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Title of Research
The Investigation of Accidents Related to Aeronautical Decision-making in Flight Operations

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ABSTRACT

Aeronautical decision-making (ADM) is defined by the FAA (1991) as 'a systematic approach to the mental process used by aircraft pilots to consistently determine the best course of action in response to a given set of circumstances'. Jensen and Benel (1977) found that decision errors contributed to 35% of all nonfatal and 52% of all fatal general aviation accidents in the United States. Diehl (1991) proposed that decision errors contributed to 56% of airline accidents and 53% of military accidents. This research analyzes 51 accident reports obtained from ROC Aviation Safety Council (ASC) published between 1999 and 2008. Each accident report was independently analyzed using the Human Factors Analysis and Classification System (HFACS) framework (Weigmann and Shappell, 2003). The presence or the absence of each HFACS category was evaluated from the narrative of each accident report. Statistical relationships linking fallible decisions in upper management were found to directly affect supervisory practices, thereby creating the psychological preconditions for unsafe acts and hence indirectly impairing the performance of pilots' decision-making. It was observed that 68% of accidents in this sample included a decision error. The results show clearly defined, statistically-described paths with pre-cursors to decision errors at both the immediately adjacent and also higher levels in the organization. This study provides an understanding, based upon empirical evidence, of how actions and decisions at higher managerial levels in the operation of commercial aircraft result in decision errors on the flight deck and subsequent accidents. To reduce the accident rate resulting from decision errors in flight operations the 'paths to failure' relating to these organizational and human factors issues must be addressed.

Keywords: Accident Prevention, Aeronautical Decision-making, Human Error, Human Factors Analysis and Classification System

INTRODUCTION

Flying a high-technology aircraft is not only an issue of skilled psychomotor performance but also of real-time decision-making involving situation awareness, choice amongst alternatives and assessment of risk within a limited-time frame (Endsley, 1993 & 1997; Prince & Salas, 1993). Pilots must perform a wide array of tasks in addition to simply getting the aircraft from one point to another. As a result, pilots must learn to make decisions and develop judgments related to mission performance in addition to making those decisions related directly to flying the aircraft. Aeronautical decision-making (ADM) has traditionally been viewed as an intrinsic quality or as a by-product of flying experience (Buch & Diehl, 1984).

Jensen and Benel (1977) found that decision errors contributed to 35% of all nonfatal and 52% of all fatal general aviation accidents in the United States between 1970 and 1974. Furthermore, Diehl (1991) proposed that decision errors contributed to 56% of airline accidents and 53% of military accidents. More recent studies (Shappell & Wiegmann, 2004) have found decision errors contributed to 45% of accidents in the USAF and 55% in the US Navy.

O'Hare (2003) reviewed aeronautical decision-making and came to the conclusion that 'it is difficult to think of any single topic that is more central to the question of effective human performance in aviation than that of decision-making'. Current FAA regulations require that decision-making is taught as part of the pilot-training curriculum (FAA, DOT 61.125), however, little guidance is provided as to how that might be accomplished, and none is given as to how it might be assesses outside of the practical test. Endsley (1997) suggested the key to effective decision-making rests in correctly understanding the situation. Pilots' situation awareness and risk management are key parts of the aeronautical decision-making process. Larkin, McDermott, Simon, & Simon (1980) advised that problem-solving studies show fundamental differences between novices and experts in how problems are interpreted, what strategies are devised, what information is used, expert's memory for critical information, and the speed and accuracy of problem solving. Experienced decision makers consider a large number of cues in building situation assessments, and under certain specific circumstances may take actions that appear contrary to those prescribed by checklist. Experts can see underlying causes and have more complex models of the problem space than novices.

LITERATURE REVIEW

Aeronautical decision-making is defined by the FAA (1991) as 'a systematic approach to the mental process used by aircraft pilots to consistently determine the best course of action in response to a given set of circumstances' (Hunter, 2003). Jensen (1997) defined pilot judgment as 'the mental process that pilots use in making decision'. Both definitions implicitly include both process and outcome. Fischer, Orasanu, & Wich (1995) suggested that risk and time pressure are situational variables that constrain the decision process, as risk and time pressure may call for an immediate response whether or not the problem was fully understood. Lower risk levels and fewer time constraints, in contrast, permit additional diagnostic actions to be undertaken or the deliberation of options. Jensen, Guilke & Tigner (1997) suggested that risk management should be a key part of the decision-making process. Risk assessment feeds into decision making in two ways: during the assessment of the precipitating threats and in evaluating potential courses of action. Janis and Mann (1977) proposed that a good decision-making process is one in which the decision maker successfully accomplishes the collection of information about a wide range of alternatives, carefully assessed the risks and benefits of each course of action, and prepares contingency plans for dealing with known risks.

