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The Human Factors Analysis and Classification System–HFACS

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16. Abstract

Human error has been implicated in 70 to 80% of all civil and military aviation accidents. Yet, most accident reporting systems are not designed around any theoretical framework of human error. As a result, most accident databases are not conducive to a traditional human error analysis, making the identification of intervention strategies onerous. What is required is a general human error framework around which new investigative methods can be designed and existing accident databases restructured. Indeed, a comprehensive human factors analysis and classification system (HFACS) has recently been developed to meet those needs. Specifically, the HFACS framework has been used within the military, commercial, and general aviation sectors to systematically examine underlying human causal factors and to improve aviation accident investigations. This paper describes the development and theoretical underpinnings of HFACS in the hope that it will help safety professionals reduce the aviation accident rate through systematic, data-driven investment strategies and objective evaluation of intervention programs

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THE HUMAN FACTORS ANALYSIS AND CLASSIFICATION SYSTEM–HFACS

INTRODUCTION

Sadly, the annals of aviation history are littered with accidents and tragic losses. Since the late 1950s, however, the drive to reduce the accident rate has yielded unprecedented levels of safety to a point where it is now safer to fly in a commercial airliner than to drive a car or even walk across a busy New York city street. Still, while the aviation accident rate has declined tremendously since the first flights nearly a century ago, the cost of aviation accidents in both lives and dollars has steadily risen. As a result, the effort to reduce the accident rate still further has taken on new meaning within both military and civilian aviation.

Even with all the innovations and improvements realized in the last several decades, one fundamental question remains generally unanswered: "Why do aircraft crash?" The answer may not be as straightforward as one might think. In the early years of aviation, it could reasonably be said that, more often than not, the aircraft killed the pilot. That is, the aircraft were intrinsically unforgiving and, relative to their modern counterparts, mechanically unsafe. However, the modern era of aviation has witnessed an ironic reversal of sorts. It now appears to some that the aircrew themselves are more deadly than the aircraft they fly (Mason, 1993; cited in Murray, 1997). In fact, estimates in the literature indicate that between 70 and 80 percent of aviation accidents can be attributed, at least in part, to human error (Shappell & Wiegmann, 1996). Still, to off-handedly attribute accidents solely to aircrew error is like telling patients they are simply "sick" without examining the underlying causes or further defining the illness.

So what really constitutes that 70-80 % of human error repeatedly referred to in the literature? Some would have us believe that human error and "pilot" error are synonymous. Yet, simply writing off aviation accidents merely to pilot error is an overly simplistic, if not naive, approach to accident causation. After all, it is well established that accidents cannot be attributed to a single cause, or in most instances, even a single individual (Heinrich, Petersen, and Roos, 1980). In fact, even the identification of a "primary" cause is fraught with problems. Rather, aviation accidents are the end result of a number of causes, only the last of which are the unsafe acts of the aircrew (Reason, 1990; Shappell & Wiegmann, 1997a; Heinrich, Peterson, & Roos, 1980; Bird, 1974).

The challenge for accident investigators and analysts alike is how best to identify and mitigate the causal sequence of events, in particular that 70-80 % associated with human error. Armed with this challenge, those interested in accident causation are left with a growing list of investigative schemes to chose from. In fact, there are nearly as many approaches to accident causation as there are those involved in the process (Senders & Moray, 1991). Nevertheless, a comprehensive framework for identifying and analyzing human error continues to elude safety professionals and theorists alike. Consequently, interventions cannot be accurately targeted at specific human causal factors nor can their effectiveness be objectively measured and assessed. Instead, safety professionals are left with the status quo. That is, they are left with interest/fad-driven research resulting in intervention strategies that peck around the edges of accident causation, but do little to reduce the overall accident rate. What is needed is a framework around which a needs-based, data-driven safety program can be developed (Wiegmann & Shappell, 1997).

Reason's "Swiss Cheese" Model of Human Error

One particularly appealing approach to the genesis of human error is the one proposed by James Reason (1990). Generally referred to as the "Swiss cheese" model of human error, Reason describes four levels of human failure, each influencing the next (Figure 1). Working backwards in time from the accident, the first level depicts those *Unsafe Acts* of Operators that ultimately led to the accident[1]. More commonly referred to in aviation as aircrew/pilot error, this level is where most accident investigations have focused their efforts and consequently, where most causal factors are uncovered.

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[1] Reason's original work involved operators of a nuclear power plant. However, for the purposes of this manuscript, the operators here refer to aircrew, maintainers, supervisors and other humans involved in aviation.

After all, it is typically the actions or inactions of aircrew that are directly linked to the accident. For instance, failing to properly scan the aircraft's instruments while in instrument meteorological conditions (IMC) or penetrating IMC when authorized only for visual meteorological conditions (VMC) may yield relatively immediate, and potentially grave, consequences. Represented as "holes" in the cheese, these active failures are typically the last unsafe acts committed by aircrew.

However, what makes the "Swiss cheese" model particularly useful in accident investigation, is that it forces investigators to address latent failures within the causal sequence of events as well. As their name suggests, latent failures, unlike their active counterparts, may lie dormant or undetected for hours, days, weeks, or even longer, until one day they adversely affect the unsuspecting aircrew. Consequently, they may be overlooked by investigators with even the best intentions.

Within this concept of latent failures, Reason described three more levels of human failure. The first involves the condition of the aircrew as it affects performance. Referred to as *Preconditions for Unsafe Acts*, this level involves conditions such as mental fatigue and poor communication and coordination practices, often referred to as crew resource management (CRM). Not surprising, if fatigued aircrew fail to communicate and coordinate their activities with others in the cockpit or individuals external to the aircraft (e.g., air traffic control, maintenance, etc.), poor decisions are made and errors often result.

