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Eric E. Geiselman

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## APPLIED THREAT AND ERROR MANAGEMENT: TOWARD CREW-CENTERED SOLUTIONS

Eric E. Geiselman  
Aptima, Inc.  
Dayton, Ohio

For an operator, a high level of understanding regarding procedures enables appropriate defenses to be built into a robust Threat and Error Management (TEM) framework. Currently, airline flightdeck crewmember training and reference information is concentrated heavily on what and how procedures are performed, but not on why they must be performed a standard way. This missing component of certainty invites misinterpretation of the standards and induces error. I propose a Crew-Centered TEM (CC/TEM) approach designed to arm flight crewmembers with more depth of procedural understanding than that currently afforded. A recent accident where human error was identified as a probable cause is used as an example of how a CC/TEM approach may have prevented the occurrence. CC/TEM solutions have further application within other safety-critical domains, such as medicine and emergency response.

Post investigation statistics indicate 70-80% of air carrier accidents include human error as a causal factor (Shappell and Wiegmann, 2000). Use of the term “human error” is intended to be inclusive, versus the old term “pilot error,” in order to recognize that humans other than pilots often contribute to the error chain. The current terminology may be appropriate, but it is also less descriptive and ultimately less meaningful toward the determination of cause. One may ask: “are twenty percent of air carrier accidents truly free of human error?”

One candidate as a “machine cause” accident is the crash of United Flight 232 at Sioux City, Iowa on July 19, 1989 (NTSB, 1989). The three-engine DC-10 was at cruise altitude when the tail-mounted engine experienced an uncontained catastrophic failure. Shrapnel from the engine pierced through the starboard horizontal stabilizer and severed the hydraulic lines where all three of the systems were plumbed together. This resulted in a profound loss of controllability due to the total loss of hydraulic pressure in a triple-redundant system. Through the use of differential thrust via the remaining two engines, the crewmembers were able to approach a runway at the Sioux City airport. Because of the lack of controllability, the aircraft contacted the ground in a wing-low attitude, broke up, and caught fire. Of the 296 passengers and crew aboard, 111 people died.

From the perspective of cause, it is clear that the flightdeck crew were not a factor, but was the accident free of human error? The investigation determined that a maintenance inspection failed to detect a fatigue crack in the engine part found to be responsible for the failure. Even beyond that, the engine cowling was designed to contain this mode of failure. Was the redundancy of the hydraulic system vulnerable due to faulty design? The inclusiveness of the term “human error” extends all the way to the designers’ drawing board.

Because aviation is a human endeavor, it can be stated that human error, at some level, is always involved in its failure. Given this, the use of inclusive human error as causal factor in accident should be placed at 100% versus the 70-80% static often used. This does not mean that problem is worse than previously indicated. It means that the determination of human error as the cause of failure serves only as a description of what happened and falls well short of explaining why the failure occurred. In terms of prevention, it is not as important to classify the human error as it is to determine the cause of the error. Human error does not cause crashes; whatever causes human error is what causes crashes. When we fall short of a complete understanding of error cause, we also miss an opportunity to avoid future occurrence by the generation of effective defenses within Threat and Error Management (TEM) applications at the system operator level.

### Conventional TEM

Conventional TEM begins with threats that can be expected to be faced by operators (flightdeck crewmembers). A series of defenses are in place to allow the crew to manage threats as they develop. Defenses built into the model include training, procedures, technology, automation, standards, regulations, Crew Resource Management (CRM) practices, etc. The defenses can be thought of as multiple layers of a protective barrier to fend off failure (Reason, 1990). If the barrier is breached, error is generated. The error is now protected by another down-stream barrier with the intent of trapping and correcting the error. If the error is able to propagate along the

model, an undesired state is produced. Failure of the crew to detect and correct the undesired state indicates that another defense-set barrier was breached. If left unmitigated by some entity external to the crew (such as air traffic control), then an occurrence is the result. An occurrence can be an accident, incident, regulation violation, or any other negative outcome. In reality, the model is complex, multidimensional, and dynamic. Included are feed-forward and feedback loops which enable errors and undesired states themselves to become threats, which then reenter at the beginning of the dynamic model.

When occurrences are realized, the conventional solution is to patch or add additional layers of defense into the applied TEM model. This is similar to the addition of redundancy within hardware and software systems. But, if those systems are faulty, the addition of redundancy does nothing to prevent individual component failure. Similarly, additional layers of defense within the conventional TEM model do not prevent error generation as much as they are present to reduce error propagation. It is proposed that a higher-level approach is required to help prevent error generation. This is the objective of a Crew-Centered TEM (CC/TEM) approach.

