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Applying Reason: the human factors analysis and classification system (HFACS)

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Abstract

Human error has been implicated in 70 to 80% of 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. Toward these ends, a comprehensive human factors analysis and classification system (HFACS) has recently been developed to meet those needs. The HFACS framework has been used successfully within the military, commercial, and general aviation sectors to systematically examine underlying human causal factors and 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 the objective evaluation of intervention programmes.

Introduction

Sadly, the annals of aviation history are littered with accidents and loss of life. Since the late 1950s, however, the drive to reduce the accident rate has yielded unprecedented levels of safety so that today it is safer to fly in a commercial airliner than to drive a car or even walk across a busy New York City street. Still,

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while the aviation accident rate has declined impressively 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 aviation accident rate still further has taken on a new meaning.

However, even with all the innovations and improvements realised in the last several decades, one fundamental question remains unanswered: 'Why do aircraft crash?' The answer may not be as straightforward as one might think. For example, 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 % of aviation accidents can be attributed, at least in part, to human error (Shappell and Wiegmann, 1996).

So what really constitutes that 70-80 % of human error associated with aviation accidents? 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. Instead, aviation accidents are the result of a number of causes, only the last of which are the unsafe acts of the aircrew (Reason, 1990; Shappell and Wiegmann, 1997a; Heinrich, Peterson and Roos, 1980; Bird, 1974).

The challenge for accident investigators and researchers alike is how best to identify and mitigate the causal sequence of events leading up to an accident, particularly that 70-80 % attributed to 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 and error analysis as there are those involved in the process (Senders and Moray, 1991). Nevertheless, a comprehensive framework for identifying and analysing 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 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 (Wiegmann and Shappell, 1999). What is needed is a framework around which a needs-based, data-driven safety programme can be developed (Wiegmann and Shappell, 1997).

Purpose of the present paper

Recently, a comprehensive Human Factors Analysis and Classification System (HFACS) has been developed to meet those needs (Shappell and Wiegmann, 1998; Wiegmann and Shappell, 1998). This system, which is based on Reason's (1990) model of latent and active failures, is the result of several years of research and testing within both military and civilian aviation settings. The HFACS framework was originally developed for, and has recently been adopted by the U.S. Navy and Marine Corps as an accident investigation and data analysis tool. HFACS is also currently being employed by the U.S. Army and Air Force, and Canadian Forces, as well as the Federal Aviation Administration (FAA) and the National Aeronautics and Space Administration (NASA) as a complement to pre-existing systems. The purpose of the present paper, therefore is to describe the HFACS framework and its underlying theoretical foundation, as well as to summarise the empirical research supporting its utility as an error analysis and accident investigation framework.

The human factors analysis and classification system

In perhaps one of the most widely cited books in the field, Jim Reason (1990) described four levels of human failure within an organisation, each influencing the next in the genesis of accidents (Figure 1). In many ways, Reason's 'Swiss cheese' model of accident causation revolutionised common views on the subject. Unfortunately, however, Reason's model is mainly a theory with few details on how to apply it in real-world settings. In other words, the theory never described what the 'holes in the cheese' really are so they can be identified during accident investigations or better yet, detected and corrected before an accident occurs. To remedy this, the HFACS framework was developed to apply Reason's conceptual model by describing the holes at each of four levels of human failure: 1) Unsafe Acts, 2) Preconditions for Unsafe Acts, 3) Unsafe Supervision, and 4) Organisational Influences. A description of the major components and causal categories follows, beginning with the level most closely tied to the accident – the unsafe acts of operators.

Unsafe acts

Working backward in time from the accident, the first level of HFACS describes those *unsafe acts* of operators that led to the accident. More commonly referred to in aviation as aircrew/pilot error, this level is where most accident investigations are focused and consequently, where the majority of causal factors are uncovered. 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. Violations, on the other hand, refer to the wilful disregard for the rules and regulations. However, merely distinguishing between errors and violations does not provide the level of granularity required of most error analyses and 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).

