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**ERROR AND THREAT DETECTION: A REVIEW AND EVALUATION OF CURRENT LITERATURE**

Christina Frederick-Recascino and Michael Gosiewski

**ABSTRACT**

The present project provides a comprehensive review of the literature related to threat and error detection. Although there are current models for understanding the concepts of error and threat, little is known about how individuals detect errors and threats when they occur. Awareness of error and threat is crucial for advancement of safety in the aviation domain. Four areas were discussed related to error and threat detection. First, the general error and threat detection literature was reviewed. Second, the physiological foundations for error and threat detection were discussed. Third, the paper examined cognitive aspects of error and threat detection. Last, the paper elaborated on the role emotion may play in threat detection. The review concludes with suggestions for error and threat management and courses of action that can be taken within the aviation domain to train individuals in error and threat detection.

A primary goal of aviation is to ensure passenger safety. One means by which safety has been enhanced is through the use of the Line Oriented Safety Audit (LOSA). LOSA is a fundamentally new process that monitors cockpit behavior of pilots and identifies those actions that are made in error (Maurino, 2002). LOSA deviates from traditional CRM or flight checks in that it is assumed that error can and does occur in the cockpit on a daily basis. Most errors are minute and therefore unimportant to the overall safety of the flight. However, a combination of small errors may occur causing a more serious safety incident. Currently the LOSA system of error observation and review has been tested in a small number of different airlines and the procedure continues to develop. In order for the LOSA system to progress and its use become more widespread, it is important to have a complete understanding of the process by which errors and threats in the cockpit can be detected and dealt with in order to ensure flight safety. The present paper addresses the topic of error and threat detection. It will focus attention on the process by which detection occurs, incorporating knowledge from cognitive psychology and physiological psychology.

***Definitions of Threat and Error***

A great deal of attention has been paid to creation of a taxonomy for understanding error. Dorner & Sachaub (1994) and Wehner & Stadler (1994) argue that human error is an innate part of the human cognitive system. Dorner and

Schaub link error to flaws in information processing that include the tendency for humans to forget information, our fear of being viewed as incompetence, and our inability to manage all the facets of complex systems in a dynamic environment. Wehner & Stadler attribute human error to fundamental flaws and biases in human perceptual processing, as articulated through Gestalt theories of processing. Using a more social-cognitive framework, Kroll & Ford (1992) link human error to failures in motivation.

Although the underlying causes of human error may be diverse, Maurino, Reason, Johnson & Lee (2002) present a comprehensive system for classifying errors using the concepts of slips, lapses and mistakes. First, their model indicates that all errors are unintentional, however they occur for different reasons in different situations. Slips are inappropriate actions taken during times when the actor is engaged in well-practiced, well-learned tasks. Slips can be based in lack of attention, a failure of memory, or a misinterpretation of perceptual information. An example of a slip is when a pilot accustomed to landing on a specific runway during a familiar flight, fails to land on a different runway even when clear air traffic commands have directed him to the new runway. Lapses, on the other hand, occur when the actor fails to perform a necessary action. An example of a lapse may be when one is baking a cake and forgets to put sugar in the recipe, or omits a necessary action from a pre-flight checklist.

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Maurino et al. (1995) also consider the case of mistakes. Although the errors they may create are unintentional, mistakes involve intentional actions. Mistakes occur when, through lack of knowledge or understanding, the actor chooses the wrong course of action or applies the wrong rules to solve a problem. For example, a pilot may respond to a cockpit alarm by performing the wrong checklist, even though he/she believes it to be correct.

Dorner & Schaub (1994) used Reason's (1990) model of understanding error and applied it to mistakes made in complex domains. Dorner & Schaub argue that there are six different components of the action regulation system and that mistakes can and do occur in each phase of the process. The first step in the system is goal regulation. Errors made at this level of the system involve either a lack of attention paid to initial goal elaboration, or an inability to recognize competing goals within the system and one's inability to reconcile all potential system needs. The second step in the action regulation system involves the collection of information and creation of hypotheses used to help define future behavior and decision-making. In the second step of action regulation, what Dorner and Schaub refer to as "channeling errors" are likely to occur. This type of error is defined by the inability to develop a complete and accurate decision-making model, exacerbated by the human confirmatory bias, whereby we focus on information that confirms what we already know or believe.

