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Human Factors Analysis of Naval Transport Aircraft Maintenance and Flight Line Related Incidents

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ABSTRACT

To study maintainer error, the Naval Safety Center's Human Factors Accident Classification System (HFACS) was adapted for Maintenance Related Mishaps (MRMs). The HFACS Maintenance Extension (ME) successfully profiled the errors present Naval Aviation Class A MRMs. In order to assess its suitability for studying major and minor airline accidents, a post hoc analysis was conducted on 124 Naval Fleet Logistics Support (VR) Wing maintenance related mishap, hazard, and injury reports. Two judges separately coded the 124 VR Wing incidents; a Cohen's kappa of .78 was achieved, indicating an "excellent" level of agreement. Generally, HFACS-ME was able to profile maintainer errors found in more minor incidents and the factors that contribute to them. Common factors observed include errors attributed to third party maintenance, inadequate supervision, failed communications, skill-based errors, and procedural violations.

INTRODUCTION

Marx (1998) in a comprehensive review of maintenance error investigation and analysis systems states that human error is "under-served" by traditional event investigation methods. He contends that they effectively end with the identification of a human error without an effort to determine why it occurred. Many have previously observed this same problem and attributed it to several factors: 1) reporting criteria, 2) investigator biases, 3) report scope, depth, and quality, 4) reporting system design, and 5) database construction (Adams & Hartwell, 1977; Boyle, 1980; Edwards, 1981; Benner, 1982; Pimble & O'Toole, 1982; Andersson & Lagerloff, 1983). Marx (1998) reflects many argue that through human factors oriented investigation and reporting process "industry can now begin to understand why people make certain mistakes."

Harle (1994) posits that "accident prevention is critically linked to the adequacy of the investigation of human factors." However, the same issues can plague such systems as traditional systems if not properly designed, implemented, and supported. Zotov (1996) in reflecting on the standard International Civil Aviation Organization (ICAO) reports involving human factors states that they "frequently generated more heat than light." Further, Bruggin (1996) finds the reactive use of human factors accident data fails to "exploit the preventive potential of the human element that safeguards the system."

Even though there is a general agreement in the aviation industry that human factors based investigation methods are better, they are not being widely used. Marx (1998) cited that of 92 carriers trained to use the Maintenance Error Decision Aid (MEDA), only six were in the United States. He notes that this was in spite of the fact that 15 percent of air carrier mishaps are attributed to maintenance error at an annual cost of over a billion dollars. Some of the reasons cited were their tendency to place blame, not transcend the proximate causes, emphasize static who, what, and when variables and not dig for underlying causes.

A conceptual framework of human error that had gained fairly wide acceptance across the government, military, and commercial sector is that established by Reason's model (1980; 1997). It showed unsafe individual acts were not the only accident generating agent, and that organization processes and task/environment conditions "set the stage" for their occurrence (see Figure 1). Marx (1998) lamented that despite this acceptance, the model does not provide for the identification of precursors to accidents.

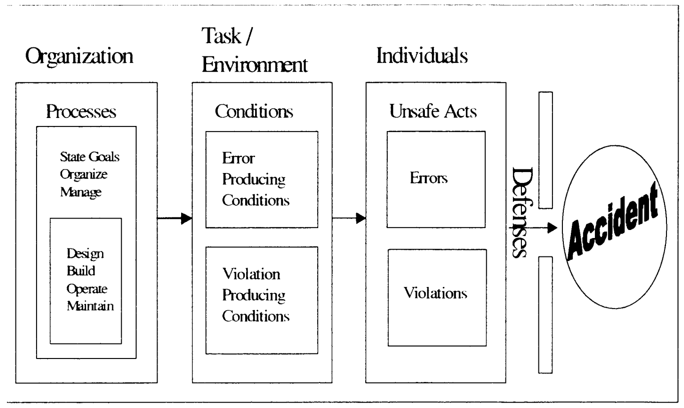

Figure 1. Reason's Model

HUMAN FACTORS ACCIDENT CLASSIFICATION SYSTEM - MAINTENANCE EXTENSION

The Human Factors Accident Classification System (HFACS) was developed by the Naval Safety Center to analyze human errors contributing to Naval Aviation mishaps. It incorporates features of Heinrich's "Domino Theory" (Heinrich, Petersen, & Roos, 1980) and Edward's "SHEL Model" (Hawkins, 1993) as well as Reason's model to fully depict factors that are precursors to accidents. Latent conditions and active failures are partitioned into one of three categories (see Figure 2). These categories enable an analyst to identify failures at three levels historically related to accidents: supervisory condition, operator condition, and operator act. These classifications can then be used to target appropriate intervention strategies.