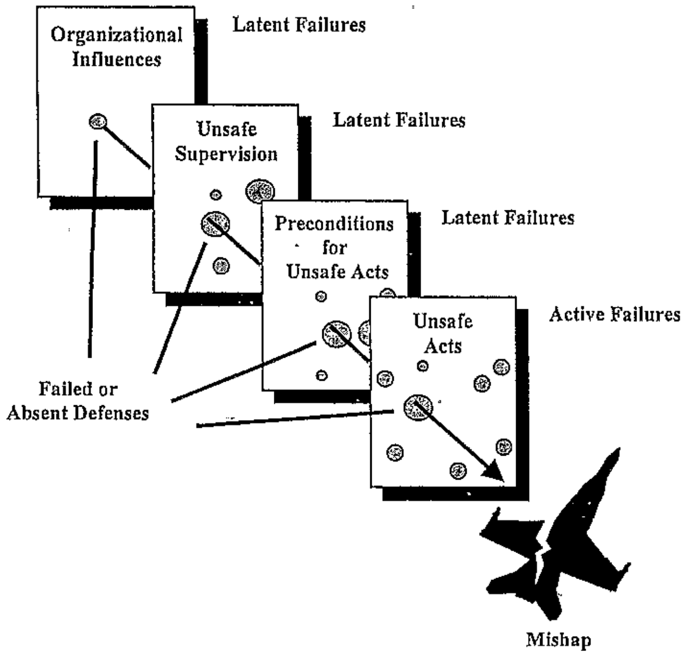

Figure 1 The 'Swiss cheese' model of human error causation (adapted from Reason, 1990)

Errors

Skill-based errors Within the context of aviation, skill-based behaviour is best described as 'stick-and-rudder' and other basic flight activities 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, and the inadvertent activation of controls (Table 1). Consider, for example, a crew that becomes so fixated on trouble-shooting a burned out warning light that they fail to monitor their altimeter and fatally descends into the terrain. Perhaps a bit closer to home, consider the unfortunate soul who locks him/herself out of the car or misses their exit because they were either distracted, in a hurry, or daydreaming. These are both examples of attention failures that commonly occur during highly automated behaviour. While at home or driving around town, these attention failures may merely be frustrating. However, in the air they can become catastrophic.

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 prioritise attention	Flew an unauthorised approach
Inadvertent use of flight controls	Violated training rules
Omitted step in procedure	Flew an overaggressive manoeuvre
Omitted checklist item	Failed to properly prepare for the flight
Poor technique	
Over-controlled the aircraft	Briefed unauthorised flight
	Not current/qualified for the mission
Decision Errors	Intentionally exceeded the limits of the aircraft
Improper procedure	
Misdiagnosed emergency	Continued low-altitude flight in VMC
Wrong response to emergency	
Exceeded ability	Unauthorised low-altitude canyon running
Inappropriate manoeuvre	
Poor decision	
Perceptual Errors (due to)	
Misjudged distance/altitude/airspeed	
Spatial disorientation	
Visual illusion	

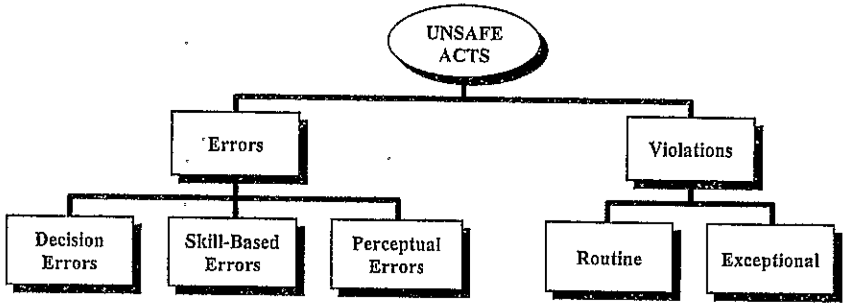

Figure 2 **Categories of unsafe acts committed by aircrews**

In contrast, memory failures often appear as omitted items in a checklist, place losing, or forgotten intentions. For example, many of us have forgotten to replace the gas cap after refuelling the family car or failed to put the coffee in the coffee-pot before turning it on. Likewise, it is not difficult to imagine that when under the stress of an in-flight emergency for example or after a long, fatiguing flight, critical steps/procedures can be missed. Yet, 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 class of skill-based errors involves the manner, or technique, individuals employ while controlling their aircraft. For example, two pilots with identical training, flight grades, and experience may differ significantly in the way they fly. That is, some pilots may fly smooth and effortlessly, while others are more forceful and rough on the flight controls. Both may be safe and equally proficient in the air; however, given certain scenarios the techniques they employ could set them up for failure. Ultimately, such techniques are as much a factor of innate ability and aptitude as they are an overt expression of one's personality, making efforts at the prevention and mitigation of technique errors particularly difficult.

Decision errors Perhaps the most heavily investigated of all error forms, decision errors represent intentional behaviour that proceeds as intended, yet the plan proves inadequate or inappropriate for the situation. Often referred to as 'honest mistakes,' this type of error can generally be grouped into one of three categories: procedural errors, choice errors, 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. In fact, 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 recognised or misdiagnosed, and the wrong procedure is applied.

Even in aviation however, not all situations have corresponding procedures that address them. Instead, many situations require that a choice be made among multiple response options. Consider for instance the pilot who unexpectedly confronts a line of thunderstorms directly along the flight path. He or she 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. When confronted with situations such as these, 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 individuals chose well, and sometimes they don't.

Finally, there are occasions when a problem is not well understood, and formal procedures or response options are not available. It is during these ill-defined situations that the construction of a novel solution is required. In a sense, individuals find themselves where no one has been before, and in many ways, must '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. Consequently, while this type of decision making is more infrequent then other forms, the relative proportion of errors committed is markedly higher.