The processes of decision-making center around two elements; situation assessment, which is used as a pre-cursor to generate one (or more) plausible courses of action and mental simulation to evaluate those courses of action for risk management purposes. However, only if a pilot recognizes there is sufficient time for making wide-ranging considerations will s/he evaluate the dominant response option by conducting a mental simulation to see if it is likely to work. If there is not adequate time, the pilot will tend to implement the course of action that experience (if any) dictates is the most likely to be successful. Klein (1993) found that whereas experts used a recognition-primed or perception-based decision process to retrieve a single likely option, novices were more likely to use an analytical approach, systematically comparing multiple options. It was also found that experience affects the processes of decision-making by improving the accuracy of situation assessment, increasing the subsequent quality of the courses of action considered and enabling the decision maker to construct a mental simulation. Situation assessment is a fundamental precursor to situation awareness, which is itself the precursor for all aspects of decision-making (Nobel, 1993; Prince & Salas, 1997). In a dynamic tactical environment, effective decision-making is highly dependent on situation awareness (Endsley & Bolstad, 1994).

Automated aids on the flight deck are designed specifically to decrease pilots' workload by performing many complex tasks, not only including information processing, system monitoring, diagnosis and prediction, but also controlling the aircraft itself. Flight management systems (FMS) are designed not only to keep the aircraft on course, but also to manage many aspects of the flight task, such as calculating fuel-efficient routes, navigation or detecting and diagnosing system malfunctions. An inevitable facet of this high level of automation is that it has changed the way pilots perform tasks and make decisions. However, the use of a high degree of automation also decreases the likelihood that decision makers will make the cognitive effort to process all the available information in cognitively complex ways. Parasuraman and Riley (1997) described this tendency toward over-reliance as 'automation misuse'. In addition, automation can increase the probability that decision makers will terminate the situation assessment process prematurely when prompted to take a certain course of action by the automated aids. Experimental evidence of automation-induced commission errors was produced during full-mission simulations in the NASA Ames Advanced Concepts Flight Simulator (Mosier, Skitka, Heers and Burdick, 1998). Automation commission errors are errors made when decision makers inappropriately follow automated information or directives (e.g. when other information in the environment contradicts or is inconsistent with the automated cue). These have recently begun surfacing as unintentional by-products of the use of highly automated systems.

For over 30 years the importance of aeronautical decision-making has been recognized as critical to the safe operation of aircraft. Decision-making is a complex cognitive process and is affected by situational and environmental conditions (Payne, Bettman, & Johnson, 1988). Orasanu and Connolly (1993) have suggested that much decision-making occurs in an organizational context, and that the organization influences decisions directly by stipulating standard operating procedures, and indirectly, through the organization's norms and culture. Maurino et al. (1995) suggested that it is important to understand how decisions made by people at the sharp-end (pilots) are influenced by the actions of the people at the blunt-end of their operating worlds (i.e. the higher managerial levels in their organizations). However, there is little empirical work formally describing the relationship between organizational structures, psychological pre-cursors of accidents and the actual errors committed by pilots. Dekker (2001) proposed that human errors are systematically connected to features of peoples' tools and tasks, and as acknowledged more recently, their operational and organizational environment. Latent failures are spawned in the upper management levels of organizations which may be related to manufacturing, regulation and/or other aspects of management. As Reason (1997) noted, complex systems such as airlines are designed, operated, maintained and managed by human beings. As a result it is not surprising that human decisions and actions are implicated in most accidents.

This research utilizes the Human Factors Analysis and Classification System - HFACS (Shappell and

Weigmann, 2001; Weigmann and Shappell, 2003) `HFACS was developed from Reason's organizationally based model of human error (Reason, 1990, 1997). In this model active failures (errors) of front-line operators (in this case pilots) combine with latent failures lying dormant in the system to breach its defenses. These latent failures are spawned in the upper levels of the organization and are related to management and regulatory structures.

HFACS addresses human errors and the factors underpinning them at four levels. Level 1 (unsafe acts of operators - active failures) is concerned with the behaviors of the flight crew on the flight deck that contribute directly to the accident. Failures at this level are further classified into two sub-categories; errors and violations. Errors fall into three basic error types (skill-based, decision, and perceptual). Violations, however, are instances of the willful disregard of rules, which subsequently result in an accident. Level 2 (preconditions for unsafe acts - latent/active failures) addresses the psychological pre-cursors to the active failures at level 1, such as the substandard conditions of the operators and the operating environment which predispose them to making an error. Level 3 (unsafe supervision - latent failures) traces the causal chain of events producing the unsafe acts up to the level of the front-line supervisors. Level 4 (organizational influences - latent failures) describes the contributions of fallible decisions in upper levels of management that directly affect supervisory practices, as well as the conditions and actions of front-line operators. Higher levels in the HFACS framework are hypothesized to affects lower organizational levels.

This study analyses accidents occurring to civil aircraft in the ROC using the HFACS framework to establish how, both directly and indirectly actions and decisions at higher managerial levels in the operation of commercial aircraft result in decision errors on the flight deck (and subsequently accidents).

METHOD

<u>Data:</u> The reports for aviation accidents occurring between 1999 and 2008 were obtained from ROC Aviation Safety Council. A total of 51 accidents occurred and had been subject to complete investigations within this period. There were 24 different types of aircraft involved in the accidents analyzed, including commercial jets airliners (Airbus A300, A320 and A330; Boeing B737 and B747; McDonnell-Douglas MD11, MD82, MD83 and MD90): private jets (Bombardier BD700): turbo-prop powered aircraft (ATR 72-200; De Havilland Canada DASH-8-300, Fokker 50) and commercial helicopters (Bell UH-1H, 206 and 430; Boeing 234; Eurocopter BK117). Full copies of all these accident reports may be found on the ROC Aviation Safety Council web site (http://www.asc.gov.tw/asc_en/accident_list_1.asp).