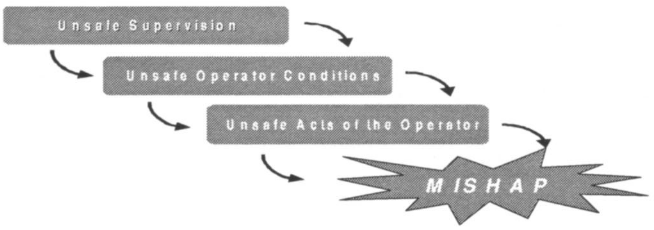

Figure 2. HFACS Component Levels

The original HFACS framework was adapted to classify human errors and other factors that contribute to MRMs. The HFACS addition, termed "Maintenance Extension" (ME), consists of four error categories: Supervisory Conditions (latent), Maintainer Conditions (latent), Working Conditions (latent), and Maintainer Acts (active).

Following the HFACS-ME, Supervisory, Maintainer, and Working Conditions are latent factors that can impact a maintainer's performance and can contribute to an active failure, an Unsafe Maintainer Act. An Unsafe Maintainer Act may lead directly to a mishap or injury. For example, a maintainer runs a forklift into the side of an aircraft and damages it. The Unsafe Maintainer Act could also become a latent Maintenance Condition, which the aircrew would have to deal with on take-off, in-flight, or on landing. For example, an improperly rigged landing gear that collapses on touchdown or an over-torqued hydraulics line that fails in flight causing a fire. It is important to note that Supervisory Conditions related to design for maintainability, prescribed maintenance procedures, and standard maintenance operations could be inadequate and lead directly to a Maintenance Condition (see Figure 3).

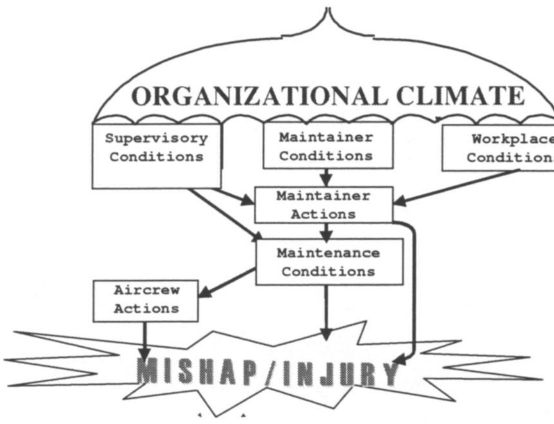

Figure 3. HFACS Maintenance Extension Model

The following paragraphs provide a brief illustration of the HFACS Maintenance Extension taxonomy levels.

Latent Supervisory Conditions that can contribute to an active failure includes both unforeseen and squadron. Examples of unforeseen supervisory conditions include:

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

Examples of squadron supervisory conditions include:

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

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

- A maintainer who has a marital problem and cannot focus on a maintenance action (Mental State)
- A maintainer who worked for 20 hours straight and suffers from fatigue (Physical State)
- A maintainer who is short can not visually inspect aircraft before it is launched (Physical Limitation).

Examples of maintainer crew coordination conditions include:

- A maintainer who leads a taxiing aircraft into another due to improper hand signals (Communication)
- A maintainer who performs a task, not in accordance with standard procedures, because the maintainer was overly submissive to a superior (Assertiveness)
- A maintainer who downplays a downing discrepancy to meet the flight schedule (Adaptability)

Examples of maintainer readiness conditions include:

- A maintainer who is working on an aircraft skipped the requisite OJT evolution (Training)
- A maintainer who engages in a procedure that they have not been qualified to perform (Certification)
- A maintainer who is intoxicated on the job (Violation)

Latent Working Conditions that can contribute to an active failure include environmental, equipment, and workspace. Examples of environmental working conditions include:

- A maintainer who is working at night on the flightline does not see a tool he left behind (Lighting/Light)
- A maintainer who is securing an aircraft in a driving rain fails to properly attach the chains (Weather)
- A maintainer who is working on a pitching deck falls from the aircraft (Environmental Hazard)

Examples of equipment working conditions include:

- A maintainer who is using a defective test set does not precheck it before troubleshooting (Damaged)
- A maintainer who starts working on landing gear without a jack because all in use (Unavailable)
- A maintainer who uses an old manual because a CD-ROM reader is not available (Dated)

Examples of workspace working conditions include:

- A maintainer who is working in a hangar bay cannot properly position the maintenance stand (Confining)
- A maintainer who is spotting an aircraft with his view obscured by catapult steam (Obstructed)
- A maintainer who 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 Latent Maintenance Condition, they include errors and violations.