### Crew-Centered TEM

It can be generalized that threats come at the crew, and errors come from the crew. By default, this centralizes threat and error management responsibility to the crew. The new concept of Crew-Centered TEM (CC/TEM) is intended to provide crewmembers with high-level resilient defenses (super defenses) against threat and error propagation. This is accomplished through training, manual-based information, and the appropriate modification of standard procedures. The objective of CC/TEM training is to promote standardized conceptual-level understanding of why procedures are required to be performed in a specified manner (procedure explanation). CC/TEM requires that explanation training be added to current training practices, which focus almost exclusively on what and how standard procedures are to be performed (procedure directives). Specific CRM training will reinforce CC/TEM objectives by emphasizing the importance of professional conduct and standards discipline. A CC/TEM manual system will be consistent with and complement training by providing procedure explanation reference material designed to promote crewmember understanding. Within the manuals, procedure explanations should be aligned logically and co-located within the expanded checklist sections. A complete CC/TEM program includes as standards only those procedures that can be explained. In addition to the above, when changes are made to standard procedures, an explanation of why the change is required will accompany the introduction of the change. When the change is implemented, crew training and the manual system will include an updated procedure explanation. Once acquired, this level of standardized conceptual understanding on the part of the crew will produce better judgment and decision making by promoting the execution of standard procedures as they are intended to be performed. The overall objective of CC/TEM is to reduce uncertainty and maintain a stronger defense against all error producing variables. Failure on the part of a crewmember to understand why a standard procedure exists is by itself a significant threat. Uncorrected, the threat may lead to misinterpretation and selective noncompliance errors. The following accident is an example of the type of occurrence which can and does result.

### CC/TEM Example

#### *Comair Flight 5191 Accident*

Comair (dba: Delta Connection) Flight 5191 was scheduled to depart for Atlanta, Georgia (ATL) from Lexington, Kentucky (LEX) at 6:00am on August 27<sup>th</sup>, 2006. Having arrived separately the previous evening, the crewmembers (captain, first officer (F/O), and flight attendant) met for the first time approximately one hour prior to scheduled departure time. During the pre-flight setup and checks, a ramp agent delivered the dispatch release documents to the crew indicating that they were on the wrong airplane (a Bombardier CL-600). The crew shutdown the airplane and transferred to the correct plane. Now behind schedule, they continued their pre-flight system checks while the passengers were boarded. The flightdeck conversation was friendly and informal. The captain briefed the F/O and indicated that he was “laid back” and “easy going.” The F/O indicated that he “appreciated that.” The F/O briefed the captain that he had flown in the night prior and that there were “a bunch of lights out all over the place.”

Contrary to company standard procedures, the F/O gave a top-level taxi route briefing to the captain: “right turn alpha taxi to the runway.” The F/O referred to runway 24 and was corrected by the captain: “you mean runway 22?” The company Flight Standards Manual (FSM) and Operations Manual (OM) requires the captain to brief the

taxi route and refer to the airport diagram while doing so. The tower controller cleared flight 5191 to: “taxi to runway 22 cleared for takeoff runway 22.” While maneuvering the aircraft, the captain called for Before Takeoff Checklist items to be completed at the F/O’s “leisure.” While completing the checklist items, the F/O violated sterile cockpit conditions on several occasions. At the end of the runway, the controls of the airplane were transferred to the F/O, who was the pilot flying. The takeoff roll was initiated while the tower controller attended to some administrative paperwork. His back was turned to the active runway.

The runway the aircraft was actually on was not the 7003-foot-long runway 22 for which it was cleared. Instead, the airplane was lined up on for takeoff on runway 26: a 3500-foot-long general aviation runway. The aircraft became airborne but gained little altitude before hitting a small rise and then a fence off the end of runway. The aircraft contacted trees, slid across a field, and burned. Of the 50 people on board, 49 were killed. The F/O survived the crash, but suffered severe injury and permanent disablement.

#### *National Transportation Safety Board (NTSB) Investigation*

The following is the probable cause statement from the Flight 5191 NTSB final report. (NTSB, 2007):

*The National Transportation Safety Board determines that the probable cause of this accident was the flight crewmembers' failure to use available cues and aids to identify the airplane's location on the airport surface during taxi and their failure to cross-check and verify that the airplane was on the correct runway before takeoff. Contributing to the accident were the flight crew's non-pertinent conversation during taxi, which resulted in a loss of positional awareness, and the Federal Aviation Administration's (FAA) failure to require that all runway crossings be authorized only by specific air traffic control (ATC) clearances.*

The probable cause statement addresses what the NTSB believes happened and characterizes it as multiple failures (errors of omission) on the part of the crew to notice cues which should have led them to realize they had lined up on the wrong runway. One other error of commission is the violation of sterile cockpit. There is nothing mentioned within the probable cause statement to indicate what may have caused the errors.