The third stage in action regulation is prognoses, in which we are asked to extrapolate our actions into the future, basing this projection on past and current occurrences. Dorner and Schaub indicate that humans are poor prognosticators due to our limited memory abilities. We often forget the past and can not use it to accurately judge the future. When change is not linear or occurs quickly, our relatively poor prediction abilities decline even further. The fourth step in action regulation is planning for action. In complex systems we use the information we have in memory to determine which actions need to occur. Mistakes made at this step in the process often involve the inability to recognize the side effects or long term consequences of our actions. In complex systems this is a grave concern. An action taken early on in a situation may cause unforeseen consequences hours or days later. These potential consequences lead to the fifth step in the action regulation system, namely monitoring the effects of our actions. In complex systems, the direct and indirect consequences of actions may occur days, weeks, months or years later. This delay creates a "deadtime" that needs to be monitored. Humans, however have limited attention spans

and often just forget to monitor the system for longterm effects. Last, at the end of Dorner and Schaub's (1994), regulation cycle, humans optimally engage in intensive self-reflection about their actions. However, again humans often neglect to critically examine their decisions and actions due to fear of repercussions or the desire to avoid feeling incompetent. However, a lack of self-reflection leads to fostering further incompetence in the future.

Sarter and Alexander (2000) used the Maurino et al. framework to analyze aviation-based errors as compiled using Aviation Safety Reporting System (ASRS) incident reports. Of the 245 ASRS incidents that were examined in the study, 20.1% were classified as slips, 41.4% were lapses and 38.5% were mistakes. The most frequently occurring aviation errors tended to be altitude deviations (35.9%), heading or course deviations (32.2%) and runway incursions (10.2%).

In contrast to errors, threats imply recognizable hazards that are perceived as serious and must be ameliorated effectively and swiftly (Kinney, 1996). Furthermore, threats can be classified as either direct or conditional. Direct threats are threats that are clearly defined and whose consequences are known. For example, loss of hydraulic power is a direct threat to the safety of the flight. Conditional threats are those which involve a set or series of actions and whose consequences are only determined by that set of actions. Conditional threats include "if" statements, such as "if I lose the right engine, then there will be a threat to passenger safety." When the conditional action does not occur, the threat ceases to exist.

Errors and threats exist in relationship to one another. While errors may be small, undetected, isolated incidents that may or may not affect the overall health of a flight, Reason (1990) and Maurino, et al. (1995) provide a framework for understanding how errors may evolve into threats. It is proposed that errors can accumulate under local working conditions, at the same time existing defenses and safeguards may break down or fail. When these two conditions occur, an accident trajectory is created, which can culminate in a critical safety incident. While errors alone may not create accidents or unsafe conditions, the accumulation of errors can create dangerous situations. The awareness of this fact and the recognition of the need for immediate action can be labeled as a threat.

### **Threat and Error Detection**

Regardless of what we know about the classification of errors and how they combine to create a threatening event, much less is known about the detection of errors and threats. Sellen (1994) defines error detection as

“knowing (either consciously or subconsciously) that an error has occurred” (p. 476). Following detection the actor may also engage in error identification and error recovery. For the purposes of this paper, we will concentrate on the identification process. In addition to elaborating on the error identification process, we will focus on the concept of threat detection. Threat detection differs from simple error detection in that threat detection is associated with a negative emotional valence and in some cases with potentially disastrous consequences (Kinney, 1996).