Perceptual error 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 either degraded or 'unusual', as is the case with visual illusions and spatial disorientation (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 must make a 'best guess' typically when normal visual (horizon) cues are absent. In either event, the unsuspecting individual often is left to make a decision based on a faulty perception of the situation where the potential for committing an error is exacerbated.

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 pilots have experienced spatial disorientation (often referred to as the 'leans') when flying into the weather. However, in instances such as these, pilots are taught to rely on their primary instruments, rather than their senses when controlling the aircraft. Nevertheless, some pilots fail to monitor their instruments when flying in adverse weather or at night when visual cues are minimal. Unfortunately, these aircrew and others who have been fooled by illusions and other disorientating flight regimes may end up involved in an aircraft accident, many of which prove fatal.

Violations

By definition, errors occur while aircrew are behaving within the rules and regulations implemented by an organisation and typically dominate most accident databases. In contrast, violations represent the wilful disregard for the rules and regulations that govern safe flight and, fortunately, occur much less frequently (Shappell et al., 1999b).

While there are many ways to distinguish between types of violations, two distinct forms have been identified, based on their aetiology (Table 1). The first, routine violations, tend to be habitual by nature and are 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 authorised for visual meteorological conditions only. While both certainly violate governing regulations, many drivers or pilots do the same thing. Furthermore, people 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.

Often referred to as 'bending the rules', these violations are often tolerated and, in effect, sanctioned by 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, local authorities started handing out traffic citations for exceeding the speed limit on the highway by 9 mph or less, then it is less likely that individuals would violate the rules. By definition then, if a routine violation is identified, investigators must look further up the causal chain to identify those individuals in authority who are not enforcing the rules.

In contrast, exceptional violations appear as isolated departures from authority, not necessarily characteristic of an individual's typical behaviour 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 particularly dangerous and prohibited manoeuvres 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. Unfortunately, the unexpected nature of exceptional violations make them particularly difficult to predict and problematic for organisations to deal with.

Preconditions for unsafe acts

What makes Reason's (1990) 'Swiss cheese' model particularly useful in accident investigation, is that it encourages investigators to address the latent failures within the causal sequence of events as well as the more obvious active failures described above. 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. Historically, such latent failures have often been overlooked by investigators largely because the types of latent failures or 'holes in the cheese' that adversely affect aircrew performance have not been clearly defined. To remedy this, the HFACS framework describes the first layer of latent conditions, *Preconditions for Unsafe Acts*, within the context of substandard conditions of operators and the substandard practices they perform (Figure 3).

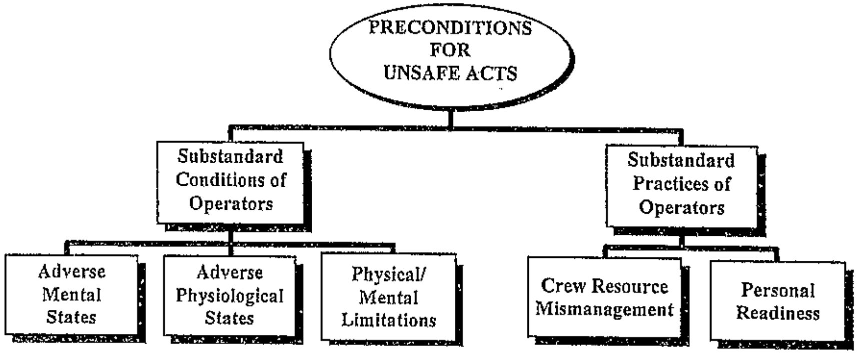

Figure 3 Categories of preconditions of unsafe acts

Substandard conditions of operators

Adverse mental states Being prepared mentally is critical in nearly every endeavour, 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 here are personality traits and pernicious attitudes such as overconfidence, complacency, and misplaced motivation.

Consider, for example, the individual who is mentally fatigued or suffering the effects of sleep loss. The likelihood that an error will occur given these preconditions becomes much more predictable. In a similar manner, 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 these pre-existing adverse mental states if a thorough understanding of the causal chain of events is to be realised.

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/co-ordinate
Distraction	Failed to conduct adequate brief
Mental fatigue	Failed to use all available resources
Get-home-it is	Failure of leadership
Haste	Misinterpretation of traffic calls
Loss of situational awareness	
Misplaced motivation	
Task saturation	
Adverse Physiological States	*Personal Readiness*
Impaired physiological state	Excessive physical training
Medical illness	Self-medicating
Physiological incapacitation	Violation of crew rest requirement
Physical fatigue	Violation of bottle-to-throttle requirement
Spatial Disorientation	
Visual Illusions	
Physical/Mental Limitation	
Insufficient reaction time	
Visual limitation	
Incompatible intelligence/aptitude	
Incompatible physical capability	

Adverse physiological states The second category, adverse physiological states, refers to those medical or physiological conditions that interfere with 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 of simply being ill on cockpit performance. 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 medications. In fact, when confronted with a stuffy nose, aviators typically are only concerned with the effects of a painful sinus block as cabin altitude changes. However, it is not the overt symptoms that 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 adverse physiological states as well as other more obvious ones such as spatial disorientation and visual illusions within the causal chain of events.

