ASSESSING NAVAL AVIATION MAINTENANCE SAFETY:
Error Reporting, Data Management, and Trend Analysis

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ABSTRACT

Naval Aviation has redoubled its long-standing efforts to eliminate mishaps, especially those linked to human error. The focus was expanded not only to cover aircrew error, but maintainer error as well. To examine maintainer error, the Naval Safety Center's Human Factors Analysis and Classification System (HFACS) was adapted to analyze reportable Naval Aviation maintenance mishaps. A total of 470 MRMs for Fiscal Years 90-97 were analyzed. The HFACS Maintenance Extension effectively profiled the nature of maintenance errors and depicted the latent supervisory, working, and maintainer conditions that "set the stage" for subsequent maintainer acts that were the proximate factors leading to a maintenance mishap. The profile and general findings held true for both major and less severe, reportable maintenance mishaps.

INTRODUCTION

Naval Aviation over the past 50 years has significantly lowered its Class A Flight Mishap rate, reducing those mishaps resulting in death, permanent disability, and or aircraft damage of over a million dollars during flight operations (see Figure 1). The reductions are primarily attributed to an array of engineering (e.g., collision avoidance system, etc.) and administrative (e.g., crew rest policy, etc.) intervention strategies for flight operations (Dirren, 2000). Paralleling these efforts was a series of human factors initiatives targeting aircrew and flight operations (e.g., human engineering & flight physiology training).

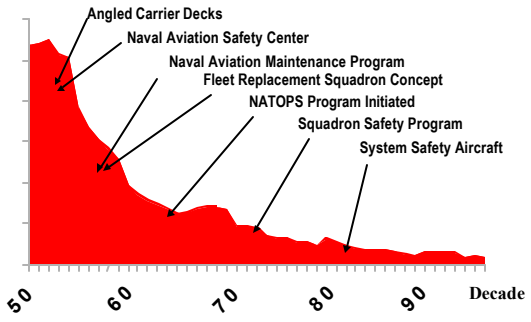

Figure 1. Naval Aviation Safety Initiatives

In examining the last ten years of mishaps, human factors have consistently been present in four of every five mishaps (80%). The nature of the mishap prevention proposed impact human factors, but they take an engineering or administrative control approach to eliminate just human error. They do not provide for personnel control measures or enhanced human performance, two areas which also could potentially reduce the chances of having a flight (or other type) mishap. This is a by-product of the engineering tradition and bureaucratic organization that are the foundation of Naval Aviation.

Following the tragic Nashville, TN F-14 Tomcat flight mishap, Naval Aviation leadership instituted a Human Factors Quality Management Board (HFQMB) to strive toward cutting human error flight mishaps in half (Nutwell & Sherman, 1997). The HFQMB instituted a three prong approach to attack human error: mishap data analysis, best practices benchmarking, and command safety assessment, each leading to insights that may suggest intervention recommendations. This paper "hi-lites" aspects of the first prong mishap data analysis (MDA), and especially how it relates to maintenance related mishaps and maintainer error

MDA IN NAVAL AVIATION

The Naval Aviation Safety Program (OPNAVINST 3750) specifies the reporting requirements for both the US Navy and US Marine Corps flight, flight related, and aircraft ground mishaps of varying classifications (severity). It provides for identifying multiple causal factors that contribute to a mishap event. The factors considered are supervisory, aircrew, material, maintenance, and facilities. The present reporting requirements and process tend to focus on engineering and administrative causes, and only to some extent human factors. Furthermore, the process is heavily geared toward mishaps involving aircrew factors that would be found in controlled flight into terrain, midair, or out of controlled flight mishaps. (Department of the Navy, 1991)

Naval Aviation mishap investigations once reported, are codified and entered into the Naval Safety Center's Safety Information Management System (SIMS). It is a relational database designed following OPNAVINST 3750 and its reporting requirements. It permits both structured reports, as well as, on-line queries. Unfortunately, since the framework underlying how the data was captured, reported, and archived did not have an integral human factors theoretical framework, the ensuing mishap analysis, aggregate trend analysis, and

proposed interventions primarily took the form of identifying engineering or administrative issues and making related recommendations for resolution.