The detection of errors and threats is crucial to aviation safety. As mentioned earlier, errors are believed to occur in all cockpit operations. It is only when errors multiply, are recognized, and are determined to be a threat to safety that a serious problem results. Although conceptualization of error has a fairly lengthy literature associated with it, the error detection literature is less articulated and is quite complex. A general overview of this process will follow with detailed analysis of the physiological, emotional and cognitive elements included in later sections of the paper.

A general view of error detection. How and when do humans detect errors in their actions? Error detection is a complex phenomenon requiring that the information processing, emotional processing and physiological systems of humans work together to detect errors that have escalated to a level of threat in the environment. In general, however, some simple conclusions can be drawn about error detection based on prior literature. First, it appears that error detection is contingent upon level of expertise and development of domain-specific declarative knowledge (Blandin & Proteau, 2000; Ohlsson, 1996). Thus the more expertise one has, the more likely one is to recognize that an error has occurred. This would also imply that over time, with domain-specific experience and practice, most individuals would become more skilled at error detection and recovery. Dorner & Schaub (1994) support this conclusion and state that the best way to detect errors is through training in which individuals develop knowledge by being confronted with any errors they have committed. LOSA is an example of a review and training program that utilizes this premise. Second, there is evidence that motivation plays a role in error detection (Kroll & Ford, 1992). Individuals with high task-orientation, a motivational state in which task engagement is strong, do better at recognizing errors than individuals with a more ego-based orientation. An ego orientation is reflective of a motivational style that is competitive and outcome-oriented, rather than the process-based task orientation.

A limited amount of research has examined

general error detection processing. Sellen (1994) examined detection of everyday errors in a sample of 75 individuals. In Sellen’s study, participants kept daily diaries participants that detailed their errors and how they became aware of them. Sellen was able to create a framework for classifying error detection. In action-based detection, errors are caught due to the perceptual system detecting the error. In most cases the visual system perceives (sees) the error, but detection can also be auditory, or proprioceptive. In aviation, alarms and warning lights alert the pilot to the error and it is detected. In outcome-based detection, errors are detected based on the undesired or unanticipated consequence of the action. Outcome-based detection is the most frequently occurring form of detection. In aviation, it may not be until a runway incursion has occurred that the initial error in flight operations has been detected. The third form of detection is referred to as limiting function detection. In the case of limiting function detection, errors are caught because the error has created a situation in the physical environment in which further action is not possible. In low altitude, high speed flight, free time is very limited. An error may create a CFIT accident. Due to limited free time, avoidance of the accident is impossible. Last, errors can be undetected. Sellen defines undetected errors as those that are detected, but by someone other than the actor. This is the second most prevalent form of error detection. In aviation, an error may be detected by a member of the flight crew other than the pilot, or by ATC. Overall, Sellen (1994) provides a fundamental framework for categorizing error detection, based upon actual empirical information.

In a similar vein, Sarter and Alexander (2000) also examined how errors were detected in the aviation domain. In a majority of the cases, the error was not caught by the aircrew or by the individual committing the error, but rather by ATC (52.7%). In the 43% of cases where the error was detected by a crew member, a majority of the time the error was detected by the person who committed the error. Results of this study underlie the need to study error detection further. Specifically, in the aviation domain, error detection needs to be studied as it relates to group action, and how it occurs in complex and dynamic environments.

The remainder of this paper will explore threat and error detection in much greater detail, focusing on physiological, emotional and cognitive elements associated with the process of detection. This project is meant to be a blueprint for understanding the process of error and threat detection, providing researchers with potential avenues for future inquiry.