Physical/mental limitations The final class of substandard conditions 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, when driving an automobile, many drivers do not necessarily slow down or take additional precautions. Likewise, in aviation, while slowing down is not necessarily an option, increasing one's vigilance for other aircraft or obstacles whose size or contrast interferes with their detection will often increase the safety margin.

Similarly, there are occasions when the time required to complete a task or manoeuvre exceeds an individual's capacity. That is, while good pilots are typically noted for their ability to respond quickly and accurately, individuals vary widely in their ability to process and respond to information. Still, even given individual differences, if any operator or pilot is required to respond quickly (as is the case in many aviation emergencies), the probability of making an error will likely increase.

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 or dexterity to operate in the unique aviation environment, 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 determining whether physical abilities or 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 individuals do to themselves 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 co-ordination has been the mantra of industrial/organisational and personnel psychology for decades. Not surprising then, crew resource management has been a cornerstone of aviation for the last few decades (Helmreich and Foushee, 1993; Wiegmann and Shappell, 1999). As a result, the category of crew resource mismanagement was created to account for occurrences of poor co-ordination among personnel (Table 2). Within the context of aviation, this includes co-ordination both within and between aircraft, with air traffic control facilities and maintenance control, as well as with facility and other support personnel as necessary. Likewise, good crew resource management includes co-ordination before and after the flight in the form of pre-flight briefings and debriefings as necessary.

Unfortunately, the history of aviation is replete with instances where the lack of crew co-ordination has led to confusion and poor decision making in the cockpit, resulting in an accident (Wiegmann and Shappell, 1999). One of the more notable failures of crew resource management within the commercial airline industry was the crash of a civilian airliner at night in the Florida Everglades in 1972 (NTSB, 1973). It seems the crew was busily trying to troubleshoot what amounted to a burnt out indicator light, and no one was monitoring the aircraft's altitude as the altitude hold was inadvertently disconnected. Ideally, the crew would have co-ordinated the trouble-shooting task ensuring that at least one crewmember was monitoring basic flight instruments and 'flying' the aircraft. Regrettably, this wasn't the case, as they entered a slow, unrecognised descent, into the Florida 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 (Table 2). 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. Not surprising for example, when individuals violate crew rest requirements, they run the risk of mental fatigue and other adverse mental states, which may ultimately lead to errors and accidents. Note however, that violations that affect personal readiness are not considered 'unsafe act, violations' 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 military pilot 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 behaviour, pilots must use good judgement when deciding whether they are 'fit' to fly an aircraft.

Unsafe supervision

Exactly why do preconditions for unsafe acts exist in the first place? This is perhaps where Reason's work departed from the more traditional engineering approaches when addressing human error. Specifically, Reason traced the circumstances, or causal chain of events, producing unsafe acts up the supervisory chain of command, beginning with front-line supervisors. Referred to as *Unsafe Supervision*, the third level of human failure can be parsed into four broad categories: inadequate supervision, planned inappropriate operations, failure to correct a known problem, and supervisory violations (Figure 4).

Inadequate supervision Put simply, the role of any supervisor is to provide the opportunity to succeed. To do this, supervisors must provide guidance, training opportunities, leadership, motivation and oversight to their subordinates (Table 3). 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. Consequently, aircrew co-ordination skills could 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 magnified.

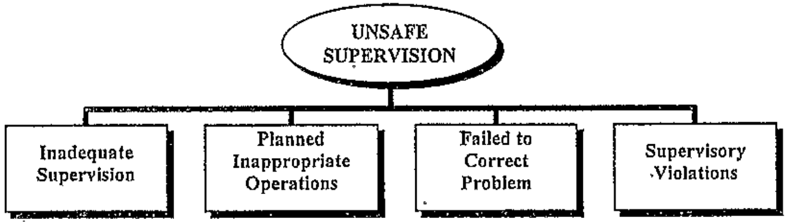

Figure 4 Categories of unsafe supervision

Likewise, sound professional guidance and oversight are essential ingredients of any successful organisation. While empowering individuals to make decisions and function independently are certainly essential, this does not divorce the supervisor from accountability. For instance, the lack of guidance and oversight has proven to be the breeding ground for many of the violations that have crept into the cockpit. Consequently, 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.