HUMAN FACTORS ANALYSIS & CLASSIFICATION SYSTEM MAINTENANCE EXTENSION (HFACS-ME)

Naval Aviation, in order to achieve a better understanding of human error involvement in mishaps, adopted a conceptual framework that has gained fairly wide acceptance across the government, military, and commercial sectors -- Reason's model of human error causation (1990). It shows that an unsafe act by an individual is not only an accident-generating agent, but that organizational processes and environmental/ task conditions lead to their occurrence. The HFACS taxonomy was developed by the Naval Safety Center to analyze human errors contributing to Naval Aviation mishaps (Shappell, 1997). It integrates features of Heinrich's "Domino Theory" (Heinrich, Petersen, & Roos, 1980) and Edward's "SHEL Model" (Edwards, 1972) as well as Reason's "Human Error" model (Reason, 1990; 1991) to fully depict factors that are precursors to accidents. The latent factors or "conditions" set the stage for the active factors or "failures" that precede a mishap. These classifications can target areas for intervention.

The HFACS-ME taxonomy was adapted to classify factors in maintenance mishaps (Schmidt, Schmorrow, & Hardee, 1998). The "Maintenance Extension" consists of Supervisory, Maintainer, and Working Conditions, and Maintainer Acts. In HFACS-ME (see Figure 2), "conditions" are latent and can impact maintainer performance, contributing to an active failure in the form of an unsafe Maintainer Act. Such failures may directly lead to a mishap or injury, for example an operator runs a forklift into an aircraft, damaging it; or can lead to a latent Maintenance Condition, that aircrew would handle on take-off, in-flight, or on landing, for example, an improperly rigged landing gear that collapses on landing or an over-torqued hydraulics line that fails in flight causing a fire. Supervisory Conditions tied to poor design for maintainability, inadequate maintenance procedures, or improper standard maintenance operations can lead directly to a Maintenance Condition. Finally, latent Supervisory, Maintainer, and/or Working Conditions can also interact with one another.

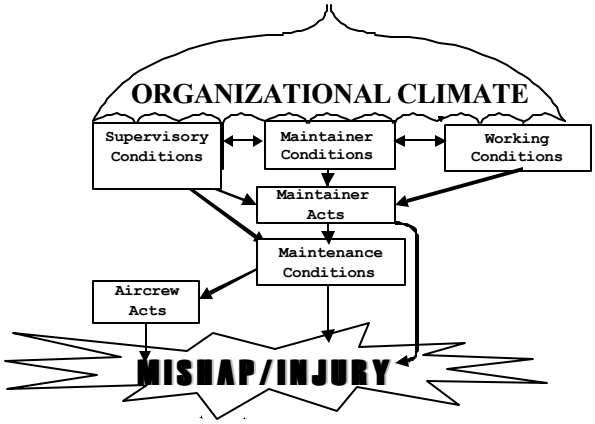

Figure 2. HFACS - Maintenance Extension

This section provides a brief illustration of the HFACS-ME taxonomy. The three orders of maintenance error: first, second, and third reflect a decomposition of the error types from a molar to a micro perspective (see Table 1).

Table 1. HFACS-ME Taxonomy

1st Order	2nd Order	3rd Order
Supervisory Conditions	Unforeseen	Hazardous Operations Inadequate Documentation Inadequate Design
	Squadron	Inadequate Supervision Inappropriate Operations Failed to Correct Problem Supervisory Violation
Maintainer Conditions	Medical	Adverse Mental State Adverse Physical State Physical/Mental Limit
	Crew Coordination	Communication Assertiveness Adaptability/Flexibility
	Readiness	Preparation/Training Qualification/Certification Violation
Working Conditions	Environment	Lighting/Light Exposure/Weather Environmental Hazard
	Equipment	Damaged/Broken Unavailable Dated/Uncertified
	Workspace	Confining Obstructed Inaccessible
Maintainer Acts	Error	Attention/Memory Rule/Knowledge Skill/Proficiency
	Violation	Routine Infraction Exceptional