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### ***Physiological and Emotional Correlates of Threat Detection***

Threat detection can be broken down into three fundamental modules, physiology, emotion, and cognition. Although each one has their own separate processes, they are all linked through the structures in the brain. Physiological psychologists describe human cognition using a network model. Knowledge structures are stored in memory as nodes that are linked to each other based on strong associations. When certain memories are triggered, other memories that are strongly associated with the original memory may also be triggered. In threat detection, emotion strengthens the associations. Events or objects are perceived as more threatening if they are associated with negative emotions. The neural networks that tie emotion into cognition include a direct connection to the brain's primary motivational systems (Lang, Davis, & Ohman, 2000). These motivational systems are driven by appetitive (positive) and adverse (negative) stimuli. Adverse stimuli trigger fear within the brain's defense mechanisms that help identify the stimuli as threatening. It has been found that functional activation in the occipital cortex was more extensive when the arousal stimuli included such things as scenes of violent deaths, threats, and erotica (Bradley, Sabatinelli, Lang, Fitzsimmons, King, & Desai, 2003). This shows that arousing stimuli create a longer activation of the visual or occipital cortex, which in turn creates a motivated attention toward the threat, and facilitates the processing of the adverse stimuli (Bradley, Sabatinelli, Lang, Fitzsimmons, King, & Desai, 2003).

The term "fight or flight" has been used to describe the physiological and psychological response to a threat that is automatic and involuntary (Ratey, 2001). During "fight or flight", the brain stem will release increased quantities of norepinephrine, which in turn causes the adrenal glands to release more adrenaline. An increase in adrenaline causes faster heart rate, pulse rate, and respiration rate. There is also, shunting of the blood to more vital areas, and release of blood sugar, lactic acid and other chemicals, all of which are involved in readying one for fighting the danger, or running away from the threat. Feelings of dread, fear, impending doom, are also common. Threat triggers various physiological reactions that help us cope with a dangerous situation. These reactions give humans the change to fight or escape.

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In contrast to threat detection, error detection is much more cognitively influenced and is more associated with the monitoring systems of the brain. These monitoring systems compare correct performance and the current performance at the same time causing a negative event related potential (ERP) 80ms after the response (Ullsperger, Yves von Cramen, & Muller, 2002). The anterior cingulate cortex (ACC), which is associated with attentional and cognitive control has been shown to be activated during error detection (Van Veen, Cohen, Botvinick, Stenger, & Carter, 2001). Van Veen, et al. found that the ACC "contributes to executive functions through the detection of conflicts occurring at later or response-related levels of processing" (pg. 1302). The lateral prefrontal cortex has also been shown to assist in responding to conflicts and interference and helping the ACC with performance monitoring.

Future studies may help to link threat and error detection through the biological makeup of the brain. Error detection utilizes the monitoring systems of the brain to compare current situations and the correct actions to detect a possible negative consequence. These errors create negative even related potentials in the cingulated motor area of the anterior cingulated cortex. The monitoring system is spread out between the anterior cingulated cortex, and the lateral prefrontal cortex.

A review of physiological functioning indicates that the brain is a very complex structure housing cognition, behavior and emotions. Our bodies can react to a threat without being consciously aware of the stimulus, while at the same time, the brain's cognitive structures can be activated in order to take the correct action to alleviate the threat. Reactions to threat, such as affect, startle, and freezing, help to imbed the memory of the event into a linked network to assist in future threat detection. Emotion creates a motivated attention that stimulates the sensory regions of the brain, which in turn increases the organism's fine tune scanning abilities. Most research identifies the difference between threat and error detection through the presence or absence of emotion. Emotion and motivated attention are more highly associated with threat detection than with error detection. In contrast, error detection occurs primarily in the cortical areas of brain. Areas of brain activation associated with threat and error detection are presented in Figure 1.