<u>Classification framework</u>: The version of the HFACS framework described in Wiegmann and Shappell (2003) was utilized in this study. Level-1 of the HFACS categorizes events under the headings of 'unsafe acts of operators' that can lead to an accident. This comprises four sub-categories of 'decision errors'; 'skill-based errors'; 'perceptual errors' and 'violations'. Level-2 of HFACS is concerned with 'preconditions for unsafe acts'. This has seven sub-categories within it: 'adverse mental states'; 'adverse physiological states'; 'physical/mental limitations'; 'crew resource management'; 'personal readiness'; 'physical environment', and 'technological environment'. Level-3 of HFACS is concerned with 'unsafe supervision' which includes the four categories: 'inadequate supervision'; 'planned inappropriate operation'; 'failure to correct known problem', and 'supervisory violation'. Level-4, the highest level in the framework is labeled 'organizational influences' and comprises of three sub-categories: 'resource management'; 'organizational climate' and 'organizational process'.

Research Design: Two aviation human factors specialists coded each accident report independently. The analysts had previously been trained together on the use of the analysis and categorization framework to ensure that they achieved a detailed and accurate understanding of it. This training consisted of three half-day modules delivered by an aviation psychologist. The training syllabus included an introduction to the HFACS framework; explanation of the definitions of the four different levels of HFACS; and a further detailed description of the content of the eighteen individual HFACS categories. Prior to undertaking the present study these analysts also undertook the analysis a total of 523 accident reports (Li and Harris, 2006, 2008). The presence (coded 1) or absence (coded 0) of each HFACS category was evaluated from the narrative of each accident report. Each HFACS category was counted a maximum of only once per accident, thus this count acted simply as an indicator of the presence or absence of each of the 18 categories within a given accident. Where there were discrepancies in the categorization of an accident, the raters convened and resolved their observations.

Statistical Analysis: Chi-square (χ^2) analyses of the cross-tabulations to measure the statistical strength of association between the categories in the higher and lower levels of the HFACS were used. As the χ^2 test is a simple test of association these analyses were supplemented with further analyses using Goodman and Kruskal's Tau (**τ**) which was used to calculate the proportional reduction in error (PRE). Tau (**τ**) has the advantage of being a directional statistic. The lower level category of decision error in the HFACS was designated as being dependent upon the categories at the higher levels in the framework, which is congruent with the theoretical assumptions underlying HFACS. The value for Tau (**τ**) indicates the strength of the relationship, with the higher levels in the HFACS being deemed to influence (cause) changes at the lower organizational levels, thus going beyond what may be deemed a simple test of co-occurrence between categories. Furthermore, odds ratios were calculated to provide an estimate of the likelihood of the presence of a contributory factor in one HFACS category being associated concomitantly with the presence of a factor in another category. However, it must be noted that as odds ratios are an asymmetric measure they are only really theoretically meaningful when associated with a non-zero value for Tau. From a theoretical standpoint, lower levels in the HFACS cannot adversely affect higher levels. Finally, the inter-rater reliabilities were assessed using Cohen's Kappa and the percentage rate of agreement to indicate the reliability between raters.

RESULTS

Sample Characteristics

In total, 321 instances of human error, describing the underlying causal factors in the 51 accidents, were recorded using the HFACS framework (Table 1). It must be noted in the following analyses that the percentages quoted refer to the percentage of times that an HFACS category was implicated in the sequence of events leading up to an accident. However, in most instances many more than just a single factor was implicated in an accident sequence, hence the percentages quoted sum to more than 100% across the results section as a whole. 'Decision errors' were involved in 35 of the accidents (68.6%) and was the most frequent category in HFACS framework. Initial results found that acts at the level of 'unsafe acts of operators' (level 1) were involved in 109 (33.9%) instances; the 'preconditions for unsafe acts' level (level 2) was as a causal factor in 81 (25.2%) instances; the 'unsafe supervision' level (level 3) was involved in 74 (23.1%) instances, and the 'organizational influences' level in the HFACS model (level 4) was involved as a factor in 57 (17.7 %) instances.

Inter-rater reliability

Prior to the resolution of discrepancies in coding between the raters, the inter-rater reliabilities, calculated on a category-by-category, basis were assessed using Cohen's Kappa. There were 10 categories where the Kappa value was in excess of 0.40, which is regarded as being acceptable (Landis and Koch, 1977). For the remainder of the categories, though, the Kappa value failed to achieve this level. Below 0.40 is regarded as a poor level of inter-rater reliability. However, Cohen's Kappa has several weaknesses as an index of inter-rater reliability. Low observed frequencies can distort Kappa values, deflating its value where there is actually a very high level of agreement. Cohen's Kappa becomes unreliable when the vast majority of observations fall into just one of the categories and there is also a high percentage of agreement between raters in this category. In such a case Cohen's Kappa will be low as the statistic is based upon expected probabilities calculated from the marginal observed totals. Kappa does not take in account raters' sensitivity and specificity and becomes unreliable when raters' agreement is either very small or very high (Huddlestone, 2003). As a result, inter-rater reliabilities were also calculated as a simple percentage rate of agreement. These showed reliability figures of between 56.9% and 96.1%, indicating acceptable reliability between the raters (Table 1). Decision-error had a Kappa value of 0.52 and a 80.4% percentage rate of agreement for inter-rater reliability.