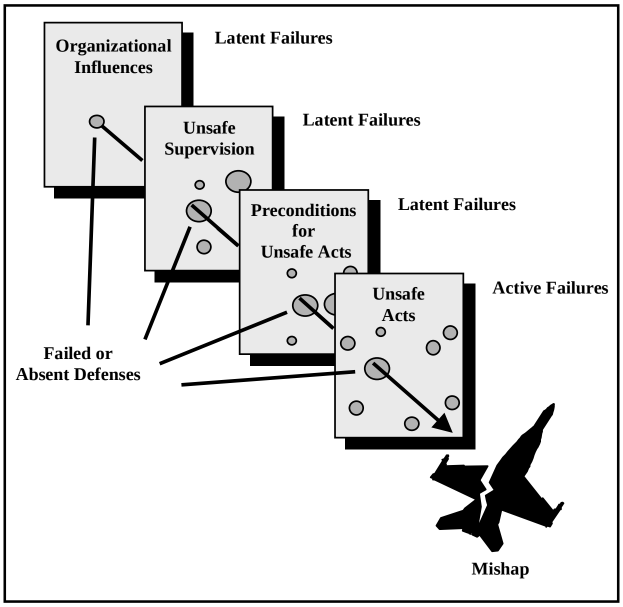

Figure 1. *The "Swiss cheese" model of human error causation (adapted from Reason, 1990).*

But exactly why did communication and coordination break down in the first place? This is perhaps where Reason's work departed from more traditional approaches to human error. In many instances, the breakdown in good CRM practices can be traced back to instances of *Unsafe Supervision*, the third level of human failure. If, for example, two inexperienced (and perhaps even below average pilots) are paired with each other and sent on a flight into known adverse weather at night, is anyone really surprised by a tragic outcome? To make matters worse, if this questionable manning practice is coupled with the lack of quality CRM training, the potential for miscommunication and ultimately, aircrew errors, is magnified. In a sense then, the crew was "set up" for failure as crew coordination and ultimately performance would be compromised. This is not to lessen the role played by the aircrew, only that intervention and mitigation strategies might lie higher within the system.

Reason's model didn't stop at the supervisory level either; the organization itself can impact performance at all levels. For instance, in times of fiscal austerity, funding is often cut, and as a result, training and flight time are curtailed. Consequently, supervisors are often left with no alternative but to task "non-proficient" aviators with complex tasks. Not surprisingly then, in the absence of good CRM training, communication and coordination failures will begin to appear as will a myriad of other preconditions, all of which will affect performance and elicit aircrew errors. Therefore, it makes sense that, if the accident rate is going to be reduced beyond current levels, investigators and analysts alike must examine the accident sequence in its entirety and expand it beyond the cockpit. Ultimately, causal factors at all levels within the organization must be addressed if any accident investigation and prevention system is going to succeed.

In many ways, Reason's "Swiss cheese" model of accident causation has revolutionized common views of accident causation. Unfortunately, however, it is simply a theory with few details on how to apply it in a real-world setting. In other words, the theory never defines what the "holes in the cheese" really are, at least within the context of everyday operations. Ultimately, one needs to know what these system failures or "holes" are, so that they can be identified during accident investigations or better yet, detected and corrected before an accident occurs.

The balance of this paper will attempt to describe the "holes in the cheese." However, rather than attempt to define the holes using esoteric theories with little or no practical applicability, the original framework (called the *Taxonomy of Unsafe Operations*) was developed using over 300 Naval aviation accidents obtained from the U.S. Naval Safety Center (Shappell & Wiegmann, 1997a). The original taxonomy has since been refined using input and data from other military (U.S. Army Safety Center and the U.S. Air Force Safety Center) and civilian organizations (National Transportation Safety Board and the Federal Aviation Administration). The result was the development of the Human Factors Analysis and Classification System (HFACS).

THE HUMAN FACTORS ANALYSIS AND CLASSIFICATION SYSTEM

Drawing upon Reason's (1990) concept of latent and active failures, HFACS describes four levels of failure: 1) Unsafe Acts, 2) Preconditions for Unsafe Acts, 3) Unsafe Supervision, and 4) Organizational Influences. A brief description of the major components and causal categories follows, beginning with the level most closely tied to the accident, i.e. unsafe acts.

Unsafe Acts

The unsafe acts of aircrew can be loosely classified into two categories: errors and violations (Reason, 1990). In general, errors represent the mental or physical activities of individuals that fail to achieve their intended outcome. Not surprising, given the fact that human beings by their very nature make errors, these unsafe acts dominate most accident databases. Violations, on the other hand, refer to the willful disregard for the rules and regulations that govern the safety of flight. The bane of many organizations, the prediction and prevention of these appalling and purely "preventable" unsafe acts, continue to elude managers and researchers alike.

Still, distinguishing between errors and violations does not provide the level of granularity required of most accident investigations. Therefore, the categories of errors and violations were expanded here (Figure 2), as elsewhere (Reason, 1990; Rasmussen, 1982), to include three basic error types (skill-based, decision, and perceptual) and two forms of violations (routine and exceptional).

Errors

Skill-based errors. Skill-based behavior within the context of aviation is best described as "stick-and-rudder" and other basic flight skills that occur without significant conscious thought. As a result, these skill-based actions are particularly vulnerable to failures of attention and/or memory. In fact, attention failures have been linked to many skill-based errors such as the breakdown in visual scan patterns, task fixation, the inadvertent activation of controls, and the misordering of steps in a procedure, among others (Table 1). A classic example is an aircraft's crew that becomes so fixated on trouble-shooting a burned out warning light that they do not notice their fatal

