintenance supervisors), mishap investigators-for data retrieval (Aircraft Mishap Board members, squadron safety officers), and analysts (from the Naval Safety Center, the command's safety officer or one from its higher headquarters). A usability study demonstrated the effectiveness of the tool. This tool allows can directly lead to a decreased mishap rate and overall increased mission readiness due to the training and analysis opportunity it provides.

Usability Study. You will be given a packet of instructions to guide you through MEIMS. You will be asked to make comments on the effectiveness and usability of the prototype system during your testing phase. Additionally, you will be asked to complete an "exit survey" after completion of your testing. Questions will include demographic information, objective questions about MEIMS usability, and subjective questions and comments for areas not covered in the objective section. The study should take no more than 15-20 minutes.

Completion of Study. Upon completion of your testing and survey you will be asked to return your packet of instructions to CDR Wood's office (E-305, East Wing Herrmann Hall). Pull this cover sheet off and put in the box marked "Cover Sheet." Put the remainder of the survey (ensure stapled) in box marked "Remainder of Survey."

Thank you again,
Brian Wood

Instructions for Prototype Maintenance Error Information Management System (MEIMS) Tool Evaluation

Start-up

1. Go to room E-300 (Computer Lab), E-320 (Ready Room), or E-322 (Computer Lab). Turn on computer (does not need to be logged into NPS LAN).

Question 1: What is the name of your computer (aircraft name on CPU)?

2. When Log-in menu appears, select <ESC> (this bypasses log-in requirement).
3. When Desktop (main Icon screen) appears, double click (clicks are always with left mouse, unless otherwise stated) on "MEIMS" Icon. This will start the MEIMS application (in Microsoft Access 97).

Main Menu

4. You will now have the Main Menu displayed with the world famous Supersonic Hornet photo in the background.
5. Note the five categories next to the command buttons on the bottom right portion of the screen. The system has "focus" on "Query Menu". Note the information on this button in the bottom left gray buffer above the Windows Start button. Place the mouse pointer over the Query Menu box (don't click, if you do, select <Back> on subsequent page) and note information that appears in the Text Box (both of these sources of information will be available throughout MEIMS).
6. Select <Tab> and view the same information for the remaining four command buttons (note, if you select <Exit> you will have to re-enter the system (see step 3 above).

Question 2: Is the terminology clear enough to understand what each of the four command buttons does? If not, what could be changed to make it clearer?

7. Select (click or tab to & enter) <Query Menu>

Query Menu

8. Note there are two sections on the Query Menu. The left half of the screen has seven categories to help you define how you would like to view the mishap data. The right half of the screen has four command buttons.
9. Select <Aircraft Model>

10. Another form appears: "Query by Aircraft Model". Select your type aircraft, then select <View Selection>. "Summary of Mishap" Form appears. Note, your aircraft selection has a blue background. Review the "Brief Description" of the mishap and the "Contributing Factors." View

Question 3: What aircraft did you select? _____

How many separate mishaps of that type aircraft are in the database? _____

View one of the mishaps.

What are the level 3 codes & what do they mean? _____

How did you find that info? _____

When you are through viewing the data, select <Close Form>

Select another aircraft model (optional).

When complete select <Back> on Query by Aircraft Model Form

11. Select another category (your option) & view the data.

Question 4: Which (if any) of the seven categories do you find useful?

Which (if any) of the seven categories do you not find useful?

12. Select <Multiple Criteria>. Create your own query using two or more criteria.

Question 5: Did you find this function useful? Why or why not?

13. Return to Query Menu. Select <HFACS-ME Elements>.

Question 6: How many total mishaps are in the database? _____

How many mishaps have a level one category of Maintainer Conditions? _____

How many mishaps have a level two category of Violations? _____

14. Return to Query Menu. Select <HFACS-ME Summary>.

Question 7: How many total mishaps are in the database? _____

How many mishaps have a level one category of Maintainer Conditions? _____

How many mishaps have a level two category of Violations? _____

Further define the system by your aircraft model (or select another type).

Question 8: What aircraft did you select? _____

How many separate mishaps of that type aircraft are in the database? _____

Conduct further queries as desired. When complete, return to Query Menu & return to Main Menu.

15. Select <Report Menu>. Review the six command buttons and their functions.

16. Select <Mishap Distribution - Aircraft>. Find your type aircraft (or review another) in the report. <Close> the report & return to the Report Menu.