Table 1 Frequency, Percentage, Rank and Inter-rater Reliabilities of each HFACS category for all 51 accidents between 1999 and 2008.

HFACS Category		**Frequency**	**Percentage**	**Rank**	**Cohen's Kappa**	**Inter-rater Reliability (percentage Agreement)**
Level-4, Organizational Influences	Organizational process	25	49.0	6	.415**	70.6%
	Organizational climate	6	11.8	16	.457**	86.3%
	Resource management	26	51.0	5	.113	56.9%
Level-3, Unsafe Supervision	Supervisory violation	24	47.1	7	.295*	64.7%
	Failed correct a known problem	8	15.7	14	.287*	70.6%
	Planned inappropriate operations	9	17.6	12	.316**	70.6%
	Inadequate supervision	33	64.4	2	.261*	66.7%
Level-2, Preconditions for Unsafe Acts	Technology environment	12	23.5	11	.105	70.6%
	Physical environment	24	47.1	7	.606***	80.4%
	Personal readiness	7	13.7	15	.441***	80.4%
	Crew resource management	24	47.1	7	.499***	74.5%
	Physical/mental limitation	3	5.9	17	.086	80.4%
	Adverse physiological states	2	3.9	18	.480***	96.1%
	Adverse mental states	9	17.6	12	.225	70.6%
Level-1, Unsafe Acts of Operators	Violations	30	58.8	3	.485***	76.5%
	Perceptual errors	14	27.5	10	.549***	78.4%
	Skilled-based errors	30	58.8	3	.493***	76.5%
	Decision errors	**35**	**68.6**	**1**	**.529*****	**80.4%**

* *Note that the percentages in the table will not equal 100%, because in many cases more than one causal factor was associated with the accident*

Indirect Paths of Association between Latent Failures and Active Failures

Analysis of the strength of association between categories at HFACS level-4 'organizational influences' versus level-3 'unsafe supervision' indicated that of a possible 12 relationships, three pairs of associations were significant ($p<0.05$). 'Organizational process' was significantly associated with 'inadequate supervision'; 'planned inappropriate operations'; and 'supervisory violations' at level-3. These statistically significant relationships are summarized in Table 2. There were several tests of association performed between categories at HFACS level-4 and 3 very with high odds ratios, all of which are associated with non-zero values for Tau (τ). Inadequate supervision was over twenty-seven times more likely to occur when there were organizational level issues associated with poor 'organizational process'. The strength of association between categories at level-3 'unsafe supervision' versus level-2 'pre-conditions for unsafe acts' indicated that of a possible 28 relationships, six pairs of associations were significant ($p<0.05$). These were 'inadequate supervision' at level-3 versus 'CRM'; 'adverse mental states'; and 'personal readiness' at level-2; 'planned inappropriate operations' with the 'physical environment' and 'CRM'; and 'supervisory violation' versus 'personal readiness'. Of these comparisons it can be seen that poor 'personal readiness' was over eleven times more likely to occur in the presence of 'inadequate supervision' at the higher level. Similarly, poor CRM was over nine times more likely to occur in the presence of 'inadequate supervision' at the higher level.

Table 2 Significant chi-square test of association ($p<0.05$), associated values for Goodman and Kruskal's Tau (τ) and odds ratio for the analysis of upper level and adjacent downward level categories in the HFACS framework

Significant association between upper level and adjacent downward level categories in the HFACS framework	**Chi-square**		**τ**	**Odds ratio**
	Value	**p**		
HFACS Level 4 association with Level 3 categories				
Organizational process * supervisory violation	15.006	.000	.294	13.630
Organizational process * planned inadequate operations	14.644	.000	.287	26.308
Organizational process * inadequate supervision	22.187	.000	.435	27.067
HFACS Level 3 association with Level 2 categories				
Supervisory violation * personal readiness	4.249	.039	.083	3.850
Planned inadequate operations * physical environment	10.311	.001	.202	7.333
Planned inadequate operations * crew resource management	9.218	.002	.181	9.600
Inadequate supervision * personal readiness	6.800	.009	.133	11.200
Inadequate supervision * crew resource management	9.659	.002	.189	7.071
Inadequate supervision * adverse mental states	4.554	.033	.089	5.520

Direct Path of Association between Upper Categories and Decision errors

Analysis of the strength of the direct association between categories at level-4 (organizational influences); level-3 (unsafe supervision) and level-2 (pre-conditions for unsafe acts) versus 'decision errors' at level-1 (unsafe acts of operators) indicated that of a possible 14 relationships, nine pairs of associations were significant. The following categories, 'organizational process' (level-4); 'inadequate supervision'; 'planned inappropriate operations'; and 'supervisory violations' (level-3); 'adverse mental states'; 'physical/mental limitations'; 'crew resource management'; 'personal readiness'; and 'physical environment' (level-2) were all significantly associated with 'decision errors' at level-1. Of these comparisons it can be seen that 'decision errors' was over fifteen times more likely to occur in the presence of poor 'CRM' practices, over thirteen times more likely to occur in the presence of 'planned inappropriate operations', and over four times more likely to occur in the presence of 'organizational process' (Table 3).