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

Consider, 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 co-ordination problems are likely to occur. Commonly referred to as the trans-cockpit authority gradient, such conditions likely contributed to the fatal 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. Nevertheless, the captain continued a fatal takeoff in icing conditions with less than adequate takeoff thrust. As a result, the aircraft stalled and crashed into the icy river, killing the crew and many of the passengers.

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
Authorised unnecessary hazard
Failed to enforce rules and regulations
Authorised unqualified crew for flight

Clearly, the captain and crew were held accountable - they died in the accident. Nevertheless, 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 that would arguably be considered unsafe supervision here.

Failure to correct a known problem The third category, 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 favours. The failure to correct the behaviour, either through remedial training or, if necessary, removal from flight status, in effect sealed the fate of the pilot - not to mention the others who may have been on board.

Likewise, the failure to consistently correct or discipline inappropriate behaviour fosters an unsafe atmosphere and promotes the violation of rules. Aviation history is rich with 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 pays the price. Ultimately, failures such as these committed by supervisors have played a significant role in accident causation.

Supervisory violations Although arguably rare, supervisors have been known to violate the rules and doctrine when managing their assets prompting a category to account for these failures (Table 3). For example, allowing unqualified individuals to fly in adverse weather conditions or pressuring crews to overlook safety precautions in the interest of time and profit have both lead to accidents. 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 invariably set the stage for the sequence of events that predictably follow.

Organisational influences

Reason's model didn't stop at the supervisory level either. In fact, fallible decisions of upper-level management directly affect supervisory practices, as well as the conditions and actions of operators. 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, including the organisation as a whole. Unfortunately, these organisational failures often go unnoticed by safety professionals, due in large part to the lack of a clear framework from which to investigate them. With this in mind, the HFACS framework was designed to capture the most elusive of these latent failures including resource management, organisational climate, and operational processes (Figure 5).

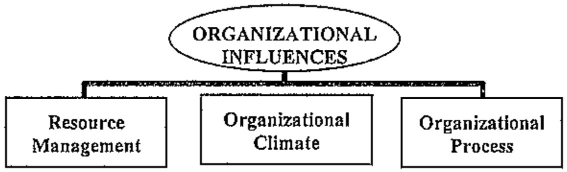

Figure 5 Organisational factors influencing accidents

Resource management This category encompasses the realm of corporate-level decision making regarding the allocation and maintenance of organisational assets such as human resources (personnel), monetary assets, and equipment/facilities (Table 4). Generally speaking, corporate decisions about how such resources should be managed centre 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, 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 safety and training are often the first to be cut in organisations having financial difficulties.

Excessive cost cutting can 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, all effecting the delicate balance between safety and profit.

Organisational climate This category refers to a broad class of organisational variables that influence worker performance (Table 4). Formally, it was defined as the 'situationally based consistencies in the organisation's treatment of individuals' (Jones, 1988). In general, however, organisational climate can be viewed as the working atmosphere within the organisation. One telltale sign of an organisation's climate is its structure, as reflected in the chain-of-command, delegation of authority and responsibility, communication channels, and formal accountability for actions. Just like in the cockpit, communication and co-ordination are vital within an organisation. If management and staff within an organisation are not communicating, or if no one knows who is in charge, organisational safety clearly suffers and accidents do happen (Muchinsky, 1997).

An organisation'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, and other day-to-day operations. Culture, on the other hand, refers to the unofficial or unspoken rules, values, attitudes, beliefs, and customs of an organisation – sort of 'the way things really get done around here.' Regardless, when policies are ill-defined, adversarial, or conflicting, or when they are supplanted by unofficial rules and values, confusion abounds within the organisation. Ultimately, safety is bound to suffer under such conditions.

Operational process The final category, operational process, refers to corporate decisions and rules that govern everyday activities within an organisation. Specifically, such processes as the establishment and use of standardised operating procedures and formal methods for maintaining checks and balances (oversight) between the workforce and management is included here (Table 4). It is not difficult to envision instances when those within the upper echelon of an organisation 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 jeopardise crew rest and produce sub-optimal crew pairings, putting aircrew at increased risk.

Table 4 Selected examples of Organisational Influences (Note: This is not a complete listing)

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

Regrettably, not all organisations have procedures in place to address such contingencies 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 too many' (Reinhart, 1996). It is incumbent upon any organisation to fervently seek out the 'holes in the cheese' and plug them up, before they create a window of opportunity for catastrophe to strike.

Evaluating the framework

Clearly, HFACS or any other framework only contributes to an already burgeoning list of human error taxonomies if it does not prove useful in the operational setting. Therefore, to ensure that the HFACS taxonomy would have utility as an accident investigation and data analysis tool, and is not merely the result of a long academic exercise, it was designed around an explicit set of criteria. Specifically, five criteria were used throughout the development process: comprehensiveness, diagnosticity, reliability, usability, and validity (Hollnagel, 1998; O'Connor and Hardiman 1996).