17. Select <All Mishaps-Chronological Listing>. Review data. <Close> the report when complete & return to Report Menu. Return to Main Menu.

18. Select <Expert Graph Menu>. Follow directions. Create one graph with aircraft model (yours and 1 or 2 others) on the X-Axis and HFACS-ME Level One (all four codes) on the Y-Axis.

Question 9: What aircraft did you select? _____

Did you notice a difference in the level one codes between the aircraft (if so, what)?

Return to <Expert Graph Menu>. Try more graphs as desired. When complete, return to Main Menu.

19. Select <Add New Data>. Enter the following three mishaps to the database:

Question 10: What is the Mishap Numbers for the data you are entering?

Check to see if your entries were added to the database by Looking at the end of the Chronological Listing on the Report Menu (look for your Mishap Numbers).

Question 11: Did you see your data in the Chronological Listing? _____

Return to Main Menu & Exit the Program.

20. Please fill out the Exit Survey Questionnaire.

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APPENDIX C

PROTOTYPE MAINTENANCE ERROR INFORMATION MANAGEMENT SYSTEM (MEIMS) TOOL EXIT SURVEY

User's Impression of the Maintenance Error Information Management System (MEIMS) Prototype Tool

Purpose: This survey evaluates a user's overall satisfaction of the Maintenance Error Information Management System (MEIMS) prototype tool. It consists of three parts.

Part I: *Demographic Information.* Part I provides the user's aviation background, computer experience, and availability of software and hardware systems used in the Navy and Marine Corps.

Part II: *User Satisfaction with the Four Sections of the MEIMS Prototype Tool.* Part II deals directly with user feedback as they use the prototype tool.

Part III: *User Overall Satisfaction with the MEIMS Prototype Tool.* Part III allows users to give general feedback about the prototype tool.

Part I. Demographic Information

Follow the instructions after each numbered question or statement.

1. I am attached to a command that **primarily performs maintenance** (military and/or civilian) at the:

(Select one from the list and check the box)

- Squadron Level
- Intermediate Level (AIMD)
- Depot Level (NADEP)
- Command does not perform aircraft maintenance
- Other (describe if other) _____

2. **How long** have you been using a computer?

(Select one from the list and check the box)

- Less than one month
- One month to less than one year
- One year to less than two years
- Two years or more

3. What **software** do you normally use?
(Check all boxes that apply)

Microsoft Office (Word, PowerPoint, Excel, Access)
What version?

(Check all boxes that apply)

- 97
- 2000
- not sure of version
- other (describe if other) _____

Lotus Smart Suite (Word Pro, Lotus 123...)
What version?

(Check all boxes that apply)

- 97
- 9.5
- not sure of version
- other (describe if other) _____

Corel Word Perfect Office (Word Perfect, Quattro Pro...)
What version?

(Check all boxes that apply)

- Corel Office 7
- 2000
- not sure of version
- other (describe if other) _____

Other (describe if other) _____

4. What **software application categories** are you familiar with?
(Check all boxes that apply)

- Word Processing (MS Word, Word Perfect, Word Pro...)
- Spreadsheet (Excel, Lotus 123, Quattro Pro...)
- Presentations (PowerPoint, Harvard Graphics...)
- Graphic Software (Corel Draw, Adobe Photoshop...)
- E-Mail (Outlook, Eudora, AOL...)
- Database (Access, DBase...)

5. What computer **operating systems** do you use?
 (Check all boxes that apply)

- Windows (3.1, 95, 98, 2000)
- Windows NT
- Macintosh
- UNIX
- Linux
- Other (describe if other) _____

Part II. User Satisfaction with the Four Sections of the MEIMS Prototype Tool

Select the category that best matches your impression of each of the below categories (and check the box).

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
I feel the information on the MEIMS tool was in a logical form	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
(comments) _____					
I found the MEIMS tool easy to navigate	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
(comments) _____					
My tour of the MEIMS tool was very interesting	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
(comments) _____					
The information presented on the MEIMS tool is relevant to maintenance operations	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
(comments) _____					
The concept of the MEIMS tool is a good one.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
(comments) _____					

Part III. User Overall Satisfaction with the MEIMS Prototype Tool

Please make any comments on the MEIMS Prototype Tool not reflected in your comments in sections 1 and 2.

The most positive aspects of the MEIMS prototype tool were:

The most negative aspects of the MEIMS prototype tool were:

I would make these changes (if any) to the MEIMS prototype tool:

Thank you! Your participation is greatly appreciated!

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