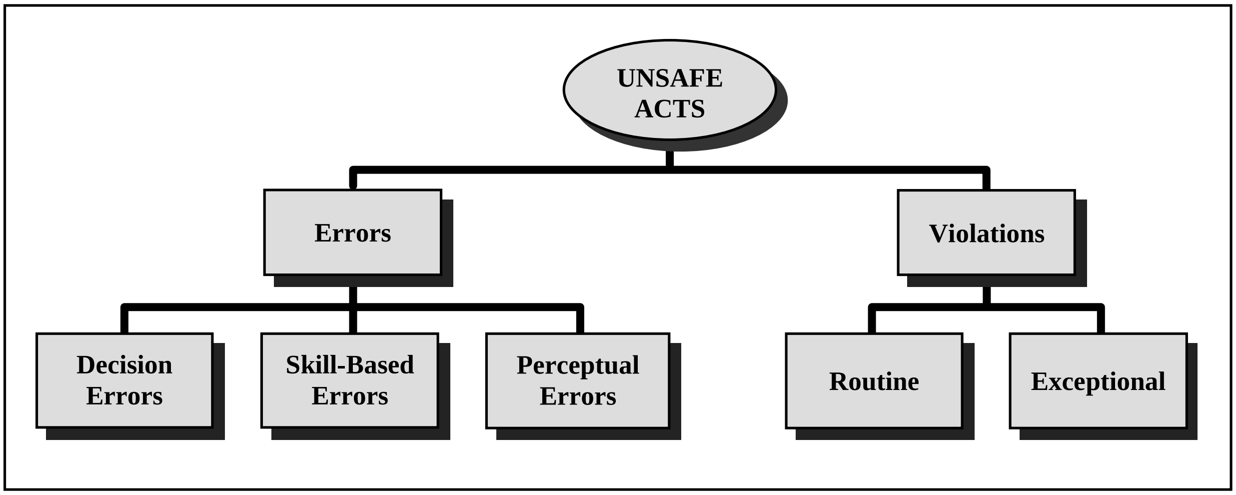

Figure 2. *Categories of unsafe acts committed by aircrews.*

TABLE 1. Selected examples of Unsafe Acts of Pilot Operators (Note: This is not a complete listing)

ERRORS	VIOLATIONS
Skill-based Errors	Failed to adhere to brief
Breakdown in visual scan	Failed to use the radar altimeter
Failed to prioritize attention	Flew an unauthorized approach
Inadvertent use of flight controls	Violated training rules
Omitted step in procedure	Flew an overaggressive maneuver
Omitted checklist item	Failed to properly prepare for the flight
Poor technique	Briefed unauthorized flight
Over-controlled the aircraft	Not current/qualified for the mission
Decision Errors	Intentionally exceeded the limits of the aircraft
Improper procedure	Continued low-altitude flight in VMC
Misdiagnosed emergency	Unauthorized low-altitude canyon running
Wrong response to emergency	
Exceeded ability	
Inappropriate maneuver	
Poor decision	
Perceptual Errors (due to)	
Misjudged distance/altitude/airspeed	
Spatial disorientation	
Visual illusion	

descent into the terrain. Perhaps a bit closer to home, consider the hapless soul who locks himself out of the car or misses his exit because he was either distracted, in a hurry, or daydreaming. These are both examples of attention failures that commonly occur during highly automatized behavior. Unfortunately, while at home or driving around town these attention/memory failures may be frustrating, in the air they can become catastrophic.

In contrast to attention failures, memory failures often appear as omitted items in a checklist, place losing, or forgotten intentions. For example, most of us have experienced going to the refrigerator only to forget what we went for. Likewise, it is not difficult to imagine that when under stress during inflight emergencies, critical steps in emergency procedures can be missed. However, even when not particularly stressed, individuals have forgotten to set the flaps on approach or lower the landing gear – at a minimum, an embarrassing gaffe.

The third, and final, type of skill-based errors identified in many accident investigations involves technique errors. Regardless of one's training, experience, and educational background, the manner in which one carries out a specific sequence of events may vary greatly. That is, two pilots with identical training, flight grades, and experience may differ significantly in the manner in which they maneuver their aircraft. While one pilot may fly smoothly with the grace of a soaring eagle, others may fly with the darting, rough transitions of a sparrow. Nevertheless, while both may be safe and equally adept at flying, the techniques they employ could set them up for specific failure modes. In fact, such techniques are as much a factor of innate ability and aptitude as they are an overt expression of one's own personality, making efforts at the prevention and mitigation of technique errors difficult, at best.

Decision errors. The second error form, decision errors, represents intentional behavior that proceeds as intended, yet the plan proves inadequate or inappropriate for the situation. Often referred to as "honest mistakes," these unsafe acts represent the actions or inactions of individuals whose "hearts are in the right place," but they either did not have the appropriate knowledge or just simply chose poorly.

Perhaps the most heavily investigated of all error forms, decision errors can be grouped into three general categories: procedural errors, poor choices, and problem solving errors (Table 1). Procedural decision errors (Orasanu, 1993), or rule-based mistakes, as described by Rasmussen (1982), occur during highly structured tasks of the sorts, if X, then do Y. Aviation, particularly within the military and commercial sectors, by its very nature is highly structured, and consequently, much of pilot decision making is procedural. There are very explicit procedures to be performed at virtually all phases of flight. Still, errors can, and often do, occur when a situation is either not recognized or misdiagnosed, and the wrong procedure is applied. This is particularly true when pilots are placed in highly time-critical emergencies like an engine malfunction on takeoff.

However, even in aviation, not all situations have corresponding procedures to deal with them. Therefore, many situations require a choice to be made among multiple response options. Consider the pilot flying home after a long week away from the family who unexpectedly confronts a line of thunderstorms directly in his path. He can choose to fly around the weather, divert to another field until the weather passes, or penetrate the weather hoping to quickly transition through it. Confronted with situations such as this, choice decision errors (Orasanu, 1993), or knowledge-based mistakes as they are otherwise known (Rasmussen, 1986), may occur. This is particularly true when there is insufficient experience, time, or other outside pressures that may preclude correct decisions. Put simply, sometimes we chose well, and sometimes we don't.

Finally, there are occasions when a problem is not well understood, and formal procedures and response options are not available. It is during these ill-defined situations that the invention of a novel solution is required. In a sense, individuals find themselves where no one has been before, and in many ways, must literally fly by the seats of their pants. Individuals placed in this situation must resort to slow and effortful reasoning processes where time is a luxury rarely afforded. Not surprisingly, while this type of decision making is more infrequent then other forms, the relative proportion of problem-solving errors committed is markedly higher.