Comprehensiveness

In this context, comprehensiveness refers to the extent to which an error taxonomy captures all the information surrounding an error or accident (O'Connor and Hardiman, 1996). Assessing comprehensiveness is a reiterative process that involves mapping frameworks onto existing accident databases to identify if any human causal factors are left unaccounted for. Our early efforts to develop a comprehensive human error taxonomy (Shappell and Wiegmann, 1995; Wiegmann and Shappell, 1995; Wiegmann and Shappell, 1997) involved testing error frameworks already existing in the literature against the U.S. Navy/Marine Corps aviation accident database. These exiting frameworks, however, focused primarily on the information processing or unsafe acts level of operator performance, and missed several other key human factors considered causal to many of the accidents. Consequently, a new error taxonomy, was developed to capture the preconditions and unsafe supervisory factors associated with many of these accidents (Shappell and Wiegmann, 1997a).

The Taxonomy of Unsafe Operations, as it was originally called, was then tested against the U.S. Navy/Marine Corps aviation accident database and others made available by military (U.S. Army Safety Center and U.S. Air Force Safety Center) and civilian organisations (National Transportation Safety Board). Again, however, additional latent organisational factors were found that remained unaccounted for by the framework and further modifications were required. The resulting taxonomy was the HFACS framework described here (Shappell and Wiegmann, 1998; Wiegmann and Shappell, 1998).

The HFACS framework was once again mapped onto each of these military and civilian databases, resulting in a complete capture of the human-causal factors contributing to operator error in these data sources (Shappell and Wiegmann, 1999). Since then, evaluations of the comprehensiveness of HFACS have also been performed using error data from other contexts (e.g., aircraft maintenance and air traffic control). The results of these efforts suggest that the taxonomy is robust and complete in its error categories with regard to the types of errors that occur in other operational settings as well (Schmidt, 1998; Pounds, et al., 1999).

Diagnosticity

For years the U.S. Navy/Marine Corps, like other military and civilian organisations, has been limited to reporting aviation accident trends as rates (accidents per 100,000 flight hours) which included all types of accidents regardless of causal genesis. That is, accidents due to human error have not been differentiated from those due to other non-human causal factors such as mechanical failures and environmental conditions. As such, the extent to which human error has been analysed has been to simply report that human error is associated with 60-80% of aviation accidents making intervention strategies difficult to identify, implement, and evaluate (Wiegmann and Shappell, 1997).

To be useful then, an error taxonomy must have good diagnosticity. That is, it must be able to identify relationships between errors and to penetrate all levels of the system in such a way that previously unforeseen accident trends or causes are revealed (O'Connor and Hardiman, 1996). Diagnosticity also refers to the sensitivity of a taxonomy to changes in error trends, allowing for the successful assessment and monitoring of selected interventions strategies.

Recently for example, 181 U.S. Navy and Marine Corps tactical aircraft (TACAIR) and helicopter accidents occurring between fiscal years 1991 to 1997 were analysed using HFACS (Shappell et al., 1999). Of these 181 accidents, 35% were associated with at least one violation of the rules and regulations. To put these numbers into perspective, a similar HFACS analysis was also performed on U.S. Army and U.S. Air Force aviation accident data. A comparison across similar types of aircraft revealed that during roughly this same time frame, violations were identified in 27% (17 of 62 accidents) of the U.S. Army accidents examined and only 7% (5 of 67 accidents) of those in the U.S. Air Force. Because of this analysis, the U.S. Navy/Marine Corps underwent a programme designed to specifically reduce this particular unsafe act among Naval aviators.

One potentially viable intervention might have been to punish the violators or even to remove them from flight status so that they (or others) would not repeat the offence. However, a closer examination of the data revealed that the majority of violations associated with these accidents were considered 'routine' by HFACS standards (i.e., habitual actions often associated with unsafe supervisory conditions). Consequently, intervention strategies that incorporated the supervisory chain as well as the aircrew were needed. Therefore, in late 1997 the US Navy/Marine Corps embarked on an organised agenda to promote supervision, professionalism, accountability, and enforcement of the rules to mitigate violations in the fleet. Subsequent HFACS analyses revealed that by fiscal year 1998 the Navy/Marine Corps had nearly halved its percentage of accidents associated with violations to approximately 17% and that this trend has continued into fiscal year 1999 (Neubauer, Murdock, Fraser and Veronneau, 1999).

A second illustration of the HFACS framework's diagnosticity involves the issue of aviator readiness/proficiency. Given the drawdown within the military over the last several years and the marked reduction in flight hours, there has been a growing concern regarding a concomitant reduction in the proficiency of our aircrews. Translated into HFACS terminology, these monetary and training cutbacks are an organisational, resource management issue, whereas proficiency is best defined within the context of skill-based errors. Recall that skill-based behaviour in the cockpit typically refers to those stick-and-rudder and other basic flight skills (e.g., instrument and out of cockpit scan patterns) that are highly practised and typically occur without much conscious thought.