Supervisory Conditions that lead to an active failure consists of both unforeseen and squadron level errors:

<u>Examples of unforeseen supervisory conditions</u>-
• An engine change is performed despite a high sea state and it falls off a stand (Hazardous Operation)
• A manual omits a step calling for an o-ring that leads to a fuel leak (Inadequate Documentation)
• Poor component layout prohibited direct viewing maintenance being per-formed (Inadequate Design)

<u>Examples of squadron supervisory conditions</u>-
• A supervisor does not ensure that personnel wear required protective gear (Inadequate Supervision)
• A supervisor directs a nonstandard procedure with -out considering risks (Inappropriate Operations)
• A supervisor neglects to correct cutting corners on in performing a routine task (Failed to Correct Problem)
• A supervisor willfully orders personnel to wash an aircraft without training (Supervisory Violation)

Maintainer Conditions that lead to an active failure are medical, crew coordination, and readiness:

Examples of maintainer medical conditions-
• A maintainer has a marital problem and cannot focus on a maintenance action (Adverse Mental State)
• A maintainer works for 20 hours straight and suffers from fatigue (Adverse Physical State)
• A short maintainer can not visually inspect an aircraft component (Physical Limitation)

Examples of maintainer crew coordination conditions-
• A maintainer leads a taxiing aircraft into another due to improper hand signals (Communication)
• A maintainer signs off an inspection due to perceived pressure (Assertiveness)
• A maintainer downplays a discrepancy to meet the flight schedule (Adaptability/Flexibility)

Examples of maintainer readiness conditions-
• A maintainer working on an aircraft skipped a requisite on the job training evolution (Preparation/Training)
• A maintainer engages in a procedure they are not been qualified to perform (Qualification/Certification)
• A maintainer is intoxicated on the job (Violation)

Working Conditions that can contribute to an active failure are environment, equipment, and workspace:

Examples of environment working conditions-
• A maintainer working at night on the flight line does not see a tool left behind (Lighting/Light)
• A maintainer securing an aircraft in a driving rain fails to properly attach the chains (Exposure/Weather)
• A maintainer working on a pitching deck falls from an aircraft (Environmental Hazard)

Examples of equipment working conditions-
A maintainer uses the only test set that is faulty (Damaged)
• A maintainer starts working on a landing gear without a jack because all are in use (Unavailable)
• A maintainer uses an old manual because a CD-ROM is not available to review the new one (Dated/Uncertified)

Examples of workspace working conditions-
• A maintainer working in a hangar bay cannot properly position the maintenance stand (Confining)
• A maintainer is spotting an aircraft with his view obscured by catapult steam (Obstructed)
• A maintainer is unable to perform a corrosion inspection that is beyond his reach (Inaccessible)

Maintainer Acts are active failures which directly or indirectly cause mishaps, or lead to a Latent Maintenance Condition that an aircrew would have to respond to during a given phase of flight, they include errors and violations:

Examples of errors in maintainer acts include-
• A maintainer misses a hand signal and backs a tow tractor into an aircraft (Attention/Memory)
• A maintainer inflates an aircraft tire using a pressure required by a different aircraft (Rule/Knowledge)
• A maintainer roughly handles a delicate engine valve causing damage (Skill/Proficiency)

Examples of violations in maintainer acts-
• A maintainer engages in practices, condoned by management, that bend the rules (Routine)
• A maintainer strays from accepted procedures to save time, bending a rule (Infraction)
• A maintainer willfully breaks standing rules disregarding the consequences (Exceptional)

HFACS-ME ANALYSIS OF MAINTENANCE MISHAPS

Two Officers with Naval Aviation and Maintenance experience applied the HFACS-ME taxonomy to the Class A, B, and C maintenance mishaps (see Table 2). Percents for each error type were determined for major and minor mishaps, and results were charted (see Figure 3).