Perceptual errors. Not unexpectedly, when one's perception of the world differs from reality, errors can, and often do, occur. Typically, perceptual errors occur when sensory input is degraded or "unusual," as is the case with visual illusions and spatial disorientation or when aircrew simply misjudge the aircraft's altitude, attitude, or airspeed (Table 1). Visual illusions, for example, occur when the brain tries to "fill in the gaps" with what it feels belongs in a visually impoverished environment, like that seen at night or when flying in adverse weather. Likewise, spatial disorientation occurs when the vestibular system cannot resolve one's orientation in space and therefore makes a "best guess" — typically when visual (horizon) cues are absent at night or when flying in adverse weather. In either event, the unsuspecting individual often is left to make a decision that is based on faulty information and the potential for committing an error is elevated.

It is important to note, however, that it is not the illusion or disorientation that is classified as a perceptual error. Rather, it is the pilot's erroneous response to the illusion or disorientation. For example, many unsuspecting pilots have experienced "black-hole" approaches, only to fly a perfectly good aircraft into the terrain or water. This continues to occur, even though it is well known that flying at night over dark, featureless terrain (e.g., a lake or field devoid of trees), will produce the illusion that the aircraft is actually higher than it is. As a result, pilots are taught to rely on their primary instruments, rather than the outside world, particularly during the approach phase of flight. Even so, some pilots fail to monitor their instruments when flying at night. Tragically, these aircrew and others who have been fooled by illusions and other disorientating flight regimes may end up involved in a fatal aircraft accident.

Violations

By definition, errors occur within the rules and regulations espoused by an organization; typically dominating most accident databases. In contrast, violations represent a willful disregard for the rules and regulations that govern safe flight and, fortunately, occur much less frequently since they often involve fatalities (Shappell et al., 1999b).

While there are many ways to distinguish between types of violations, two distinct forms have been identified, based on their etiology, that will help the safety professional when identifying accident causal factors. The first, routine violations, tend to be habitual by nature and often tolerated by governing authority (Reason, 1990). Consider, for example, the individual who drives consistently 5-10 mph faster than allowed by law or someone who routinely flies in marginal weather when authorized for visual meteorological conditions only. While both are certainly against the governing regulations, many others do the same thing. Furthermore, individuals who drive 64 mph in a 55 mph zone, almost always drive 64 in a 55 mph zone. That is, they "routinely" violate the speed limit. The same can typically be said of the pilot who routinely flies into marginal weather.

What makes matters worse, these violations (commonly referred to as "bending" the rules) are often tolerated and, in effect, sanctioned by supervisory authority (i.e., you're not likely to get a traffic citation until you exceed the posted speed limit by more than 10 mph). If, however, the local authorities started handing out traffic citations for exceeding the speed limit on the highway by 9 mph or less (as is often done on military installations), then it is less likely that individuals would violate the rules. Therefore, by definition, if a routine violation is identified, one must look further up the supervisory chain to identify those individuals in authority who are not enforcing the rules.

On the other hand, unlike routine violations, exceptional violations appear as isolated departures from authority, not necessarily indicative of individual's typical behavior pattern nor condoned by management (Reason, 1990). For example, an isolated instance of driving 105 mph in a 55 mph zone is considered an exceptional violation. Likewise, flying under a bridge or engaging in other prohibited maneuvers, like low-level canyon running, would constitute an exceptional violation. However, it is important to note that, while most exceptional violations are appalling, they are not considered "exceptional" because of their extreme nature. Rather, they are considered exceptional because they are neither typical of the individual nor condoned by authority. Still, what makes exceptional violations particularly difficult for any organization to deal with is that they are not indicative of an individual's behavioral repertoire and, as such, are particularly difficult to predict. In fact, when individuals are confronted with evidence of their dreadful behavior and asked to explain it, they are often left with little explanation. Indeed, those individuals who survived such excursions from the norm clearly knew that, if caught, dire consequences would follow. Still, defying all logic, many otherwise model citizens have been down this potentially tragic road.

Preconditions for Unsafe Acts

Arguably, the unsafe acts of pilots can be directly linked to nearly 80 % of all aviation accidents. However, simply focusing on unsafe acts is like focusing on a fever without understanding the underlying disease causing it. Thus, investigators must dig deeper into why the unsafe acts took place. As a first step, two major subdivisions of unsafe aircrew conditions were developed: substandard conditions of operators and the substandard practices they commit (Figure 3).

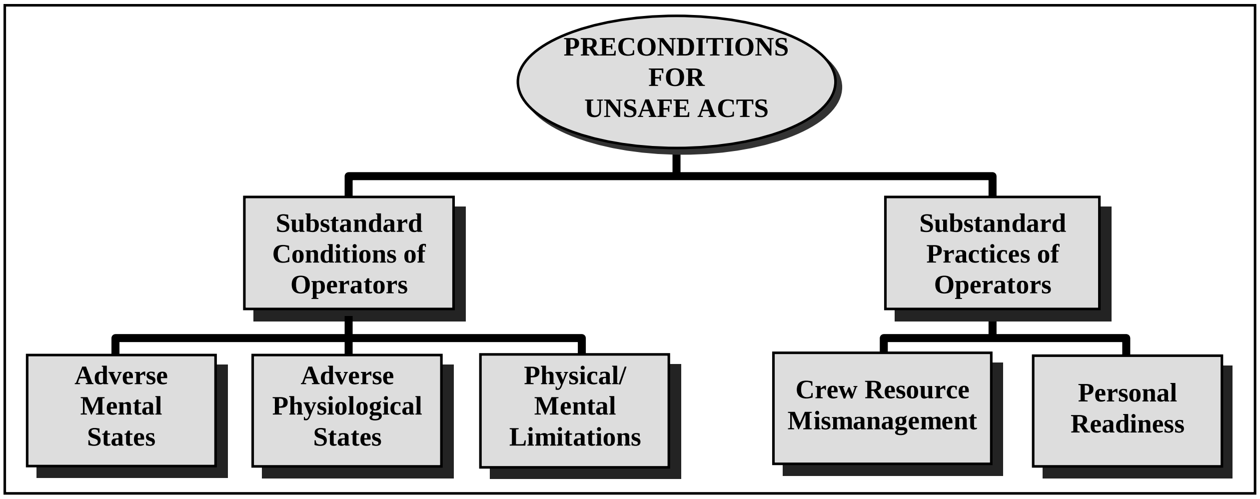

Figure 3. *Categories of preconditions of unsafe acts.*

Substandard Conditions of Operators

Adverse mental states. Being prepared mentally is critical in nearly every endeavor, but perhaps even more so in aviation. As such, the category of Adverse Mental States was created to account for those mental conditions that affect performance (Table 2). Principal among these are the loss of situational awareness, task fixation, distraction, and *mental* fatigue due to sleep loss or other stressors. Also included in this category are personality traits and pernicious attitudes such as overconfidence, complacency, and misplaced motivation.