To the extent that skill-based errors are a measure of proficiency, it would seem logical to examine the percentage of accidents associated with skill-based errors across the years of this military drawdown. Indeed, an HFACS analysis of TACAIR and Rotary Wing accidents since 1991 (Shappell, et al., 1999) revealed a steady rise in the percentage of accidents associated with skill-based errors over the last eight years, suggesting a steady erosion in proficiency. Unfortunately, intervention strategies for improving proficiency are not nearly as clear cut as those associated with violations. Nevertheless, the HFACS framework suggests that any intervention will need to re-emphasise the basics tenets of flying, including efficient instrument scan, prioritising attention, recognising extremis situations, basic flight skills (Stick-and-Rudder). The extent to which these interventions are effectively implemented and funded by upper level management and thus directly impact proficiency will have to be assessed through future HFACS analysis of error and accident data.

With regard to diagnosticity then, the HFACS framework has been found to be an effective instrument, having utility as both an error analysis and intervention assessment tool. Other illustrations not discussed here (e.g., Shappell and Wiegmann, 1997b; Wiegmann and Shappell, 1999) include evaluations of such intervention programmes as ground proximity warning systems (GPWS) to prevent controlled flight into terrain (CFIT), as well as aircrew co-ordination training to prevent CRM errors in the cockpit. In general, these and other systematic applications of HFACS to the analysis of human factors accident data have 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.

Reliability

According to O'Connor and Hardiman (1996), an error framework should produce reliable insights, such that its application results in different users discovering similar factors associated with the same accident or error event. Similar to assessing comprehensiveness, evaluating and improving the reliability of a taxonomic system is also a reiterative process. Specifically, the process involves assessing initial levels of inter-rater agreements, then modifying error categories, definitions, or instructions if necessary and reassessing agreement levels (usually using a new data set) to determine if reliabilities have improved to an acceptable level. Although there are several formulas for assessing reliability, Cohen's Kappa is generally regarded as the best index of inter-rater agreement for error classification or other similar tasks (see Primavara, Allison, and Alfonso, 1996 for review of methods for quantifying reliability). Cohen's Kappa is an index of agreement that has been corrected for chance. By conventional standards, index values of .60 to .74 are considered 'good' and values of .75 or higher are considered 'excellent' levels of agreement (Fleiss, 1981).

Throughout the development of HFACS, several studies to assess reliability were performed using U.S. Navy/Marine Corps and U.S. Air Force aviation accident data. In each of these studies, three independent raters classified a number of causal factors and inter-rater reliabilities were calculated for each pair of raters using Cohen's kappa. Using an earlier version of HFACS, Walker (1996) and Rabbe (1996) examined inter-rater reliability using 93 U.S. Navy/Marine Corps controlled flight into terrain (CFIT) accidents (508 causal factors) and 79 F-16 accidents (190 causal factors) respectively. The overall reliabilities for each pair of raters are presented in Table 5. While the reliabilities were generally 'good', a detailed analysis revealed that reliabilities were best for variables within the preconditions level of the taxonomy, with slightly lower reliabilities within the unsafe acts and unsafe supervision tiers, respectively. Therefore, modifications were made to the taxonomy within these levels by adding categories and refining category definitions. Two additional studies were then conducted to assess the effects that these changes had on inter-rater reliabilities. These studies used the revised taxonomy to examine 733 human causal factors from 132 navy TACAIR and Rotary Wing accidents (Ranger, 1997) and 127 human causal factors from 41 B-1, B52, F-111, and F-4 accidents (Plourde, 1997). Results from these studies revealed increases in agreement levels across pairs of raters (Table 5). Again, additional modifications were made to the framework and a fifth study using what is now known as HFACS was conducted using 186 human causal factors from 77 A-10 accidents (Johnson, 1997). Overall, pair-wise reliabilities were found be 'excellent' by conventional standards in this study (see Table 5) and consistent across levels.

Table 5 Reliability of successive iterations of the HFACS framework

Author	Cohen's Kappa		
	Rater 1 vs Rater 2	*Rater 1 vs Rater 3*	*Rater 2 vs Rater 3*
Walker (1996)	.70	.60	.65
Rabbe (1996)	.69	.78	.62
Ranger (1997)	.81	.69	.80
Plourde (1997)	.89	.85	.86
Johnson (1997)	.93	.95	.95

Since these initial studies, a concerted effort has been made to ensure that the results of the analyses obtained via the application of HFACS and its predecessor taxonomies would be reliable and consistent across investigators. Furthermore, reliability analyses have been continually performed as the framework has been expanded to capture additional human factors issues or applied to other types of aviation accidents, such as commercial and general aviation accidents (Shappell and Wiegmann, 1999).

