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# How System Errors Affect Aircrew Resource Management (CRM)

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**Abstract**

System errors, both mechanical and human in nature, can have a grave effect on aircrew judgement in flight. The effects of these errors can be massively compounded during emergency situations. Crew Resource Management (CRM) is an important process aircrews can utilize to minimize risks and enhance assessments. The employment of this technique can be validated by aviation mishaps over the last three decades and how system errors increased the probability of the incident occurring. Suggestions can be made to further prevent similar accidents from occurring in the future utilizing historical aeronautical records. This paper outlines an approach by which systems errors can be recognized and prevented using CRM. It is the hope of the authors that employing such an approach will drastically decrease the incidence rate and severity of aviation mishaps due to systems errors.


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*Keywords:* systems approaches; errors; error types; crew resource management

## 1. Introduction

Blanchard and Fabrycky [1] suggest that "an engineered or technical system is a human-made or human-modified system designed to meet functional purposes or objectives." One could inflate this declaration to also include the extension of having a minimal or error-free system. Obviously, it is extremely difficult to create an error-free man-made system, especially one which requires human interaction as part of its operation. Aircraft are one such example where a human interface is key in the safe operation. It is established that "complex systems will, inevitably, experience failures; and the cause of these failures or mishaps may be labeled operator error, but often they are

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actually caused by the confluence of technological, situational, individual, and organizational factors" [2]. This paper will discuss these factors, coupled with the instances of errors from the established literature, to function as a construct in order to describe and include them in the application of system approaches, as well as to provide potential remedies for these errors. Avoiding errors within the aviation domain is critical, given the complexity of operations inherent in such activities.

### *1.1. Aviation Accident History*

Many aviation accidents since the 1970's have triggered the National Aeronautics and Space Administration (NASA), coupled with the International Civil Aviation Organization (ICAO) and the aviation industry, to "figure out how and why effective crews make sound decisions and work cohesively under both stressful and routine conditions" [3]. Knowing what works should prevent individuals or teams working together from implementing incorrect tasks at key moments in flight. Most aviation accidents can be labeled as avoidable and a result of human error. Strauch [4] substantiates this claim also by testifying that "operator errors are the logical consequences of antecedents or precursors that had been present at the time they were committed." Miller and Shattuck [2] reference Senders and Moray [5] by suggesting that "hardware failure can contribute either directly or indirectly to abnormal system states and that human error can be proximate or remote". Regardless of mechanical failure or human error, it is human interaction (i.e., detection and corrective action) that can rectify the problem. Crew Resource Management (CRM) is a key component to correcting errors within aviation systems. CRM can be defined as "the use of all available resources – information, equipment, and people – to achieve safe and efficient flight operations" [6]. These resources are: interpersonal communication, leadership [and followership], and decision making. Other resources, like electronic flight bags (EFBs) and the Automatic Dependent Surveillance–Broadcast (ADS-B) system are tools that further the promotion of CRM. Interpersonal communication can simply be the effectiveness of two or more people communicating. Most military units have standards to combat CRM breakdown in cockpits such as standard, concise calls that direct one individual to react to a threat the other(s) is or are seeing. The second part of this equation is leadership and followership. The crewmember that foresees an issue arising must feel comfortable bringing that issue afoot, no matter who else is flying. Coincidentally, the other individual(s) must be able to take that information freely and objectively. As described by Ritzmann et al., [7] CRM training can improve individual and team performance by "applying well-tested training tools and methods to strengthen knowledge, skills, and attitudes involved in behavioral categories such as situational awareness (SA) or assertiveness."

### *1.2. CRM Error Types*

Adams and Hester [8, 9] define and discuss six explicit errors in system approaches and how they can affect a system as a whole. Reason [10, 11] substantiates this by describing error "in terms of a failure in a system's defenses." IEEE Std 24765 [12] calls error "a human action that produces an incorrect result." Regardless of the description, this discussion will analyze a series of aviation incidents and establish which errors were prevalent. From this, we can recognize what the corrective action(s) should have been in order to prevent future accidents.