Table 3 Significant chi-square tests of association ($p<0.05$), associated values for Goodman and Kruskal's Tau (**τ**), and odds ratios for the analysis of categories at upper level versus 'decision errors' at level-1 in the HFACS framework

Significant association between categories at upper level versus decision errors	**Chi-square**		**τ**	**Odds ratio**
	Value	**p**		
HFACS Level 4 association with 'decision errors'				
Organizational process * decision error	6.032	.014	.118	4.806
HFACS Level 3 association with 'decision errors'				
Supervisory violation * decision error	3.878	.049	.076	3.669
Planned inadequate operations * decision error	8.328	.004	.163	13.772
Inadequate supervision * decision error	12.602	.000	.247	10.714
HFACS Level 2 association with 'decision errors'				
physical environment * decision error	5.088	.024	.100	4.813
personal readiness * decision error	8.041	.005	.158	NC
crew resource management * decision error	15.826	.000	.310	15.714
Physical and mental limitation * decision error	4.135	.042	.081	NC
adverse mental states * decision error	5.262	.022	.103	8.864

DISCUSSION

The majority of HFACS categories had large enough numbers of instances of occurrence in the data set to allow reasonable confidence in the pattern of results obtained. It can be seen from the data presented in Table 1 that 'decision errors' had the highest percentage (68.6%) of involvement in accidents among 18 categories. The findings are in accord with previous research conducted by Jensen and Benel (1977), Diehl (1991) and Li and Harris (2006 & 2008). All categories also exhibited acceptable levels of inter-rater reliability, as assessed using percentage agreement. These values were as good as (or in excess of) the levels reported in previous studies (e.g. Weigmann and Shappell, 2003; Gaur, 2005; Li and Harris, 2005 & 2008).

Reason (1990, 1997) proposed that latent conditions promoting unsafe acts are inevitably present in all systems. The original decision on how to allocate resources made at the highest levels in the organization may originally have been based on sound commercial arguments but such inequities can create safety problems in other, operational parts of the system. The analyses in this paper clearly show that inadequacies at HFACS level-4 'organizational influences' had associations with further inadequacies at HFACS level-3 'unsafe supervision' (see Table 2 and Figure 1). The category of 'organizational process' is a particularly important factor at this highest organizational level. Poor 'organizational processes' were associated with 'inadequate supervision'; 'planned inappropriate operations'; and 'supervisory violations' at the level of 'unsafe supervision' and hence were ultimately at the root of decision errors resulting in accidents. Both Reason (1990) and Wiegmann and Shappell (2003) hypothesized that inappropriate decision-making by upper-level management can adversely influence the personnel and practices at the supervisory level, which in turn affects the psychological pre-conditions and hence the subsequent actions of the front-line operators. This study provides statistical support for this hypothesized relationship. A similar pattern of results was also found in the analysis of 523 ROC air force accidents previously reported by Li and Harris (2006, 2007). Moreover, this research proposes that not only categories at level-2 have direct influenced on pilots' decision-making, but also categories at HFACS level-4 'organizational influences' and level-3 'unsafe supervision' are directly related to pilots' decision-making at level-1 (Figure 1).