Examples of errors in maintainer acts include:

- A maintainer who misses a hand signal and backs a forklift into an aircraft (Attention)
- A maintainer who is very familiar with a procedure may reverse steps in a sequence (Memory)
- A maintainer who inflates an aircraft tire to a pressure required by a different aircraft (Rule)
- A maintainer who roughly handles a delicate engine valve causing damage (Skill)

Examples of violations in maintainer acts include:

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

The three maintenance error levels reflect a shift from a molar to a micro perspective (see Table 1).

Table 1. HFACS-ME Categories

First Order	Second Order	Third Order
Supervisory Conditions	Unforeseen	Hazardous OPS INADQ Document INADQ Design
	Squadron	*INADQ Supervision* *INAPP Operations* *Uncorrected Prob* *Supv. Violation*
Maintainer Conditions	Medical	Mental State Physical State Phys/Mental
	Coordination	*Communication* *Assertiveness* *Adapt/Flexibility*
	Readiness	Prep/Training Qual/Certification Violation
Working Conditions	Environment	Lighting/Light Exposure/Wx Environmental Hazards
	Equipment	*Damaged* *Unavailable* *Dated/Uncertified*
	Workspace	Confining Obstructed Inaccessible
Maintainer Acts	Error	Attention Memory Rule/Knowledge Skill
	Violation	*Routine* *Infraction* *Exceptional*

HFACS ANALYSIS OF CLASS A FY 90-97 MRMS

Schmidt, Schmorrow, and Hardee(1998) conducted an analysis of 63 major Class A maintenance related mishaps that occurred during FY 90-97. Four Navy maintenance personnel used the HFACS-ME to classify the human errors present. They uncovered an error profile for the major MRMs and showed that latent Supervisory, Maintainer, and Workspace Conditions can impact maintainer job performance. Specifically, inadequate supervision of maintenance evolutions, not ensuring personnel are trained and/or qualified, not enforcing rules, and poor communication characterize most latent Supervisory Conditions. Poor passdown, coordination, and communication; non-use or lack of publications, policies, and procedures; and fatigue comprise most latent Maintainer Conditions.

Due to the focus and depth of maintenance mishap reports often Maintainer and Working Conditions were not cited or ignored altogether. Finally, most Maintainer Errors reflect a lack of training, experience, and skill, whereas Maintainer Violations consist of routine non-compliance with standard procedures and practices, infractions, and bending the rules in order to meet mission requirements and the flight schedule. The HFACS-ME taxonomy was effective in capturing the nature of and relationships among latent conditions and active failures present in Class A MRMs. The insights gained provide a solid perspective for the development of potential intervention strategies.

BACKGROUND

The Naval Reserve Fleet Logistics Support (VR) Wing is a critical component of the worldwide pipeline that resupplies and transports Naval forces. The VR Wing has a fleet of 53 aircraft composed of C-9B Skytrains, C-130J Hercules, and C-20D/G Gulfstreams. Whether moving Navy and Marine Corps personnel or supplies, the VR Wing flies over 62,000 hours annually throughout the world. With the potential disastrous outcome of a flight mishap, the detrimental impact of ground damage on mission readiness, or the tragedy of a serious personnel injury, the VR Wing Commander requested that the HFACS-ME be applied to all VR Community maintenance related incidents (MRIs), regardless of their severity.

OBJECTIVE

Naval Aviation has a strong interest in applying error models to aviation incidents to facilitate the identification of human factors problems and provide a basis for tailored intervention strategy development. Given the VR Wing Commander's desire to uncover errors present that contribute to mishaps and to proactively use the results to prioritize and focus safety efforts, a post hoc analysis of all VR maintenance related mishaps, hazard, and injury (incidents) reports for the last decade were analyzed using the HFACS-ME to characterize the nature and prevalence of errors present.

METHODS

DATABASE – The Naval Safety Center's Safety Information Management System was queried to obtain all VR Community aircraft maintenance related incidents (MRI) for FY 90-98. A total of 124 VR MRI reports were considered in this analysis.