Table 2 FY 90-97 Naval Aviation Maintenance Mishaps

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

During FY 90-97 there were 63 Class A maintenance mishaps (those involving the loss of an aircraft or a fatality), of which 50 were Flight, 0 were Flight Related, and 13 were Aircraft Ground. The following is a breakout of the errors in found Naval Aviation Class A maintenance mishaps for FY 90-97:

Supervisory Conditions- 67% had squadron conditions, whereas 21% had an unforeseen one.
Maintainer Conditions- 21% had medical, crew coordination (16%), or readiness condition.
Working Conditions- 3% an environment, equipment, or workspace conditions.
Maintainer Acts- 75% had a maintainer error, whereas 40% had a violation.

During FY 90-97 there was 407 other maintenance mishaps of lesser severity (Class B/C). A significant number of them (265, 65%) involved ground and fight line activities. Consequently, the previous percentages may only hold for major maintenance mishaps. It can then be proposed that the interventions for major mishaps involving maintenance activities (e.g., engine repair) may not work for less severe mishaps involving fight line activities (e.g., aircraft towing.) The following is a breakout of the errors in found Naval Aviation Class B and C maintenance mishaps for FY 90-97:

Supervisory Conditions- 59% of Class B/C mishaps had a squadron condition; 22% of Class B/C had unforeseen condition.
Maintainer Conditions- 17% of Class B/C mishaps had a crew coordination condition.
Working Conditions- 5% of Class B/C mishaps had an environment, equipment, space condition.

Maintainer Acts- 79% of Class B/C mishaps had a maintainer error; 39% of Class B/C mishaps had a violation.

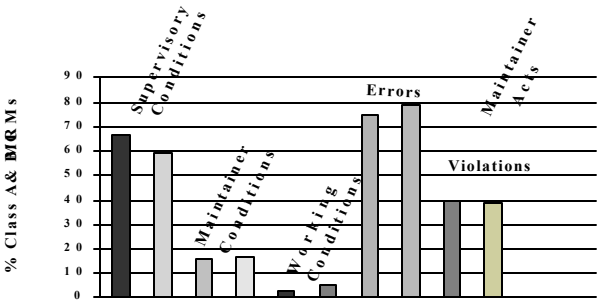

Figure 3. HFACS-ME Profile Of Class A vs B/C MRMs

DISCUSSION

HFACS-ME was effective in capturing the nature of and relationships among latent conditions and active failures present in Class A MRMs as well as less severe Class B/C MRMs. The insights gained provide a solid perspective for the development of potential intervention strategies. The major mishaps analyzed were primarily Flight Mishaps, meaning that many imposed in-flight Maintenance Conditions on aircrew, where as most of the less severe mishaps occurred on the ground and directly led to a Mishap or Injury. Potentially interventions selectively targeted at similar issues such as supervision, crew coordination, and procedural violations can be used to address problems leading to both major and minor mishaps, and those involving pure maintenance, flight line activities, and ground operations.

As a result of this effort the following actions were taken or are in the process of being undertaken by the Naval Safety Center in support of Naval Aviation safety and maintenance:

-HFACS-ME was adopted for inclusion in the update of the Naval Aviation Safety Program OPNAVINST 3750.6R

-Results are being used by to shape aspects of the Naval Aviation Maintenance Program (OPNAVINST 4790.2G)

-Tailored HFACS-ME training materials are being developed to support Aviation Safety Officers and Fleet Personnel

-An HFACS-ME data collection, reporting, and analysis tool is in development to support Mishap Investigators

-Construction of HFACS-ME database is under way to support safety training and intervention development

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Note. The opinions expressed are those of the authors and do not represent those of the Department of Defense, Department of the Navy, or the Naval Postgraduate School.