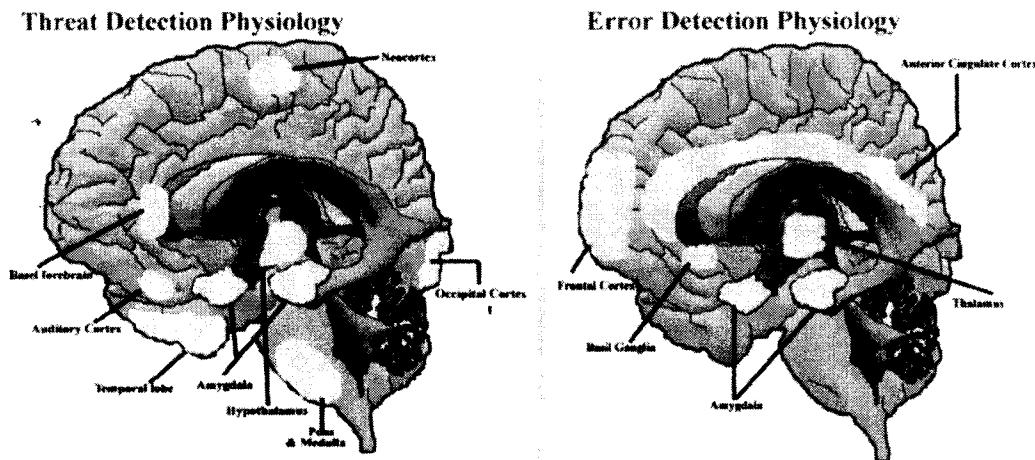


Figure 1.  
Brain activation associated with threat detection and error detection.

### *Cognitive Aspects of Error and Threat Detection*

It should be noted that much of the following section discusses cognitive aspects of threat detection, rather than error detection. This is due to the fact that little research has focused on error detection, while attending to and acting on threats has been a priority of many aviation researchers. In the works described, error is often assumed to be a precursor of threat, such that a focus on error is one of reduction or elimination, rather than simple detection.

Tomaka, Kibler, Blascovich & Ernst (1997) categorize appraisal of a situation as critical in determining its threat level. Furthermore they divide the appraisal process into two components, threat and challenge. Tomaka et al. believe that when a situation is perceived as falling within the person's resources, the task is labeled as challenging. When the task exceeds the personal resources, it becomes a threat. This interpretive bias reflects the importance of the availability of cues that help humans determine if a situation should be label a threat or a challenge.

Warnings are important aids to facilitate appraisal of a situation. Frequently, warnings are added into user interfaces to help improve usability, increase efficiency and lower attentional demand. However, low attentional demands create sensory adaptations and individuals cease to respond to non-valid warnings if the frequency of their occurrence is high. This is called the cry-wolf effect (Maltz and Meyer, 2001). The probability that a warning will actually predict that danger will occur is called the positive

predictive value (PPV). Research on warnings tends to follow the ideas of signal detection theory. Signal detection theory involves determining the threshold of a person's ability to detect the correct stimulus from background noise. Researchers look at the hits, misses, and false alarms of the participants and determine at what level individuals go beyond optimal appraisal and responding, and begin making errors.

Rozelle and Baxter (1975) also showed that appraisal of potentially threatening situations can be also based on the integration of contextual cues and dispositional traits of the individuals involved. This research found that police officers used contextual cues to infer the presence of danger to a greater extent than dispositional cues. However, this tendency was reversed for situations in which the situation indicated that the potential for danger was low. Experience of the officer also correlated with decision-making. Experienced police officers were more likely to use integrative decision-making focused on both contextual determinants of behavior and enduring personality traits of the target individual. Less experienced police officers made appraisals based primarily on personality or perceived dispositional characteristics of the target.

Situation awareness, and threat. Perhaps the most valuable way to explain the role of cognition in threat and error detection is through the idea of situation awareness. Situation awareness (SA) has become a buzzword in recent time and has been used in all sorts of domains. Its prime use has been in aviation. In order to measure situation

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awareness, it needs to be broken down into fundamental principles and problems. Endsley (1995) defines situation awareness as the "perception of the stimuli of the environment within a volume of time and space, the comprehension of their meaning, and the projection of their behavior in the near future (pg. 36)." This means that pilots first has to perceive the stimuli around them using their senses, then comprehend their meaning, significance, or danger, and finally predict how the stimuli will react. Each of these processes need to be improved in order to enhance situation awareness.