#### *NTSB Findings and Recommendations*

The specific findings in the report include 28 factual items. Of those, eight items of crewmember error are indicated. Of the crewmember errors, two specific items of procedural error are included. The procedural errors are cases where the crew failed to comply with standard operating procedure and/or federal aviation regulations. Within the context of conventional TEM, this is indicative of breached layers of defense.

The recommendations include the addition of regulatory changes (e.g. require runway cross-check with other cues) and at least one technology addition change (e.g. develop a moving map display with automatic warning capability). These recommendations represent the addition of redundant defense layers designed to mitigate the effect if the same error chain were to develop in the future. None of these recommendations, applied to the Flight 5191 scenario, would have prevented the aircraft from at least attempting to line up on the wrong runway.

#### *CC/TEM Analysis*

To help determine how a CC/TEM approach would apply to the Flight 5191 accident, we must analyze the events from within the scenario from the perspective of the people involved. Additionally, we must investigate events in the absence of information that was not available to the crew at the time of the occurrence. Also, the analysis should proceed without the benefit of knowing the outcome (Dekker, 2006). The objective is to generate questions designed to explore the plausibility of what may have caused the error and why the error was able to propagate through the entire set of TEM defenses. Once this process is complete, the most important step is to build back into the system super defenses which have a reasonable probability of preventing not just the specific chain of events of the current analysis, but also those which are quite different and unanticipated. The following is an example analysis question from Comair Flight 5191:

*What if the captain believed there was only one runway at LEX—and that belief was never disproved?*

A few of the NTSB findings allude to just such a possibility. Finding number 4: “The captain and the first officer believed that the aircraft was on runway 22 when they taxied onto runway 26 and initiated the takeoff.” Finding number 9: “...because they did not cross-check and confirm the aircraft position on the runway before takeoff, they were likely influenced by confirmation bias.” (i.e. the crew was only paying attention to those cues which confirmed what they believed to be true, to the exclusion of those cues which should have made them question their beliefs). Finding number 11: “The crew’s noncompliance with standard operating procedures (SOPs), including the abbreviated taxi briefing and the non-pertinent conversation most likely created an atmosphere in the cockpit that enabled the crew’s errors.” According to the NTSB, finding 11 enabled the other errors. So, in accordance with the CC/TEM process, we ask: what caused the noncompliance?

### *Noncompliance Issue*

Regarding the CC/TEM analysis questions, the significant noncompliance revolves around the “Captains Standard Taxi Briefing” required action prior to the “Before Starting Engines” section of the expanded checklist. The procedure is defined in and required by the company Flight Standards Manual (FSM) and the associated Operations Manual (OM). Satisfaction of a command (TAKEOFF BRIEF) and response (COMPLETE) line item on the crew checklist is intended to confirm that this briefing was delivered by the captain and received by the F/O. The SOP requires that briefing include at least the following items prior to every flight: anticipated taxi route, runway crossings, hot spots (high threat areas), etc. Furthermore, the procedure requires that the airport diagram (Figure 1) be “out and available” and reviewed during the briefing. There is no information in the manual system that presents an explanation of why the standard procedure exists in its prescribed form.

As the NTSB indicates, the Flight 5191 crew failed to comply with the standard procedure: 1) the captain allowed the first officer to deliver the taxi briefing. 2) The taxi briefing did not include any of the required subject items to the level of detail intended by the procedure. 3) There is no evidence that the airport diagram was referenced by either of the crewmembers. From the airport diagram, it is clear that there is a runway (runway 26) which must be crossed in order to taxi to runway 22 at LEX when departing to the south (Figure 1).

### *Noncompliance Cause*

Reviewing the airport diagram was the captain’s first opportunity to confirm that LEX actually has two runways, one of which must be crossed in order to taxi to the end of runway 22. It is plausible that the captain believed that LEX is a single runway airport. From an airline operational perspective, there is only one usable runway at LEX. At single runway airports, there are few critical briefing items which need to be covered. As long as the aircraft proceeds in the right direction toward the correct end of runway, there are few threats. This may have been the reason the captain was satisfied with the F/O’s non-standard briefing. The F/O was nearing an upgrade to captain status at the airline and had mentioned that fact to the captain. The captain may have chosen to overlook the non-standard conduct of the briefing to avoid shutting down the amicable rapport he had established among his crew. It is entirely possible that, by his interpretation, the captain believed he was exercising good CRM by allowing this series selective noncompliance to develop and continue uncorrected. He may have considered these infringements to be a low-risk tradeoff compared to creating conflict and coming across as less than “laid back.” On the receiving end of this behavior, the F/O is exposed to a willingness on the part of the captain to operate in a less than standard manner. In a more overt indication, the F/O was directed to run and complete standard procedures “at your leisure.” This acts only to encourage other downstream “minor” deviations from the standard such as the one-side violation of sterile cockpit procedures on the part of the F/O. These are clear examples of routine violation type unsafe acts according to the Human Factors Analysis and Classification System (HFACS) taxonomy (Shappell and Wiegmann, 2000).