Table 1 is a synopsis of the six systems errors as described by Adams and Hester [8, 9]. Several of these errors will be displayed in aviation mishaps and tied into CRM breakdowns, as well as the suggested remedies for these issues.

Table 1. Typology of systems errors (Adams & Hester, 2012, p. 239)

| Error Type | Definition | Issue |
|---|---|---|
| Type I (α) | Rejecting the null-hypothesis when the null-hypothesis is true. | False positive |
| Type II (β) | Failing to reject the null-hypothesis when the null-hypothesis is false. | False negative |
| Type III (γ) | Solving the wrong problem precisely. | Wrong problem |
| Type IV (δ) | Inappropriate action is taken to resolve a problem as the result of a correct analysis. | Wrong action |
| Type V (ε) | Failure to act when the results of analysis indicate action is required. | Inaction |

| | | |
|---|---|---|
| Type VI (ζ) | An error that results from a combination of the other five error types, often resulting in a more complex problem than initially encountered. | System of errors |

## 2. Errors in Aviation Incidents

Several errors will be discussed in detail as they pertain to a specific aviation incident in order to quantify the gravity of consequences on what simple errors can produce, as well as approaches to alleviate the system-wide ramifications of those consequences.

### *2.1. Air France Flight 447: Types I (α) and III (γ) Errors*

The date was June 1st, 2009; Air France Flight 447 was safely established at 35,000 feet enroute from Rio de Janeiro to Paris. The outside environment at this altitude was rather standard for a flight in this region. The region, which is referred to as the inter-tropical convergence, is an area of consistently severe weather near the equator [13]. This causes moderate turbulence as well as St. Elmo's fire, an aviation phenomenon seen in storms such as these. These environmental factors can cause uneasiness in an inexperienced crew. These factors, combined with aircraft systems failures, propagate the breakdown of CRM later. As is often the case, "a single incident is the result of multiple threats, such as human error committed in the attempt to recover from another threat" [14].

#### *2.1.1. Loss of Airspeed Indications: Type I (α) Error*

While established at altitude, both 1st officers were occupying the pilot and copilot seats. At this time, the captain was away from the flight deck. The pilot flying (PF) was inexperienced in this aircraft and not used to this flight routing, whereas the pilot not flying (PNF) was. The PNF was implicitly designated as the relief captain by the actual captain [15]. Precipitation from severe weather, combined with the aircraft altitude, caused the pitot tubes, which provide airspeed data to the onboard computer, to freeze [15]. Upon this action, the pilots should have initiated the unreliable indicated airspeed (IAS) checklist [15]. However, this was never done. The loss of airspeed indication caused the autopilot and auto throttle functions to disengage upon this occurrence. This created a situation where the PF would have to fly manually until the situation was resolved. Furthermore, the guidance model changes from normal mode to alternate or secondary mode, which allows the computer to still provide commands to maintain stable flight [16]. Consequently, this also allows the aircraft the ability to enter the stall envelope. Upon the loss of the airspeed indications, the PF reduced the throttle quadrant in the severe weather. This was also done in conjunction with an unusually steep climb per the guidance from the Flight Director, which was still directing the aircraft to maintain its current altitude [17]. These actions, coupled with the flight mode change, can be tied to the Type I Error (α), that of a false positive, where the PF and PNF thought there was a difference in flight characteristics, when in reality, there was no difference. The loss of the autopilot and auto throttle functions did not create an error where the pilots needed to provide any input. This error carried over to the presentation of another follow-on system error.