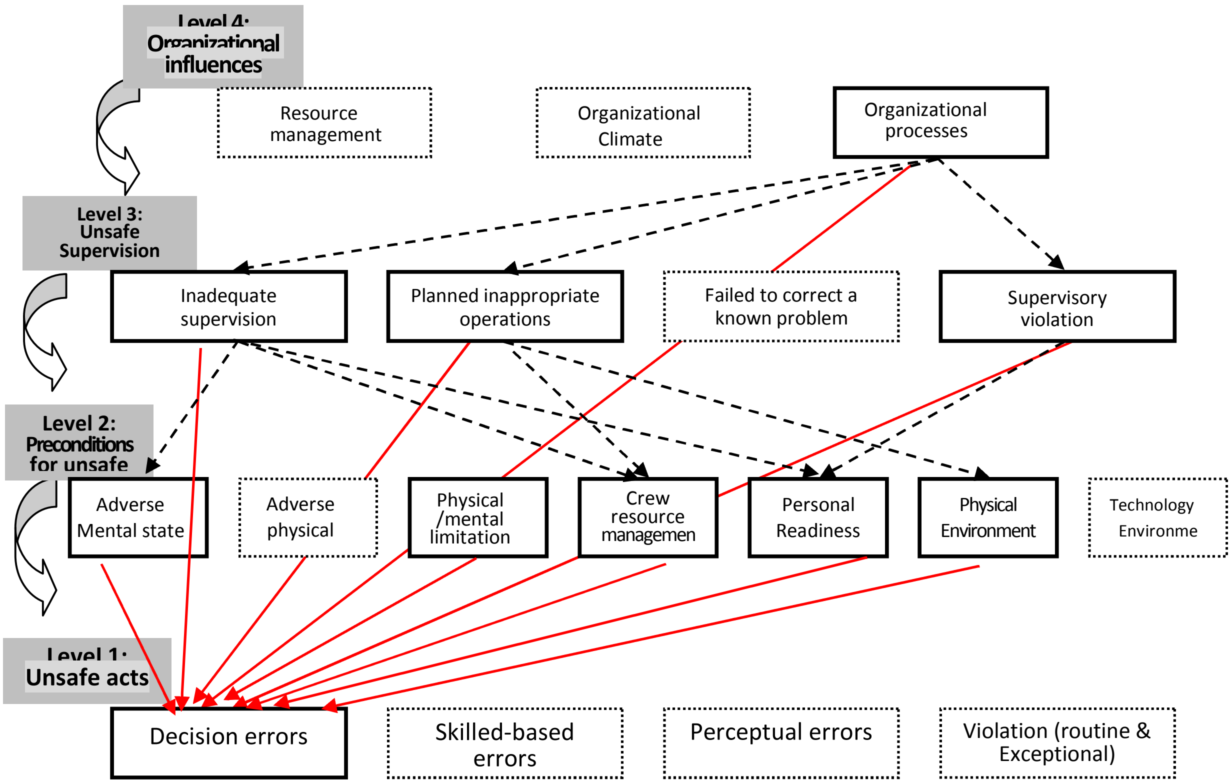

Figure 1 Paths between categories at the four levels in the HFACS framework showing the significant associations with Decision-error using Chi-square ($\chi 2$) and Goodman and Kruskal's Tau ($\boldsymbol{\tau}$) for the data derived from 51 accidents reports by ASC between 1999 and 2008.

Figure 1 reveals that the category of 'organizational process' at level-4 was the key factor in HFACS framework. 'Organizational process' refers to corporate decisions and rules that govern the everyday activities within an organization, including the establishment of standard operating procedures and formal methods for maintaining checks and balances between the workforce and management. Inappropriate 'Organizational process' practices particularly influenced pilots' decision-making at level-1 and 'inadequate supervision'; 'planned inappropriate operations'; and 'supervisory violations' at level-3. The role of supervisors is to provide their personnel with the facilities and capability to succeed and to ensure the job is done safely and efficiently. The category of 'inadequate supervision' refers to a supervisor's failure to provide professional guidance, a failure to provide proper training, failure to track the qualifications, a lack of accountability and loss supervisory situational awareness. 'Planned inappropriate operation' was created as a category to account for failures such as poor crew pairing, a failure to provide adequate briefing time, making assessments where risk outweighed benefit, and excessive workload. 'Supervisory violations' as a category is reserved for those instances when existing rules and regulations are willfully disregarded by supervisors, such as authorizing an unqualified crew for flight, a failure to enforce rules and regulations, violations of procedures, and/or inadequate documentation. Moreover, all of these three categories at level-3 not only have a direct influence on pilots' decision-making, but also have significant associations with the categories of 'adverse mental states'; 'physical/mental limitations'; 'CRM'; 'personal readiness'; and the 'physical environment' at level-2. Finally, all of these five categories at level-2 have a direct relationship with pilots' decision errors. The category of 'adverse mental states' was created to account for mental conditions that affect performance, such as loss of situational awareness, task fixation, distraction and mental fatigue due to stress. 'Physical/mental limitations' refers to those instances when operational requirements exceed the capabilities of the individual at the controls, such as visual limitations, having insufficient reaction time, information overload, incompatible physical capabilities and a lack of aptitude to fly. 'CRM' was created to account for occurrences of poor coordination among personnel, such as coordination between and within the aircraft, as well as with ATC, maintenance, or other support personnel. 'Personal readiness' refers to when individuals fail to prepare physically or mentally for duty. A breakdown in 'personal readiness' includes failures to adhere to crew rest requirements, overexertion when off-duty, self-medicating and inadequate training. 'Physical environment' refers to both the operational environment and the ambient environment, such as weather, altitude, terrain, lighting, vibration and toxins on the flight deck.

Reason (1990) suggested that human behavior is governed by the interplay between psychological and situational factors. The findings from this study show that five categories at level-2 (latent/active failures), 'adverse mental states'; 'physical/mental limitations'; 'crew resource management'; 'personal readiness'; and 'physical environment' had a strong statistical relationships with the active failures of pilots, 'decision errors' at level-1 (see Table 3 & Figure 1). Reason (1990, 1997) has suggested that there is a 'many to one' mapping of the psychological precursors of unsafe acts to the actual errors themselves, making it difficult to predict which actual errors will occur as a result of which preconditions. The results of this study using the HFACS framework support this assertion. There are statistically significant associations between causal factors at the higher organizational levels, psychological contributory factors and ultimately the decision errors made by pilots (see Figure 1). It can even be suggested that poor organizational processes at the highest levels result in poor supervisory oversight, which itself can lead to inappropriate preconditions for unsafe acts, resulting in making inappropriate decisions during flight operations. However, some care needs to be taken when interpreting the statistical relationships presented in Figure 1. In a few categories the frequency counts are moderately small. Furthermore, the frequency counts within categories were all derived from accidents. It is unknown (and unknowable) how often instances within the various HFACS categories have occurred in day-to-day operations that have not resulted in an accident. Thus, the relationships between HFACS levels and categories should not be interpreted outside the accident causal sequence. Nevertheless, the results of this study of civil aviation accidents occurring in the ROC show a remarkable similarity to the study of military accidents conducted in the air force of the same country.