### *CC/TEM Discussion*

Misinterpretation of the intent of SOPs has a negative impact on the accuracy of the information used by the decision maker. The environment for misinterpretation is created and sustained if training and informational resources do not adequately enable an unambiguous conceptual level of understanding with regard to SOPs (as well

as policies, best practices, applicable techniques, etc.). This can be considered an undesired state, or at best, a latent threat within the operating model. In the above example, a lack of this level of understanding may have initiated the events leading to the occurrence. Why is the captain required to deliver the taxi briefing and include a review of the airport diagram? It is to assure that the captain gets an accurate “big picture” appreciation for the airport layout. This situation awareness building activity is designed to inform the captain as a decision maker. If asked, line flightdeck crewmembers may not consistently identify the correct objective of the taxi briefing requirement. The following is an example of a likely misinterpretation: the reason that the captain is required to give the briefing is because taxi control is a captain function to be backed up by the F/O’s vigilance during surface movement. There are countless ways this standard procedure may be interpreted, but only one correct explanation. Arriving at the correct interpretation is simple if operators are made aware of what it is in the first place. This awareness should be considered a basic requirement of the operator knowledgebase. This is especially true for those involved in safety-critical and unforgiving endeavors. Those operators must know what, how, and why. In terms of CC/TEM processes, accurate why knowledge is a super defense, and its absence represents a very real threat.

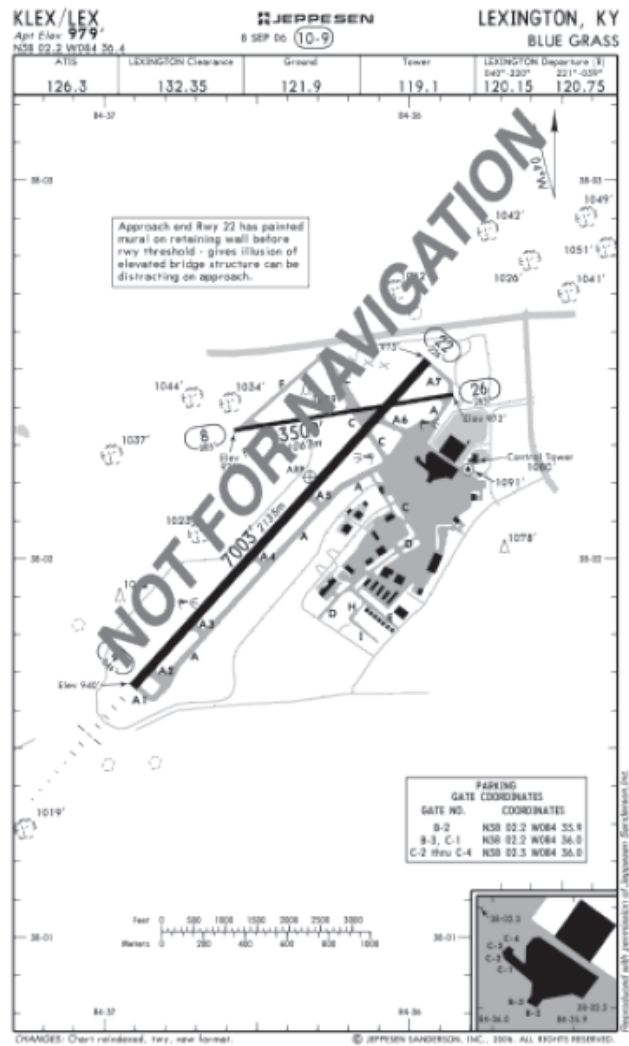


Figure 1. LEX airport diagram chart.

For Comair Flight 5191, the proper conduct of the standard taxi briefing could have resulted in the flight being just another routine completion. The difference may have been as simple as the captain taking the time for a quick glance at the airport diagram. To a large extent, this is all that is required to satisfy the spirit of the standard procedure. Had the airport diagram been reviewed per the SOP, the requirement to cross runway 26 on the way to

runway 22 may have been understood before the aircraft pushed off the gate. An objective of a CC/TEM approach is to ensure that the determination of which standards must be followed as proscribed, and which are flexible, is not a matter of crewmember interpretation.

As a new concept, CC/TEM should be considered as an extension of the significant progress made by the application of conventional TEM practices. Going forward, the components of a comprehensive CC/TEM program must be defined, developed, and integrated into existing training and information systems. It is required that the merit of the CC/TEM concept be demonstrated through objective evaluation measurements. Additionally, the applicability of CC/TEM approach should be considered for other domains where the consequence of negative occurrence is unacceptable. This is especially true where team interaction, communication, and coordination are inextricably linked to the successful completion of well-defined procedures (medicine, emergency response, command/control, process control, etc.)

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