Predictably, if an individual is mentally tired for whatever reason, the likelihood increase that an error will occur. In a similar fashion, overconfidence and other pernicious attitudes such as arrogance and impulsivity will influence the likelihood that a violation will be committed. Clearly then, any framework of human error must account for preexisting adverse mental states in the causal chain of events.

Adverse physiological states. The second category, adverse physiological states, refers to those medical or physiological conditions that preclude safe operations (Table 2). Particularly important to aviation are such conditions as visual illusions and spatial disorientation as described earlier, as well as *physical* fatigue, and the myriad of pharmacological and medical abnormalities known to affect performance.

The effects of visual illusions and spatial disorientation are well known to most aviators. However, less well known to aviators, and often overlooked are the effects on cockpit performance of simply being ill. Nearly all of us have gone to work ill, dosed with over-the-counter medications, and have generally performed well. Consider however, the pilot suffering from the common head cold. Unfortunately, most aviators view a head cold as only a minor inconvenience that can be easily remedied using over-the counter antihistamines, acetaminophen, and other non-prescription pharmaceuticals. In fact, when

TABLE 2. Selected examples of Unsafe Aircrew Conditions (Note: This is not a complete listing)

SUBSTANDARD CONDITIONS OF OPERATORS	SUBSTANDARD PRACTICE OF OPERATORS
Adverse Mental States	**Crew Resource Management**
Channelized attention	Failed to back-up
Complacency	Failed to communicate/coordinate
Distraction	Failed to conduct adequate brief
Mental fatigue	Failed to use all available resources
Get-home-itis	Failure of leadership
Haste	Misinterpretation of traffic calls
Loss of situational awareness	**Personal Readiness**
Misplaced motivation	Excessive physical training
Task saturation	Self-medicating
Adverse Physiological States	Violation of crew rest requirement
Impaired physiological state	Violation of bottle-to-throttle requirement
Medical illness	
Physiological incapacitation	
Physical fatigue	
Physical/Mental Limitation	
Insufficient reaction time	
Visual limitation	
Incompatible intelligence/aptitude	
Incompatible physical capability	

confronted with a stuffy nose, aviators typically are only concerned with the effects of a painful sinus block as cabin altitude changes. Then again, it is not the overt symptoms that local flight surgeons are concerned with. Rather, it is the accompanying inner ear infection and the increased likelihood of spatial disorientation when entering instrument meteorological conditions that is alarming - not to mention the side-effects of antihistamines, fatigue, and sleep loss on pilot decision-making. Therefore, it is incumbent upon any safety professional to account for these sometimes subtle medical conditions within the causal chain of events.

Physical/Mental Limitations. The third, and final, substandard condition involves individual physical/mental limitations (Table 2). Specifically, this category refers to those instances when mission requirements exceed the capabilities of the individual at the controls. For example, the human visual system is severely limited at night; yet, like driving a car, drivers do not necessarily slow down or take additional precautions. In aviation, while slowing down isn't always an option, paying additional attention to basic flight instruments and increasing one's vigilance will often increase the safety margin. Unfortunately, when precautions are not taken, the result can be catastrophic, as pilots will often fail to see other aircraft, obstacles, or power lines due to the size or contrast of the object in the visual field.

Similarly, there are occasions when the time required to complete a task or maneuver exceeds an individual's capacity. Individuals vary widely in their ability to process and respond to information. Nevertheless, good pilots are typically noted for their ability to respond quickly and accurately. It is well documented, however, that if individuals are required to respond quickly (i.e., less time is available to consider all the possibilities or choices thoroughly), the probability of making an error goes up markedly. Consequently, it should be no surprise that when faced with the need for rapid processing and reaction times, as is the case in most aviation emergencies, all forms of error would be exacerbated.

In addition to the basic sensory and information processing limitations described above, there are at least two additional instances of physical/mental limitations that need to be addressed, albeit they are often overlooked by most safety professionals. These limitations involve individuals who simply are not compatible with aviation, because they are either unsuited physically or do not possess the aptitude to fly. For example, some individuals simply don't have the physical strength to operate in the potentially high-G environment of aviation, or for anthropometric reasons, simply have difficulty reaching the controls. In other words, cockpits have traditionally not been designed with all shapes, sizes, and physical abilities in mind. Likewise, not everyone has the mental ability or aptitude for flying aircraft. Just as not all of us can be concert pianists or NFL linebackers, not everyone has the innate ability to pilot an aircraft – a vocation that requires the unique ability to make decisions quickly and respond accurately in life threatening situations. The difficult task for the safety professional is identifying whether aptitude might have contributed to the accident causal sequence.

Substandard Practices of Operators

Clearly then, numerous substandard conditions of operators can, and do, lead to the commission of unsafe acts. Nevertheless, there are a number of things that we do to ourselves that set up these substandard conditions. Generally speaking, the substandard practices of operators can be summed up in two categories: crew resource mismanagement and personal readiness.

Crew Resource Mismanagement. Good communication skills and team coordination have been the mantra of industrial/organizational and personnel psychology for decades. Not surprising then, crew resource management has been a cornerstone of aviation for the last few decades (Helmreich & Foushee, 1993). As a result, the category of crew resource mismanagement was created to account for occurrences of poor coordination among personnel. Within the context of aviation, this includes coordination both within and between aircraft with air traffic control facilities and maintenance control, as well as with facility and other support personnel as necessary. But aircrew coordination does not stop with the aircrew in flight. It also includes coordination before and after the flight with the brief and debrief of the aircrew.