This research shows a strong direct association between categories at level-4 and level-3 to decision errors at level-1. The results of this study show further developments in the theory underpinning HFACS. Wiegmann & Shappell (2003) proposed 'each higher level in framework will directly affect the events in lower level'. This research demonstrates that this relationship extends beyond the immediately adjacent levels in the analytical framework. The causal factors underlying accidents relevant to decision errors may be underestimated or even misunderstood, as there are potentially many accidents caused by inadequate decision making attributed to violations（Li and Harris, 2008. 'Decision making' is a complex cognitive process which is not only affected by physical factors, mental factors, flying conditions and the technical environment, but is also affected by organizational management and supervisory practices. However, 'decision making' is like any other flying skill in that it can be trained to promote flight safety (Jensen & Hunter, 2002; Klein, 1993; Prince & Salas, 1997). Therefore, the question becomes 'how to design the relevant training program' to enhance the quality of pilot's decision making.

CONCLUSIONS

Aeronautical knowledge, skill, and judgment have always been regarded as the three basic faculties that pilots must possess. Judgment has usually been considered to be a trait that good pilots innately possess (Buch & Diehl, 1984) however improved accidents-investigation technology, such as cockpit voice recorders, along with a more systematic review of accident statistics, has produced a growing realization of the significance of pilots' decision errors in aviation mishaps (Diehl, 1991; Li and Harris, 2006, 2007 & 2008). The introduction of new technology has motivated the military and airlines to put greater emphasis on the role of the pilot as a manager and decision maker. Thus, attempts are being made to improve decision skills and to better understand the underlying causes of judgment errors. However, the study of 'decision making' in training programs still remains lacking in relevant research. This study provides an understanding, based upon empirical evidence, of how actions and decisions at higher managerial levels in the operation of commercial aircraft result in decision errors on the flight deck and subsequent accidents. The results show clearly defined, statistically-described paths that relate errors at level-1 (the operational level) with inadequacies at both the immediately adjacent and also higher organizational levels. This research draws a clear picture that supports Reason's (1990) model of active failures resulting from latent conditions in the organization. To reduce the accident rate resulting from decision errors these 'paths to failure' must be addressed.

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REFERENCES

Buch, G. and Diehl, A. (1984), 'An Investigation of the Effectiveness of Pilot Judgment Training', *Human Factors*, Vol. 26 (5), p. 557-564.

Dekker, S. (2001), 'The Re-invention of Human Error', *Human Factors and Aerospace Safety,* Vol. 1 (3), p. 247-266.

Diehl, A. (1991), 'The Effectiveness of Training Programs for Preventing Aircrew Error', in Jensen, R.S. (Editor), *Sixth International Symposium on Aviation Psychology,* Vol. 2, Columbus, Ohio, U.S.A., The Ohio State University , p. 640-655.

Endsley, M.R. (1997), 'The Role of Situation Awareness in Naturalistic Decision Making', in Zsambok, C.E. and Klein, G. (Editor), *Naturalistic Decision Making*, Lawrence Erlbaum, Mahwah, p. 269-284.

Endsley, M.R. (1993), 'A survey of Situation Awareness Requirements in Air-to-Air Combat Fighters', *The International Journal of Aviation Psychology,* Vol. 3 (2), p. 157-168.

Endsley, M.R. and Bolstad, C.A. (1994), 'Individual Differences in Pilot Situation Awareness', *The International Journal of Aviation Psychology,* Vol. 4, (3), p. 241-264.

Federal Aviation Administration (1991), *Aeronautical Decision-making*, Report no. Advisory Circular 60-22, US Department of Transport, Washington.

Fischer, U., Orasanu, J., and Wich, M. (1995), 'Expert Pilots' Perceptions of Problem Situations', in Jensen, R.S. and Rakovan, L.A. (Editor), *Eighth International Symposium on Aviation Psychology,* Vol. 2, Columbus, Ohio, U.S.A., The Ohio State University, p. 777-782.

Gaur, D. (2005), '*Human* Factors Analysis and Classification System Applied to Civil Aircraft Accidents in India', *Aviation, Space, and Environmental Medicine*, Vol.76 (5), p.501-505.

Huddlestone, J.A. (2003), *An Evaluation of the Training Effectiveness of a Low-Fidelity, Multi-Player Simulator for Air Combat Training* Cranfield University, England .

Hunter, D.R. (2003), 'Measuring General Aviation Pilot Judgment Using a Situational Judgment Technique', *The International Journal of Aviation Psychology,* Vol. 13 (4), p. 373-386.

Janis, I.L. and Mann, L. (1977), *Decision making: A Psychological Analysis of Conflict, Choice, and Commitment*, Free Press, New York.

Jensen, R. and Benel, R. (1977), *Judgment Evaluation and Instruction in Civil Pilot Training*, Federal Aviation Administration, Washington, D.C.

Jensen, R. and Hunter, D. (2002), *General Aviation Aeronautical Decision-making*, FAA, Washington, D.C.

Jensen, R.S. (1997), 'The Boundaries of Aviation Psychology, Human Factors, Aeronautical Decision Making, Situation Awareness, and Crew Resource Management', *The International Journal of Aviation Psychology,* Vol. 7 (4), p. 259-268.

Jensen, R.S., Guilke, J. and Tigner, R. (1997), 'Understanding Expert Aviator Judgment', in Flin, R., Salas, E., Strub, M., and Martin, L. (Editor), *Decision Making Under Stress: Emerging Themes and Applications*, Ashgate, Aldershot, England, pp. 233-242.