JUDGES – Two Naval Officers, both well versed in the HFACS-ME taxonomy and experienced in maintenance operations reviewed the causal factors present in the VR MRI reports. The MRIs were then coded independently by the two judges and Cohen's kappa was calculated as a measure of agreement and reliability. A kappa of .79 was obtained, indicating an "excellent" agreement level between the two raters.

PROCEDURE – Each MRI report case was independently reviewed and the HFACS-ME codes for each case were entered into a spreadsheet for subsequent tabulation. Each causal factor was assigned only one HFACS-ME code, and codes were only assigned to issues clearly identified as having had contributed to the mishap. Codes, which were disputed, were discussed and resolved on the spot or after conferring with a third party.

ANALYSIS – Each HFACS-ME category level was totaled and frequencies were entered into a chart for later inspection. MRI dates were used to calculate discrete time intervals to evaluate the distribution and model the arrival process. The model was then used to predict the potential impact of targeted interventions.

RESULTS

Of the 124 MRIs, 26 (21.0%) were mishap investigation reports, 75 (60.5%) hazard reports, and 23 (18.5%) personnel injury reports. There was a total of 263 causal factors, averaging 2.1 per incident. A number of MRIs were directly attributable to maintenance performed by rework facilities (33; 26.6%). The main HFACS-ME category for these MRIs was Supervisory Conditions (30; 90.9%). To focus on Wing personnel errors, MRIs attributed to rework were partitioned out of the follow-on analysis. The first level breakout for the remaining 91 MRIs had Maintainer Acts as the most prevalent (53%), and Supervisory (19%), Maintainer(15%), and Working (13%) Conditions a distant second, third and fourth.

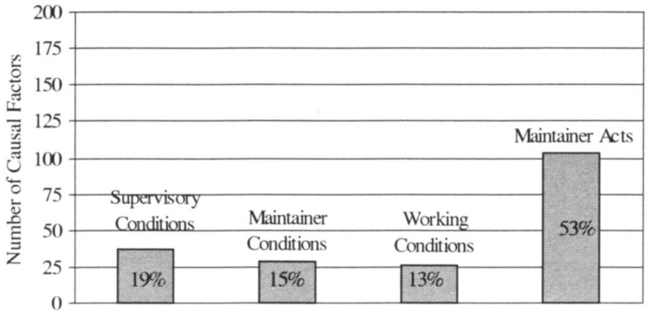

Figure 4. First Order Maintenance Error Categories

The percentage involvement of each second level HFACS-ME factor for the 91 remaining MRIs considered was derived. The most frequent factors present were as follows:

Supervisory Conditions – 11.3% of the MRIs reported Squadron Supervisory Conditions. The majority of issues involve inadequate procedure, supervision, and training.

Maintainer Conditions – 8.2% of the MRIs reported Crew Coordination. *Note: Maintainer Conditions are likely present, but under reported.* Pass down of information within work groups and from the company to the employees was listed.

Working Conditions – 8.2% of the MRIs reported Environment. *Note: Workspace Conditions are likely present, but under reported.* Lighting and confined workspace were mentioned as factors.

Maintainer Acts – 40.5% of the MRIs reported Maintainer Errors, whereas 12.3% had Violations. Most errors entailed omissions or incomplete procedures, whereas violations involved not following procedures.

Forecasted MRI totals/reductions were derived for two targets of intervention: rework error and procedural violations. The status quo incident rate over a projected 3-year period would be 13.32 incidents per year. By incorporating an intervention for rework error that is 50% effective (i.e., tighter contract monitoring) there would be a rate of 12.43 and five fewer incidents over a 3-year period. Further, by implementing an intervention that is at least 50% effective for procedural violations (i.e., procedural violations) there would be a rate of 11.45 and six fewer incidents over a 3-year period. It is important to note that most rework errors and procedural violations led to more major/serious MRIs.

CONCLUSIONS

The HFACS-ME was effective in capturing the nature of and relationships among latent conditions and active failures present in major and minor VR Community MRIs. Common factors observed include errors attributed to third party maintenance, inadequate supervision, failed communications, skill-based errors, and procedural violations. The insights gained yield a solid perspective for the suggestion of intervention strategies. Further, combining that perspective with modeling procedures provides for projection of the potential impact of intervention and a rationale for prioritization of intervention efforts and allocation of organization resources.

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