It is not difficult to envision a scenario where the lack of crew coordination has led to confusion and poor decision making in the cockpit, resulting in an accident. In fact, aviation accident databases are replete with instances of poor coordination among aircrew. One of the more tragic examples was the crash of a civilian airliner at night in the Florida Everglades in 1972 as the crew was busily trying to troubleshoot what amounted to a burnt out indicator light. Unfortunately, no one in the cockpit was monitoring the aircraft's altitude as the altitude hold was inadvertently disconnected. Ideally, the crew would have coordinated the trouble-shooting task ensuring that at least one crewmember was monitoring basic flight instruments and "flying" the aircraft. Tragically, this was not the case, as they entered a slow, unrecognized, descent into the everglades resulting in numerous fatalities.

Personal Readiness. In aviation, or for that matter in any occupational setting, individuals are expected to show up for work ready to perform at optimal levels. Nevertheless, in aviation as in other professions, personal readiness failures occur when individuals fail to prepare physically or mentally for duty. For instance, violations of crew rest requirements, bottle-to-brief rules, and self-medicating all will affect performance on the job and are particularly detrimental in the aircraft. It is not hard to imagine that, when individuals violate crew rest requirements, they run the risk of mental fatigue and other adverse mental states, which ultimately lead to errors and accidents. Note however, that violations that affect personal readiness are not considered "unsafe act, violation" since they typically do not happen in the cockpit, nor are they necessarily active failures with direct and immediate consequences.

Still, not all personal readiness failures occur as a result of violations of governing rules or regulations. For example, running 10 miles before piloting an aircraft may not be against any existing regulations, yet it may impair the physical and mental capabilities of the individual enough to degrade performance and elicit unsafe acts. Likewise, the traditional "candy bar and coke" lunch of the modern businessman may sound good but may not be sufficient to sustain performance in the rigorous environment of aviation. While there may be no rules governing such behavior, pilots must use good judgment when deciding whether they are "fit" to fly an aircraft.

Unsafe Supervision

Recall that in addition to those causal factors associated with the pilot/operator, Reason (1990) traced the causal chain of events back up the supervisory chain of command. As such, we have identified four categories of unsafe supervision: inadequate supervision, planned inappropriate operations, failure to correct a known problem, and supervisory violations (Figure 4). Each is described briefly below.

Inadequate Supervision. The role of any supervisor is to provide the opportunity to succeed. To do this, the supervisor, no matter at what level of operation, must provide guidance, training opportunities, leadership, and motivation, as well as the proper role model to be emulated. Unfortunately, this is not always the case. For example, it is not difficult to conceive of a situation where adequate crew resource management training was either not provided, or the opportunity to attend such training was not afforded to a particular aircrew member. Conceivably, aircrew coordination skills would be compromised and if the aircraft were put into an adverse situation (an emergency for instance), the risk of an error being committed would be exacerbated and the potential for an accident would increase markedly.

In a similar vein, sound professional guidance and oversight is an essential ingredient of any successful organization. While empowering individuals to make decisions and function independently is certainly essential, this does not divorce the supervisor from accountability. The lack of guidance and oversight

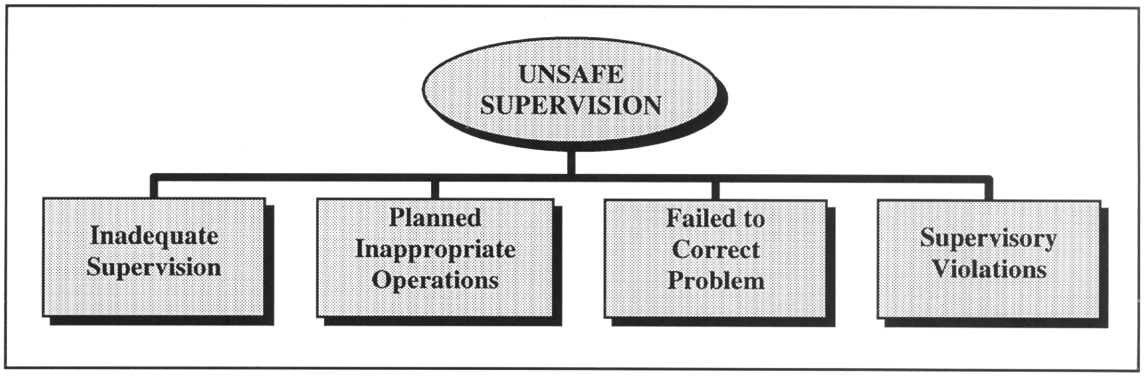

Figure 4. *Categories of unsafe supervision.*

has proven to be the breeding ground for many of the violations that have crept into the cockpit. As such, any thorough investigation of accident causal factors must consider the role supervision plays (i.e., whether the supervision was inappropriate or did not occur at all) in the genesis of human error (Table 3).

Planned Inappropriate Operations. Occasionally, the operational tempo and/or the scheduling of aircrew is such that individuals are put at unacceptable risk, crew rest is jeopardized, and ultimately performance is adversely affected. Such operations, though arguably unavoidable during emergencies, are unacceptable during normal operations. Therefore, the second category of unsafe supervision, planned inappropriate operations, was created to account for these failures (Table 3).

Take, for example, the issue of improper crew pairing. It is well known that when very senior, dictatorial captains are paired with very junior, weak co-pilots, communication and coordination problems are likely to occur. Commonly referred to as the trans-cockpit authority gradient, such conditions likely contributed to the tragic crash of a commercial airliner into the Potomac River outside of Washington, DC, in January of 1982 (NTSB, 1982). In that accident, the captain of the aircraft repeatedly rebuffed the first officer when the latter indicated that the engine instruments did not appear normal. Undaunted, the captain continued a fatal takeoff in icing conditions with less than adequate takeoff thrust. The aircraft stalled and plummeted into the icy river, killing the crew and many of the passengers.