Usability

Usability refers to the practicality of a taxonomy, or the ease at which it can be turned into a practical methodology or made operational (Hollnagel, 1998). Put simply, the degree of acceptance of an approach is reflected by how easy the framework is to use and how often it is employed. Over the past five years, numerous Flight Surgeons, Aviation Safety Officers and other safety personnel within the U.S. Navy/Marine Corps and U.S. Army have been trained to reliably use HFACS after relatively few hours of instruction. Hundreds of other non-military professionals have also been trained to use the framework through full- and half-day workshops offered at a variety of government and professional society meetings.

Since its inception, the acceptability of HFACS and its predecessor frameworks has been repeatedly assessed and improved, based on inputs from those attending these training sessions, as well as feedback from operators in the field. Some changes that have improved acceptability included the rephrasing of technical or psychological terminology (e.g., slips, lapses and mistakes), to create terms that aviators would better understand (e.g. skill-based and decision errors). Another improvement simply required changing the name of the framework from the

Taxonomy of Unsafe Operations to Human Factors Analysis and Classification System or HFACS, to make the system more palatable to management. Perhaps the clearest evidence of the framework's usability however, is that large organisations like the U.S. Navy/Marine Corps and the U.S. Army have adopted HFACS as an accident investigation and data analysis tool. In addition, HFACS is currently being utilised within other organisations such as the FAA and NASA as a supplement to pre-existing systems (Ford, Jack, Crisp, and Sandusky, 1999).

Validity

The concept of validity concerns *what* a taxonomy captures or measures, and *how well* it does so (Anastasi, 1982). While there are multiple types of validity, three types (content, face, and construct validity) will be addressed here. Theoretically, the upper boundaries of these forms of validity are determined by the extent to which the framework meets the preceding four criterion (comprehensiveness, diagnosticity, reliability, and usability). For instance, assessing the content validity of a framework involves the systematic examination of the taxonomy to determine whether it covers a representative sample of the error domain to be measured. Face validity, on the other hand, refers to whether a taxonomy 'looks valid' to investigators who will use it or administrative personnel who decide on its use. Hence, content validity is directly related to comprehensiveness and reliably, whereas face validity is directly related to the acceptability of a framework, all of which have been shown to be relatively high for HFACS or its earlier versions.

The construct validity of an error taxonomy is somewhat more difficult to assess. Construct validity refers to the extent to which the framework taps into the underlying causes of errors and accidents. In this regard, construct validity is directly related to diagnosticity, or the ability of a framework to penetrate all levels of the system and reveal the underlying causes of errors and accidents. Another method for assessing construct validity, however, is through convergent and discriminant validation procedures (Anastasi, 1982). These procedures attempt to show that a framework identifies errors that are highly correlated with other variables in which they should theoretically be correlated (convergent validity) but do not correlate significantly with variables from which they should differ (discriminant validity). For example, it is commonly believed that controlled flight into terrain (CFIT) accidents are more often caused by a lack of visual reference (as would be the case when flying in bad weather or at night) than non-CFIT accidents. Given that this belief is true, an analysis using HFACS should differentiate between CFIT and non-CFIT accidents on at least two causal categories: adverse mental states (e.g., loss of situational awareness) and adverse physiological states (e.g., spatial disorientation).

Using an earlier version of the HFACS taxonomy, Shappell and Wiegmann (1997b) analysed causal factors associated with U.S. Navy/Marine Corps CFIT and non-CFIT accidents. Results of a series of logistic regressions and Chi Square analyses supported the hypothesised error correlations and differences between accident types. As expected, these analyses revealed that a larger proportion of CFIT accidents were associated with adverse mental and physiological states, as well as supervisory violations and personal readiness failures than were non-CFIT accidents. Thus, the application of the taxonomy produced an error profile consistent with the underlying theoretical causes of CFIT accidents distinct from non-CFIT accidents, further supporting the construct validity of the framework.

Summary and conclusion

The HFACS framework presented here 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 framework, which is based upon Reason's (1990) model of latent and active failures, encompasses the multiple aspects of human error, including the conditions of operators and organisational failure. Consequently, the systematic application of the HFACS framework has resulted in the improved quality and quantity of information gathered during aviation accident investigations. Applications of the framework to database analysis have also begun to highlight critical human factors in need of further safety research. In addition, the HFACS framework has proven to be an effective instrument for monitoring the success or failure of specific intervention programmes designed to reduce specific types of human error and subsequent aviation accidents. In so doing, safety professionals have been able to readjust or reinforce intervention programmes to meet the changing needs of aviation safety. In summary, the development HFACS has proven to be a valuable first step in the establishment of a larger military and civil aviation safety programme whose ultimate goal is to reduce aviation accidents through systematic, data-driven investment strategies and the objective evaluation of intervention programmes.

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