Kaempf, G.L. and Orasanu, J. (1997), 'Current and Future Applications of Naturalistic Decision Making', in Zsambok, C.E. and Klein, G. (Editor), *Naturalistic Decision Making*, Lawrence Erlbaum, Mahwah, p. 81-90.

Klein, G.A. (1993), 'A Recognition-Primed Decision (RPD) Model of Rapid Decision Making', in Klein, G.A., Orasanu, J., Calderwood, R., and Zsambok, C.E. (Editor), *Decision Making in Action: Models and Methods*, Ablex, Norwood, New Jersey, p. 138-147.

Landis, J.R. and Koch, G.G. (1977). ‘The Measurement of Observer Agreement for Categorical Data’, Biometrics, 33, p. 159-174.

Larkin, J., McDermott, J., Simon, D.P. and Simon, H.A. (1980). Expert and Novice Performance in Solving Physics Problems. *Science* 20, p. 1335-1342.

Li, W-C. and Harris, D. (2008), ‘The Evaluation of the Effect of a short Aeronautical Decision-making Training Program for Military Pilots’, *International Journal of Aviation Psychology*, Vol. 18 (2), p.135-152.

Li, W-C. , Harris, D. and Chen, A. (2007), ‘Eastern Minds in Western Cockpits: Meta-analysis of human factors in mishaps from three nations’, *Aviation Space and Environmental Medicine,* Vol. 78 (4), p.420-425

Li, W-C. and Harris, D. (2006), ‘Pilot error and its relationship with higher organizational levels: HFACS analysis of 523 accidents’, *Aviation Space Environmental Medicine,* Vol. 77 (10), p.1056-1061.

Li, W-C. and Harris, D. (2005), ‘Aeronautical Decision-Making: Instructor-Pilot Evaluation of Five Mnemonic Methods’, *Aviation Space Environmental Medicine,* Vol. 76 (12), p. 1156-1161.

Maurino, D.E., Reason, J., Johnston, N., and Lee, R.B. (1995), *Beyond Aviation Human Factors*, Ashgate Publishing, England.

Mosier, K.L., Skitka, L.J., Heers, S. and Burdick, M. (1998), Automation Bias: Decision Making and Performance in High-Tech Cockpits. *The International Journal of Aviation Psychology*, **8**, p. 47-63.

Noble, D. (1993), ‘A Model to Support Development of Situation Assessment Aids’, in Klein, G.A., Orasanu, J., Calderwood, R., and Zsambok, C.E. (Editor), *Decision Making in Action: Models and Methods*, Ablex, Norwood, New Jersey, p. 287-305.

O’Hare, D. (2003), ‘Aeronautical Decision Making: Metaphors, Models, and Methods’, in Tsang, P.S. and Vidulich, M.A. (Editor), *Principles and Practice of Aviation Psychology: Human Factors in Transportation*, Lawrence Erlbaum, New Jersey, p. 201-237.

Orasanu, J. and Connolly, T. (1993), ‘The Reinvention of Decision Making’, in Klein, G.A., Orasanu, J., Calderwood, R., and Zsambok, C.E. (Editor), *Decision Making in Action: Models and Methods*, Ablex, Norwood, New Jersey, p. 3-20.

Orasanu, J. and Fischer, U. (1997), ‘Finding Decisions in Natural Environments: The View From the Cockpit’, in Zsambok, C.E. and Klein, G. (Editor), *Naturalistic Decision Making*, Lawrence Erlbaum, Mahwah, p.343-358.

Parasuraman, R. and Riley, V. (1997), ‘Humans and automation: use, misuse, disuse, abuse ‘, *Human Factors,* Vol. 39, p.230-253.

Payne, J.W., Bettman, J.R. and Johnson, E.J. (1988), ‘Adaptive Strategy Selection in Decision-making’, *Journal of Experimental Psychology: Learning, Memory and Cognition,* Vol. 14, p. 534-552.

Prince, C. and Salas, E. (1997), ‘Situation Assessment for Routine Flight and Decision Making’, *International Journal of Cognitive Ergonomics,* Vol. 1 (4), p. 315-324.

Prince, C. and Salas E. (1993), ‘Training and Research for Teamwork in the Military Aircrew’, in Wiener, E.L., Kanki, B.G., and Helmreich, R.L. (Editor), *Cockpit Resource Management*, Academic Press, San Diego,

Reason, J. (1990), *Human Error*, Cambridge University, New York.

Reason, J. (1997), *Managing the Risks of Organizational Accidents*, Ashgate, Aldershot, England.

Shappell, S.A., Wiegmann, D.A. (2001). Applying Reason: the Human Factors Analysis and Classification System (HFACS). *Human Factors and Aerospace Safety 1,* 59-86.

Shappell, S.A. and Wiegmann, D.A. (2004), 'HFACS Analysis of Military and Civilian Aviation Accidents: A North American Comparison', *International Society of Air Safety Investigators*, Australia, Queensland, p. 2-8.

Wiegmann, D.A. and Shappell, S.A. (2003), *A Human Error Approach to Aviation Accident Analysis: The Human Factors Analysis and Classification System*, Ashgate, Aldershot, England.

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