Clearly, the captain and crew were held accountable. They died in the accident and cannot shed light on causation; but, what was the role of the supervisory chain? Perhaps crew pairing was equally responsible. Although not specifically addressed in the report, such issues are clearly worth exploring in many accidents. In fact, in that particular accident, several other training and manning issues were identified.

Failure to Correct a Known Problem. The third category of known unsafe supervision, Failed to Correct a Known Problem, refers to those instances when deficiencies among individuals, equipment, training or other related safety areas are "known" to the supervisor, yet are allowed to continue unabated (Table 3). For example, it is not uncommon for accident investigators to interview the pilot's friends, colleagues, and supervisors after a fatal crash only to find out that they "knew it would happen to him some day." If the supervisor knew that a pilot was incapable of flying safely, and allowed the flight anyway, he clearly did the pilot no favors. The failure to correct the behavior, either through remedial training or, if necessary, removal from flight status, essentially signed the pilot's death warrant - not to mention that of others who may have been on board.

TABLE 3. Selected examples of Unsafe Supervision (Note: This is not a complete listing)

Inadequate Supervision
- Failed to provide guidance
- Failed to provide operational doctrine
- Failed to provide oversight
- Failed to provide training
- Failed to track qualifications
- Failed to track performance

Planned Inappropriate Operations
- Failed to provide correct data
- Failed to provide adequate brief time
- Improper manning
- Mission not in accordance with rules/regulations
- Provided inadequate opportunity for crew rest

Failed to Correct a Known Problem
- Failed to correct document in error
- Failed to identify an at-risk aviator
- Failed to initiate corrective action
- Failed to report unsafe tendencies

Supervisory Violations
- Authorized unnecessary hazard
- Failed to enforce rules and regulations
- Authorized unqualified crew for flight

Likewise, the failure to consistently correct or discipline inappropriate behavior certainly fosters an unsafe atmosphere and promotes the violation of rules. Aviation history is rich with by reports of aviators who tell hair-raising stories of their exploits and barnstorming low-level flights (the infamous "been there, done that"). While entertaining to some, they often serve to promulgate a perception of tolerance and "one-up-manship" until one day someone ties the low altitude flight record of ground-level! Indeed, the failure to report these unsafe tendencies and initiate corrective actions is yet another example of the failure to correct known problems.

Supervisory Violations. Supervisory violations, on the other hand, are reserved for those instances when existing rules and regulations are willfully disregarded by supervisors (Table 3). Although arguably rare, supervisors have been known occasionally to violate the rules and doctrine when managing their assets. For instance, there have been occasions when individuals were permitted to operate an aircraft without current qualifications or license. Likewise, it can be argued that failing to enforce existing rules and regulations or flaunting authority are also violations at the supervisory level. While rare and possibly difficult to cull out, such practices are a flagrant violation of the rules and invariably set the stage for the tragic sequence of events that predictably follow.

Organizational Influences

As noted previously, fallible decisions of upper-level management directly affect supervisory practices, as well as the conditions and actions of operators. Unfortunately, these organizational errors often go unnoticed by safety professionals, due in large part to the lack of a clear framework from which to investigate them. Generally speaking, the most elusive of latent failures revolve around issues related to resource management, organizational climate, and operational processes, as detailed below in Figure 5.

Resource Management. This category encompasses the realm of corporate-level decision making regarding the allocation and maintenance of organizational assets such as human resources (personnel), monetary assets, and equipment/facilities (Table 4). Generally, corporate decisions about how such resources should be managed center around two distinct objectives – the goal of safety and the goal of on-time, cost-effective operations. In times of prosperity, both objectives can be easily balanced and satisfied in full. However, as we mentioned earlier, there may also be times of fiscal austerity that demand some give and take between the two. Unfortunately, history tells us that safety is often the loser in such battles and, as some can attest to very well, safety and training are often the first to be cut in organizations having financial difficulties. If cutbacks in such areas are too severe, flight proficiency may suffer, and the best pilots may leave the organization for greener pastures.

Excessive cost-cutting could also result in reduced funding for new equipment or may lead to the purchase of equipment that is sub optimal and inadequately designed for the type of operations flown by the company. Other trickle-down effects include poorly maintained equipment and workspaces, and the failure to correct known design flaws in existing equipment. The result is a scenario involving unseasoned, less-skilled pilots flying old and poorly maintained aircraft under the least desirable conditions and schedules. The ramifications for aviation safety are not hard to imagine.

Climate. Organizational Climate refers to a broad class of organizational variables that influence worker performance. Formally, it was defined as the "situationally based consistencies in the organization's treatment of individuals" (Jones, 1988). In general, however, organizational climate can be viewed as the working atmosphere within the organization. One telltale sign of an organization's climate is its structure,

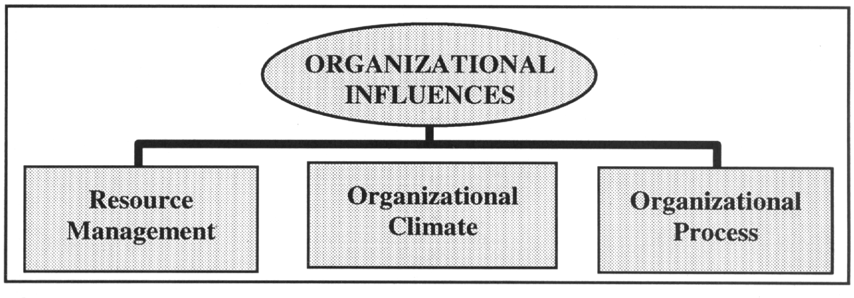

Figure 5. *Organizational factors influencing accidents.*

TABLE 4. Selected examples of Organizational Influences (Note: This is not a complete listing)