This definition of SA does not represent all of the individual's knowledge but just of that of the dynamic environment (Endsley, 1995). Environmental features are initially processed in parallel through pre-attentive sensory stores in which certain properties are detected. These properties include spatial proximity, color, simple shapes, and movement. The objects that stand out the most will be further processed using focalized attention, reflecting the importance of cue salience. Attention is a major element in perceiving and processing cues for threat detection and response. In complex and dynamic environments, information overload and multiple tasks can put a strain on a person's attention capabilities.

Errors in SA during action selection can degrade the decision making process (Endsley, 1995). SA involves using mental models, prior knowledge, schemas, and reasoning in making decisions. Acquiring and maintaining the attentional and conceptual processes that facilitate SA involves significant cognitive resources. Acquiring and maintaining SA should be thought of as an integral part of an individual's workload and repertoire.

SA is broken up into the process and the product. "The product refers to the state of awareness in terms of information and knowledge, while the process refers to the various perceptual and cognitive activities involved in constructing updating and revising the state of awareness (Adams, Teney, & Pew, 1995, pg. 88)". Although both are individually important, they can't work without each other. If environmental cues are ignored (process) it could be that these cues were not part of awareness (product).

It is very important to have some sort of knowledge base of the situation when detecting a threat. This knowledge is organized in the form of a mental model or a schema to help anticipate information and is stored in long-term memory. A mental model is a cognitive framework cognitively designed by a person to generate explanations of a situations or systems purpose and function. It is this mental model that allows an individual to help make predictions about how the environment will react (Smith, and Hancock, 1995). The ability to think ahead is a very important part of situational awareness in aviation and threat detection in general (Adams, Teney, & Pew, 1995). Problems in threat detection can then arise when the

environment defies critical cognitive functions such as activation of mental models, and may include situations where critical information is not available, it takes too long to execute a task or attention is directed elsewhere. If an individual fails to develop a mental model for a particular situation, then he/she will fail to detect the threat even though the situation may be familiar (Endsley, 1995).

**Workload and threat.** Within aviation, pilots are required to attend to many knowledge intensive and procedurally complex tasks all at one time. This limits the attention that can be devoted to scan for threats. These multitasking demands can cause pilots to initiate errors because of the high task load and cognitive demands on memory. In a study done by Jones and Endsley (1996), it was found that high cognitive workload caused 30% off all situation awareness errors and 35% of those people couldn't pick out threat cues that were clearly present. In a research example, Gugerty (1997) tested driver's knowledge of surrounding cars with direct recall and indirect performance measures. They found that a driver's knowledge of nearby cars is largely explicit and not implicit, meaning that they know where the cars are through experience and active rehearsal, and not through untraceable knowledge. When there were too many cars to track, the drivers used cues to focus on cars that might have been a threat. Gugerty also found that drivers remembered the location of hazardous cars better when they were driving than when they were in the passenger seat.

One factor that alleviates the negative effects of high workload is experience (Adams, Tenney, & Pew, 1995). With greater expertise one is better able to direct attention to threat cues that are important. Expertise facilitates decision-making and developing accurate expectations about future events. As a result of enhanced cognitive processing, expertise in a situation can help to reduce workload and make an individual better prepared to accurately detect and assess threat. It has been shown that experts have highly developed management and planning skills that help them perform efficiently (Adams, Tenney, & Pew, 1995). In aviation, expert pilots would then use experience and procedural knowledge in their judgments, while avoiding the use of less reliable heuristics to determine level of threat and plan present and future behaviors.

**Threat detection and spatial awareness.** The efficiency of one's spatial awareness is also important in determining a threat. Pilots, astronauts, and submariners possibly have the most spatially tasking jobs in the world. Each profession has to move a craft in a three dimensional space that is filled with hazards. Besides maintaining the orientation of the craft, the pilots must navigate the vehicle to the proper waypoints (Wickens, 2002). Spatial awareness needs to be heightened in order to make the environmental cues used for threat detection more accessible to the pilot.