#### *2.1.2. Recover from Stall: Type III (γ) Error*

Following the reduction of throttles and the climb initiation from the PF, the stall horn sounded, and continued to ring for 54 seconds until impact [15]. This further confused both pilots, who were still puzzled why they weren't climbing. By this time the captain had returned to the flight deck and took up the jump seat in between and behind both the PF and PNF seats. It is believed that the captain elected to keep the PF and PNF in both seats, while observing and commanding from behind for safety [13, 15]. Throughout the remainder of the flight, none of the pilots identified the stall horn and commanded a descent until it was too late to recover [15]. At approximately 2,000 feet, the captain realized the error and commanded a descent. However, the aircraft's descent rate was over 10,000 feet/min, which meant the captain commanded a descent 12 seconds before impact. The actions accomplished by the flight crew can be associated with Type III (γ) Error, that of the wrong problem. In this case, the crew was trying to solve the issue of not climbing without any airspeed indications. In order to climb more, one would pull back more on the control stick. This was the correct solution to the incorrect problem.

*2.2. Northwest Airlines Flight 6231: Type V (ζ)*

On December 1st, 1974, Northwest Airlines Flight 6231, which was chartered by the former Baltimore Colts football team, was enroute to Buffalo, NY after taking off from John F. Kennedy International Airport in New York. The only passengers were the flight crew, which consisted of a captain, first officer, and second officer (i.e., flight engineer). The flight took off on a standard instrument departure with no issues [18]. The predominant weather conditions provided to the flight crew consisted of moderate turbulence and moderate to severe rain and snow showers over a triangular area whose lines ran between Pittsburgh, New York, and Richmond which are depicted in Fig. 1.

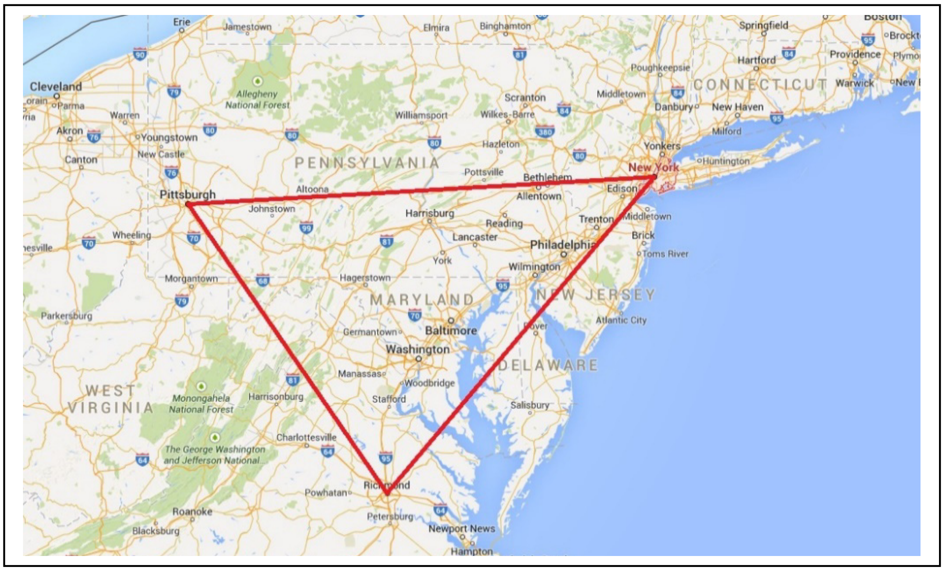


Fig. 1. December 1, 1974 Severe Weather Plot ([18], p. 4)

Upon climbing to 31,000 feet, per the aircrew's clearance, and flying westerly, air traffic control received a mayday call [18]. The aircraft was rapidly descending through 20,000 feet; approximately 80 seconds later, the aircraft impacted the ground [18]. Ultimately, the cause was due to icing of the primary and standby pitot and static sensors; which similarly to the previously described AF 447 incident, caused erroneous airspeed indications. Eventually, the safety board concluded:

> *That the heating elements were never activated because the pitot heater switches were not in the on position and the condition of the switches in the wreckage, the internal damage to the right switch, and the lack of evidence that electrical current was present in the heater circuit to the pitot head in the first officer's pitot system at the time of impact.* [18]

The inaction of the crew to activate the pitot heating system can be traced back to Type V (ζ) Error. Had the aircrew recognized that the heating elements would be a key element of their flight as part of their crew brief, higher emphasis would have been applied to ensure that the anti-ice system was activated and working prior to take-off.