- **Resource/Acquisition Management**
  - Human Resources
    - Selection
    - Staffing/manning
    - Training
  - Monetary/budget resources
    - Excessive cost cutting
    - Lack of funding
  - Equipment/facility resources
    - Poor design
    - Purchasing of unsuitable equipment
- **Organizational Climate**
  - Structure
    - Chain-of-command
    - Delegation of authority
    - Communication
    - Formal accountability for actions
  - Policies
    - Hiring and firing
    - Promotion
    - Drugs and alcohol
  - Culture
    - Norms and rules
    - Values and beliefs
    - Organizational justice
- **Organizational Process**
  - Operations
    - Operational tempo
    - Time pressure
    - Production quotas
    - Incentives
    - Measurement/appraisal
    - Schedules
    - Deficient planning
  - Procedures
    - Standards
    - Clearly defined objectives
    - Documentation
    - Instructions
  - Oversight
    - Risk management
    - Safety programs

as reflected in the chain-of-command, delegation of authority and responsibility, communication channels, and formal accountability for actions (Table 4). Just like in the cockpit, communication and coordination are vital within an organization. If management and staff within an organization are not communicating, or if no one knows who is in charge, organizational safety clearly suffers and accidents do happen (Muchinsky, 1997).

An organization's policies and culture are also good indicators of its climate. Policies are official guidelines that direct management's decisions about such things as hiring and firing, promotion, retention, raises, sick leave, drugs and alcohol, overtime, accident investigations, and the use of safety equipment. Culture, on the other hand, refers to the unofficial or unspoken rules, values, attitudes, beliefs, and customs of an organization. Culture is "the way things really get done around here."

When policies are ill-defined, adversarial, or conflicting, or when they are supplanted by unofficial rules and values, confusion abounds within the organization. Indeed, there are some corporate managers who are quick to give "lip service" to official safety policies while in a public forum, but then overlook such policies when operating behind the scenes. However, the Third Law of Thermodynamics tells us that, "order and harmony cannot be produced by such chaos and disharmony". Safety is bound to suffer under such conditions.

Operational Process. This category refers to corporate decisions and rules that govern the everyday activities within an organization, including the establishment and use of standardized operating procedures and formal methods for maintaining checks and balances (oversight) between the workforce and management. For example, such factors as operational tempo, time pressures, incentive systems, and work schedules are all factors that can adversely affect safety (Table 4). As stated earlier, there may be instances when those within the upper echelon of an organization determine that it is necessary to increase the operational tempo to a point that overextends a supervisor's staffing capabilities. Therefore, a supervisor may resort to the use of inadequate scheduling procedures that jeopardize crew rest and produce sub optimal crew pairings, putting aircrew at an increased risk of a mishap. However, organizations should have official procedures in place to address such contingencies as well as oversight programs to monitor such risks.

Regrettably, not all organizations have these procedures nor do they engage in an active process of monitoring aircrew errors and human factor problems via anonymous reporting systems and safety audits. As such, supervisors and managers are often unaware of the problems before an accident occurs. Indeed, it has been said that "an accident is one incident to many" (Reinhart, 1996). It is incumbent upon any organization to fervently seek out the "holes in the cheese" and plug them up, before they create a window of opportunity for catastrophe to strike.

CONCLUSION

It is our belief that the Human Factors Analysis and Classification System (HFACS) framework bridges the gap between theory and practice by providing investigators with a comprehensive, user-friendly tool for identifying and classifying the human causes of aviation accidents. The system, which is based upon Reason's (1990) model of latent and active failures (Shappell & Wiegmann, 1997a), encompasses all aspects of human error, including the conditions of operators and organizational failure. Still, HFACS and any other framework only contributes to an already burgeoning list of human error taxonomies if it does not prove useful in the operational setting. In these regards, HFACS has recently been employed by the U.S. Navy, Marine Corps, Army, Air Force, and Coast Guard for use in aviation accident investigation and analysis. To date, HFACS has been applied to the analysis of human factors data from approximately 1,000 military aviation accidents. Throughout this process, the reliability and content validity of HFACS has been repeatedly tested and demonstrated (Shappell & Wiegmann, 1997c).

Given that accident databases can be reliably analyzed using HFACS, the next logical question is whether anything unique will be identified. Early indications within the military suggest that the HFACS framework has been instrumental in the identification and analysis of global human factors safety issues (e.g., trends in aircrew proficiency; Shappell, et al., 1999), specific accident types (e.g., controlled flight into terrain, CFIT; Shappell & Wiegmann, 1997b), and human factors problems such as CRM failures (Wiegmann & Shappell, 1999). Consequently, the systematic application of HFACS to the analysis of human factors accident data has afforded the U.S. Navy/Marine Corps (for which the original taxonomy was developed) the ability to develop objective, data-driven intervention strategies. In a sense, HFACS has illuminated those areas ripe for intervention rather than relying on individual research interests not necessarily tied to saving lives or preventing aircraft losses.

Additionally, the HFACS framework and the insights gleaned from database analyses have been used to develop innovative accident investigation methods that have enhanced both the quantity and quality of the human factors information gathered during accident investigations. However, not only are safety professionals better suited to examine human error in the field but, using HFACS, they can now track those areas (*the holes in the cheese*) responsible for the accidents as well. Only now is it possible to track the success or failure of specific intervention programs designed to reduce specific types of human error and subsequent aviation accidents. In so doing, research investments and safety programs can be either readjusted or reinforced to meet the changing needs of aviation safety.

Recently, these accident analysis and investigative techniques, developed and proven in the military, have been applied to the analysis and investigation of U.S. civil aviation accidents (Shappell & Wiegmann, 1999). Specifically, the HFACS framework is currently being used to systematically analyze both commercial and General Aviation accident data to explore the underlying human factors problems associated with these events. The framework is also being employed to develop improved methods and techniques for investigating human factors issues during actual civil aviation accident investigations by Federal Aviation Administration and National Transportation Safety Board officials. Initial results of this project have begun to highlight human factors areas in need of further safety research. In addition, like their military counterparts, it is anticipated that HFACS will provide the fundamental information and tools needed to develop a more effective and accessible human factors accident database for civil aviation.

In summary, the development of the HFACS framework has proven to be a valuable first step in the establishment of a larger military and civil aviation safety program. The ultimate goal of this, and any other, safety program is to reduce the aviation accident rate through systematic, data-driven investment.

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