Wickens (2002) describes three issues in display design for spatial awareness. The "frame of reference" issue concerns whether information should be presented from the pilot's frame of reference (egocentric) or from a world view (exocentric). These are usually termed inside-out and outside-in respectively. An inside-out display involves the craft moving on a stationary world. An outside-in display involved a stationary craft with the world moving around it. Wickens (2002) argues that the type of display should depend on the task and the user. Egocentric views are good for flight control and tracking. Exocentric views are good for threat detection. These exocentric displays are usually depicting the airplane from behind and above. The second issue (degree of integration) is concerned with whether it is better to use a 3D display of motion or a 2D display of motion. 3D motion creates an ambiguity to locating the objects in space and 2D motion creates more attentional demands and cognitive loads on the individual. The third issue (prediction) is important to be able to determine what will happen in the future. Displays should help the pilot cope with lag time and be useful in controlling the craft. The display needs to show where the craft will be in a certain amount of time or after an input. Current technology on this issue is limited because many factors predict what will happen to the craft. A display that channels attention to the forward flight path inhibits attention to surrounding threats, even if they are displayed elsewhere in the cockpit. This means in addition to a good display the pilot needs to have good task management skills, allocate attention to sources of information for performance, and anticipate unexpected events in the environment.

#### ***Threat and Error Management***

While detecting threats and errors is extremely important, action still needs to follow detection. Knowing how to manage a threat and/or error is very important in creating effective cockpit operations and eliminating fatal accidents. While error doesn't create an outburst of emotion, threat is driven by emotion. Threats create an increase in anxiety and arousal. Learning how to cope with threat is important in helping to decrease anxiety, and stress, while increasing performance. William Glasser (1989) developed a theory called choice theory in which he believed that the only behavior that can be controlled is one's own. We always have choice or control over our own lives and behaviors. This concept is key to controlling threats. Solomon, Holmes, & McCaul (1980) found that when participants exercised control over a threat it reduced anxiety. This was found only when the control was easy to execute. In fact, just knowing that they may be able to control the threat decreased participants' anxiety levels while anticipating the threat. The problem is that difficult methods of control actually create more anxiety.

In aviation, crew resource management (CRM) can be thought of as an error management or error

countermeasure system. CRM helps avoid, trap, and reduce the consequences of errors, thus also eliminating the need for threat detection (Helmreich, Merritt, & Wilhelm, (1999). Errors can be reduced by creating proper checklists, fostering active communication and monitoring skills, and understanding the sources of the error. CRM can help convince the crew that errors are unavoidable, but by understanding human cognition and limitations, errors can be reduced. CRM can effectively teach the crew how to cope with stress, which in turn allows them to deal with threats. CRM has been developed into advanced qualification programs (AQP) that are designed by each airline to meet their standards and regulations. In AQP programs, training is presented in realistic environments to put flightcrews in realistic situations with simulated stressors, and the potential for errors and threat detection to occur.

#### **DISCUSSION**

It is clear from the review of the literature that threat and error detection is a complex process involving cognitive, physiological and emotional components. Figure 1 provides a flow chart with topic linkages related to error and threat detection. However complex, certain conclusions can be drawn from this literature and recommendations can be made about optimizing threat and error detection in aviation.

First, it is evident that humans are not very good at detecting error (Sellen, 1994), especially errors that are small and have no immediate effects on the working environment. When an error is detected, it is often recognized by someone other than the individual initiating the error. In aviation, air traffic control is the most frequent detector of errors, following by the individual committing the error and his/her crew members (Sarter & Alexander, 2000).

Second, we know that error and threat detection comprise two different processes. Error detection occurs primarily in the cortical centers of the brain, while threat detection involves the limbic and reticular activating systems, indicating a large emotional component in that process. Error detection requires cognitive attention and focused awareness of the operator. When errors accumulate or the situation becomes more unsafe, as in the case of catastrophic safety problems, the threat detection system takes over and creates immediate awareness. Unfortunately, the emotional component of threat detection necessary for immediate physical activation also carries inherent faults in that over-arousal in humans is associated with impaired performance and cognitive judgment.