## 3. Mitigation of Error Types

These errors in aviation incidents, regardless of their origins (mechanically- or human-initiated), are system errors nonetheless. Mitigating these errors is crucial for the safe operation of all aircraft types. The simple CRM training techniques listed below can prove to be a valuable asset when items fail or circumstances change.

### *3.1. Mitigation of Type I and III Errors*

Many of the contributing factors in the crash of AF 447 can be mitigated by simple agreements that can be implemented through the form of checklists and/or verbal communication. The issue of having an implied relief captain should no longer be acceptable [15]. As a replacement, designating the left seat 1st officer as the captain as well as the PNF will relegate authority and control of the flight crew to one sole individual, as opposed to the mishap arrangement [15]. Furthermore, having the PNF commanding the flight deck frees up vital brain bytes to analyze the situation and make crucial decisions. This leaves the PF with the sole job of flying the aircraft.

Inclusive with this new form of cockpit transition, aircrew should be trained and required to maintain currencies on manual flying while in alternate mode [15]. This will create a habit pattern that, if the situation arises, will provide aircrew the proficiency to make the correct analysis and decisions. Much like the patterns that pilots ascertain through experience during critical phases of flight, like takeoff and landing, these same patterns can serve as a central instrument in the safe recovery of an aircraft for landing or stable flight conditions. This training can "improve teamwork in the cockpit by applying well-tested tools and appropriate training methods targeted at specific content" [19]. As always, such training reinforces those habitual patterns that all pilots must possess for safe flying operations. For personnel and training, one should be "interested in personnel quantities and skill levels, human error rates, training rates, training times, and training equipment reliability" [1]. Additionally, the introduction of remedial changes to "operating procedures…human-machine interfaces and operator training will limit human error when contributing to system failure" [20].

### *3.2. Mitigation of Type V Error*

The resolution to the errors in the NWA 6231 incident can been seen from two points of view. First, requiring pitot and static heating systems to be on anytime power is applied to the aircraft would negate the requirement of a switch to power those heating systems [18]. This could, however, serve to be problematic in high temperature regions. A possible remedy could be a weight on wheels (WoW) switch as part of a conditional configuration to activate the system. Upon takeoff, the system automatically activates. Secondly, the other solution is to train individuals to focus on attitude indications when uncertain readings are being input from the pitot-static airspeed systems [18]. This would focus aircrew SA into maintaining stable flight in all aspects (climb out, level-off, descent) and buy critical time for the aircrew to diagnose the situation.

## 4. Conclusion

It is established that "complex systems will, inevitably, experience failures; and the cause of these failures or mishaps may be labeled operator error; but often they are actually caused by the confluence of technological, situational, individual, and organizational factors" [2]. Crew Resource Management (CRM), which functions as a safety net, can alleviate complications when complex systems inevitably fail, and can be "used…to achieve safe and efficient flight operations" [6]. Blanchard and Fabrycky [1] suggest that "an engineered or technical system is a human-made or human-modified system designed to meet functional purposes or objectives." As described by Ritzmann et al., [7] CRM training can improve individual and team performance by "applying well-tested training tools and methods to strengthen knowledge, skills, and attitudes involved in behavioral categories such as situational awareness (SA) or assertiveness." These factors, coupled with the instances of errors from the established literature functioned as a construct in order to describe and include them in the application of system approaches, as well as describing remedies for those errors.

Aviation accidents since the 1970's triggered the NASA, ICAO, and the aviation industry to "figure out how and why effective crews make sound decisions and work cohesively under both stressful and routine conditions" [3]. Most aviation accidents can be argued as avoidable and resultant of human-error. Regardless of the description, this discussion analyzed aviation incidents and established which errors were prevalent. From this, it was recognized what the corrective action(s) should have been in order to prevent future accidents. It is the hope of the authors of this paper that the suggestions provided herein will be adopted as a starting point in an effort to reduce aviation errors connected to CRM.

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