Aviation has always been concerned with increasing safety. To that end, many systems have been automated with built-in protections that alert users to potential threats and errors. Some of these systems even provide solutions to identified threats. However, it will be



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many years, if ever, that the human will be completely taken out of the cockpit. Until that time, aviation researchers and practitioners also need to consider ways to enhance human error and threat detection in aviation environments. Given known limitations of human error and threat detection systems, what suggestions can be made to enhance error and threat awareness in aviation?

The first recommendation that can be made is to create an error awareness culture that diffuses responsibility for error detection and reporting across the entire work team or aircrew. Research has shown that error detection often does not come from the operator, but from a fellow crew member or air traffic control. Error detection then becomes everyone's business. Reporting the small errors that are inevitable in aviation operations, as indicated via the LOSA system, must be mandatory and result not in punishment, but in a show of support for safe crew operations.

Second, aircrews must engage in extensive and ongoing training for increases in expertise. The literature is clear that domain experts are better able to recognize error, and they do so sooner than novices or trained novices. Not only are they better at recognizing errors, they are better able to respond to and cope with threatening situations incurred by the errors. Therefore, employing pilots and crewmembers with higher levels of expertise is important. Norman (1998) estimates that expertise does not occur until an individual has 5,000 hours or 10 years of domain-specific experience. This is not a small amount of time or effort. If this is the case, continued training of new pilots and flight attendants is crucial to bring those crewmembers to a level of expertise more quickly. LOSA actually should contribute to the training process and development of expertise. The safety audits done in LOSA should make aircrew members more knowledgeable about their own behaviors in the cockpit, the types of errors committed in the course of daily operation, and how to prevent these errors in the future. Increases in knowledge as a result of LOSA should contribute to schema change and enrichment, resulting in lasting performance gains.

Next, although this may be difficult, it is important to begin to develop training in the areas of prospective memory and extrapolation of current events into the future. Prospective memory refers to the process by which memory is sustained over long periods of time, requiring humans to remember to engage in actions in the future. In the absence of memory cues, humans are not good at prospective memory tasks, often forgetting to complete a cycle of activity or to engage in a necessary task at the right time or place. This may not only contribute to the accumulation of

error in flight operations, but can be disastrous.

Part of development of prospective awareness skills will also involve development of knowledge about extrapolating from present events into the future. Again, humans are weak in identifying the longterm impact of current actions or events. This weakness is well-elaborated by Edward Tenner (1996), who writes about revenge effects in the development of products and solutions geared toward aiding human existence. For example, the infant walker, designed to aid babies in development of walking skills, actually had the longterm effect of delaying crawling and walking in infants by a month or more. In aviation, a small error made early in a flight may not have a long term effect at all, or the effect may be delayed for hours, days or months. If the operator of the system cannot extrapolate the potential results of a small error, then the system itself becomes faulty and unsafe.

Thus, it is absolutely necessary to teach pilots and crewmembers how to think about problem solving in both a short term and long term manner. Using the concepts of situation awareness (SA) may facilitate this process. Situation awareness has components of both present and future action. The key is to focus on training for future awareness, probably the least elucidated part of the SA perspective. Training for future knowledge, analysis and decision-making is an area that is ripe for intensive study and development of training strategies.

Last, although training in aviation and the safety culture it engenders is quite advanced, research and development about error and threat detection is necessary to advance aviation safety to a new standard. Aviation is the safest form of transportation, however every accident can cost hundreds of lives and millions of dollars. Development of techniques to increase aircrews' awareness of error and threat would further limit the repercussions of aviation accidents. This report has attempted to create a state of the art review of what we currently know about error and threat detection. It is hoped that aviation researchers and organizations take this knowledge and use it to create an even safer flying environment in the future. To better serve future researchers in this area, Figure 2 provides a list of potential research areas directly related to error and threat detection. It is critical that researchers and practitioners in the field of aviation utilize this information to provide a more complete picture of how humans detect and manage error and threat.

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